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PHYSICAL SCIENCE IN MEASUREMENT AND INSTRUMENTATION EDUCATION

The paper presents arguments for the place of physical science in the teaching of measurement and instrumentation as a systematic discipline. It is argued that the discipline should be taught as general transferable concepts and principles, based on the science of information and systems. It is shown, however, on the basis of a model of the architecture of a measurement system that the concepts of information and systems alone are inadequate to treat sensors, the observed system, the interaction between them, and also the problems of inferential measurement. It is argued that these components and processes require to be described, analysed and designed using also the concepts and principles of physical science. The essential role of physical experimentation in the laboratory in the teaching of measurement and instrumentation is discussed. The place of physical science in measurement and instrumentation curricula is discussed, and it is argued that physical science should form a particularly important role in the education of specialist designers and developers of measurement and instrumentation systems.

Keywords: measurement and instrumentation discipline, physical science principles, education.

1. INTRODUCTION

Measurement and the instrumentation by which it is implemented are the essential tools of science and a key enabling technology of modern economies and societies [1].

It is important, therefore, that the discipline of measurement and instrumentation should constitute an essential component of the formation of all scientists and engineers [2].

There is a wide consensus that education in measurement and instrumentation should be based on the treatment of the field as a systematic discipline, that is a body

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of general transferable concepts and principles. The principles of the discipline are presented in [3] and [4]. The discipline is based on the treatment of measurement as an information process, and the instrumentation by which it implemented as information machines. The basic concepts and principles underlying this treatment are systems and information science. It has been argued that the teaching of measurement and instrumentation as a discipline should be design orientated [5].

To an increasing extent, arguments have been advanced that measurement and instrumentation, as a discipline, is essentially just a part of information science and technology. Therefore it is often proposed that physical science aspects of the field are not important in education in the subject. More specifically it is argued that experimentation in the laboratory can be replaced by computer simulation.

This presentation will discuss these views, but maintain that the principles of physical science continues to have a most significant role in measurement and instrumentation curricula and that experimentation using actual measurement equipment is educationally essential.

2. ARCHITECTURE OF A MEASUREMENT SYSTEM

To discuss some of the aspects of measurement and instrumentation as a discipline it is convenient to do so on the basis of a model of a measurement system. Such a model is therefore proposed for the present discussion. It is given in Fig 1.

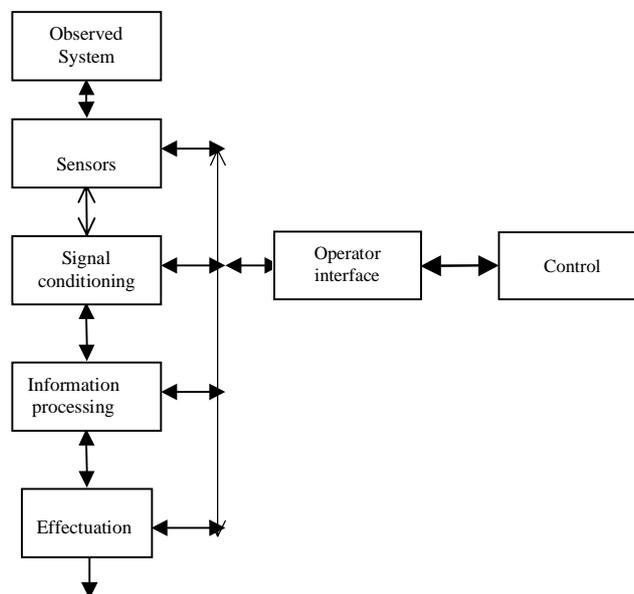


Fig. 1. Measurement system

The system consists of a number of sub-systems. There is firstly the system under measurement, or observation. This is connected to a sensor system and acts on the sensor by a flow of matter or energy. The sensor converts this flow into a signal, maintaining a functional relation between the input flow and the information carrying characteristics of the signal. There is usually a signal-conditioning bloc that converts this signal into a symbol that may be conveniently handled by the following bloc, which performs any required functions of information transformation and communication. This system passes the information to the effectuation bloc, to further processing or to the human operator. The measuring instrument system operates under the control of a control bloc. An important part of the system is the human operator interface. Through this interface the operator effects supervisory control of the measurement process. The interface embodies also any displays.

Two aspects of the model need to be considered in the case of many measurements. Firstly, there may be many multiple sensors, the information from which, after conditioning, is fused in the information processing. Secondly, many quantities in inferential measurement are estimated by state and parameter identification. Actuators are then connected to the object under measurement (these are shown in Fig. 1 as part of the sensor systems). They excite the object, by a flow of matter and energy. The response to this excitation is sensed, and system properties estimated from the relation between excitation and response.

3. PHYSICAL ASPECTS OF THE MEASUREMENT SYSTEM

The analysis and design of a modern measurement system is carried out in the conceptual phase in terms of information processing functions to be performed, and major blocs to which the functions are allocated. This conceptual design uses standard methodologies of systems and information science and technology. This conceptual design is generally implementation and embodiment independent.

The embodiment and implementation of substantial part of a modern measurement system is substantially carried out by standard equipment and software of information technology. This applies to signal conditioning, information processing, control functions and the human operator interface. These components and sub-systems are built using standard functional blocs. Their analysis and design are carried out at a high level of abstraction, using models of signal, symbol and information transformation, and the general methods of systems and information science.

For these reasons there are some voices that consider that physical science is no longer significant in measurement and instrumentation education.

However, there are components of the measurement system for which physical embodiment and effects are essential for description, analysis and design. These components are the sensors, the observed system, and the interaction between the observed systems. These will now be considered in more detail.

4. SENSORS

A functional description of a sensor, considering only the signal and information functions that it performs is inadequate. Its operation, capabilities and limitations can only be described and analysed in terms of its physical principle of operation.

In respect of sensors education in measurement and instrumentation should be based on mathematical models. Mathematical models are methods of the description of sensors, which capture their principles of operation, capabilities and limitations. They demonstrate analogies among devices of diverse form. Mathematical models can be used effectively for analysis and design.

Systematic approaches to mathematical models of sensors are extensively discussed in the literature. [6] and [7] review the topic, [4] and [7] give extensive bibliographies. An embodiment, or physical model of a sensor must be based on models of the physical effects involved, and a description in terms of physical geometry and material properties. [8] illustrates the process.

The design of a sensor, or the selection of a sensor principle, must again be based on consideration of physical effects. [9] reviews briefly the sensor design process with a brief bibliography of more detailed literature. It makes clear how knowledge of physical effects is essential to the sensor design process.

5. SYSTEM UNDER OBSERVATION

Measurement invariably involves consideration of a model of the system under observation as a physical system. The model may be purely qualitative and linguistic. However, more detailed mathematical models are frequently employed.

The model of the observed system is required to determine what variables are to be measured and where to locate sensors. A typical example is the observation of temperature in the atmosphere, in meteorological measurement, where the thermal field is distributed. Further it is essential to determine the likely disturbances, or influence variables, such as in atmospheric temperature measurement from solar and earth surface radiation.

6. INTERACTION BETWEEN SENSORS AND OBSERVED SYSTEM

As stated above sensors acquire information from the observed system by a flow of matter, or energy. This flow alters the state of the observed system and hence the measurand. The nature of this effect is discussed in detail in [4]. The estimation of this effect requires a model of the observed system. An example is provided by

a thermometric sensor. It functions by the flow of thermal energy from the observed system. This flow of energy alters the temperature of the system under measurement.

A further effect of the interconnection between the sensor and the measured system is the alteration of geometry of the measured system by the placing of the sensor within it [10]. Thus the installation of a thermometer in a stirred heated tank alters the flow pattern in the tank. The resultant change of flow conditions affects what is measured. The estimation of this effect requires a model of the observed system based on geometry, materials and the physical effects involved.

7. INFERENCEAL MEASUREMENT

Inferenceal measurement is required for all quantities that characterise the storage and transformation of energy, such as material properties, chemical composition and the like. As indicated above the observed system is interrogated by a flow of energy, and information about its response is acquired by a sensor. The measurand is inferred from the relation between the excitation and response. The inferenceal measurement takes the form of a state or parameter estimation in a model of the system under observation. Two core problems arise in this form of measurement.

The first is the choice of the energy modality of interrogation. It requires knowledge of a broad range of physical effects.

The second problem is the formulation of a mathematical model of the observed system, in which a state or parameter corresponds to the measurand.

The solution of these problems requires a wide and deep range of physical knowledge.

8. DESIGN ORIENTATION

Education in measurement and instrumentation must be based on general, transferable concepts and principles. Information and systems science provides an adequate framework for teaching the information processing aspects of measurement systems.

A systematic knowledge of physical science is, as has been argued above, a necessary prerequisite for the modelling and analysis of sensors and inferenceal measurement. However it is not sufficient. The range of physical science that is applicable is too extensive to be reliably and conveniently used to create effective systems.

Physical science aspects of measurement and instrumentation must thus be taught within a design orientated framework.

9. LABORATORY TEACHING

The teaching of principles of measurement and instrumentation must be supported by laboratory work, to provide students with experience of principles in action.

With modern computer hardware and software it is possible to gain experience of many aspects of measurement and instrumentation system by simulation. It may be more convenient and effective to teach, say, aspects of dynamic response using a simulated model of a system. Even the performance of a sensor can be investigated using a sensor model, which incorporates, say, non-linearity and noise effects.

Voices have been raised advocating the replacement of much measurement and instrumentation laboratory teaching by computer simulation. While such simulation has a very major role, it cannot replace actual measurement.

Firstly, there is always a discrepancy between model and reality. If models are to be applied with confidence, the modeller must have actual empirical experience of their limitations.

Secondly, it is necessary to familiarise students with actual measurement equipment, if they are to be able to use actual instrumentation effectively.

Laboratory teaching in measurement and instrumentation must thus be a balance between simulation and actual experimental measurement.

10. KNOWLEDGE OF PRACTICAL PROCESSES AND SYSTEMS

There is a need in an education in measurement and instrumentation to impart some knowledge and skills related to practical processes and systems and to develop positive attitudes towards them. This is in part to be achieved by a design orientation of teaching the discipline. The teaching of general concepts and principles must be supported by some teaching of practical equipment and applications.

The organisation of knowledge of practical processes and systems cannot be presented adequately within the limits of this paper. The topic has been discussed in [11]. For the purposes of the present argument it is sufficient to remark that such knowledge must be based on the principles of physical science.

11. PHYSICAL SCIENCE IN A MEASUREMENT AND INSTRUMENTATION CURRICULUM

Measurement and instrumentation as a discipline enters engineering and science curricula at different levels.

At a basic level it should be taught through laboratory work, but within a framework of general transferable concepts and principles. It goes without saying that physical science principles form a base of such teaching.

The arguments of this paper are concerned mainly with the higher levels of the teaching of measurement and instrumentation.

These are firstly the ancillary level, where measurement and instrumentation is an enabling tool for the purposes of another technology, such as control, electronics and the like. On the basis of the arguments above it is recommended that a good knowledge of relevant physical science principles should be an essential prerequisite to the teaching of measurement and instrumentation.

The most advanced level of measurement and instrumentation as a discipline is concerned with the education of specialists in the design and development of measurement and instrumentation systems. This level requires special curricula that combine principles of physical science with principles of information and systems in a design orientated framework.

12. CONCLUSIONS

Physical science forms a fundamental requirement of the teaching of measurement and instrumentation.

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