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A SYSTEM FOR THE AUTOMATIC SELECTION OF SENSORS

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Abstract: In this paper a method is proposed to assist the designer of a measurement system in finding the optimal set of sensors for a given measurement problem. The method will be implemented on a computer system and will contain a framework for optimality, where the user can define, what is optimal in his/her case.

To combat the combinatorial explosion during a search, solutions will be generated on different levels of abstraction. A solution at a high level of abstraction represents a large number of solutions at a lower level. Making choices by cutting possibilities at this high level will therefore enable to go through the search-tree in an efficient way.

Criteria with respect to the performance and costs of the solutions are discussed, together with methods to weigh different criteria against each other

The user interface should enable the user to formulate his measurement problem. This means in our view that a model must be generated of relevant aspects of the scene, in which the measurement problem occurs. Finding a solution to the measurement problem then means the design of an environment in which a measurement can be done that determines the measurand.

Keywords: Measurement Science, Knowledge-Based System, Sensor Selection

1 INTRODUCTION

At the moment 50,000 to 100,000 different commercial sensors are available on the market. Given a measurement problem, the designer will have to choose one ore several from them to solve this problem. The choice will be based on requirements to the measurement system, like accuracy, speed and size, and on economic requirements. Considering the enormous numbers of available sensors, finding a good or even optimal solution is not an easy task, certainly not for a designer, who in general is not an expert on the area of sensors. This optimisation problem has been recognised previously by sensor suppliers and designers. Suppliers include selection guides and application notes in their documentation, but these cover only their own delivery program. Designers may consult general sensor guides, but these books are incomplete and quickly run out-of-date.

In this paper the development is proposed of a method for systematic selection of sensors for a measurement system. The method will be implemented as a computer program: a Knowledge based Intelligent System for the Selection of Sensors (KISIS). The system will contain two main parts. First the user models the relevant aspects of the scene in which the measurement problem occurs and identifies the quantities, that should be determined, the *measurands*. Then the system searches interactively with the user for quantities, for which sensors are known to exist and that are physically related to the original measurands. Thus the user creates a model for a *measurement environment*, which leads to a set of *measurement principles*. A set of sensors is selected according to the chosen measurement-principles. After this, the solutions will be evaluated with technical and economical user-requirements and known specifications from the sensor suppliers. The result is an ordered list of solutions (sensors), with an assessment of the quality of each solution.

2 DEVELOPMENTS ELSEWHERE

Elsewhere people considered the problem from two viewpoints. In the application field the need for support while looking for sensors was (among others) recognised by “Syntens New Technologies”, a company of consultants on the area of sensors. A “Sensor Selection (computer) Program” [1] was set up, which communicates with users using a WEB-browser. The interface furnishes a hierarchical system of keywords, measurement themes, measurands, measurement principles and sensors with suppliers. Measurement themes are not orthogonal. They rather provide terms to be recognised by the user as being applicable to his/her problem. Examples are gas, pressure, Vision, etc. The program is based on [2] and on ideas developed during a project together with the authors of this paper [3].

From the research point of view, Harvey and Harris [4] describe the MINDS-system, a computer program, which supports the design of multi-sensor measurement systems. In this program, an expert-system has been implemented as a blackboard-architecture in which several human and computer-experts deliver their contribution to the design of the measurement system.

The two approaches stand quite far apart. The “Sensor Selection Program” considers the selection of sensors as an isolated problem. In the MINDS-system, sensor selection is only a part of the design process of a complete measurement system, to be automated as far as possible as a whole.

In this paper the emphasis will be on a measurement framework, leading from a high-level design process to a sensor choice for a measurement system, which in some sense is optimal.

3 A SKETCH OF THE SENSOR SELECTION SYSTEM

In our view, selecting a sensor without thinking about the design of the measurement system is quite useless. Without a design it is not known, if a chosen sensor will solve the measurement problem. Thus, if we want to have a system supporting the user while selecting sensors, such a system should also contain the design process, at least at a certain global level. The final objective might be to obtain a fully automated design system including the sensor selection part, but this objective is quite ambitious. In our research, the emphasis is on those aspects of the design process, contributing to the selection of an optimal set of sensors.

In this section an overview is given of the elements that will constitute the sensor selection system. In 3.1 a framework is given modelling the interaction between a “System Under Consideration” and a measurement system. In 3.2, generic state space models are proposed with state variables and parameters to be determined by measurements. From this top-level, in 3.3 a hierarchical system of models is proposed, leading to the selection of measurement principles and sensors. Section 3.4 contains some remarks about evaluating and assessing the solutions. To conclude, in 3.5 some elements of the information system are described.

It must be stressed that an interactive intelligent system will be pursued, carrying out tasks for the user, but also allowing the user to interfere and take his/her own decisions.

3.1 A functional model of a measurement system

The purpose of modelling is to make the measurement problem explicit, so that a measurement method can be sought, solving it. Modelling happens within the framework of system theory. A global sketch of a standard measurement system is given in figure 1.

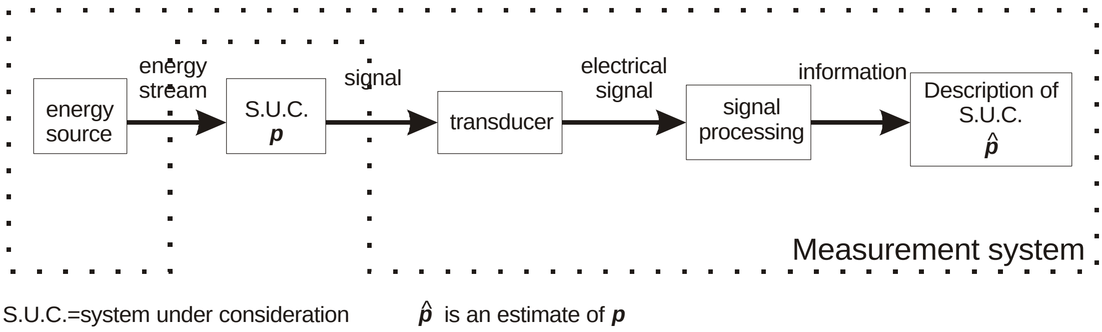

Figure 1. Sketch of a standard measurement system

The measurands are state variables or parameters of the System Under Consideration (S.U.C.) and are collected in a vector $\boldsymbol{p}$. The objective of the measurement system is to obtain an estimate of this vector. In order to get information from the S.U.C., the measurement system has to exchange energy with it. The S.U.C. may radiate energy spontaneously, or otherwise an energy source must be used, that produces an energy stream. This stream is modified by the S.U.C. and a signal arises, which should contain the desired information about $\boldsymbol{p}$. In this model, adding an energy source is basically what is meant with "creating a measurement environment".

The transducer converts the signal from a certain domain to the electrical domain and should keep as much information in the electrical signal as possible.

The actual estimate is computed by the signal processing subsystem from the electrical signal. It may or may not be possible to determine ***p*** from the electrical signal. If so, ***p*** is called observable [5] and then, the measurement system constitutes a solution for the measurement problem. Otherwise the solution has to be rejected. Observability is therefore a criterion while looking for solutions.

3.2 Generic models for the System under Consideration and its Environment

Modelling the S.U.C. aims at finding a relation between the measurands and a set of quantities that can be measured with a sensor. Modelling a physical system according to system theory and studying its behaviour is well known [4]. A simple linear system can be modelled, by the following two relations for the system dynamics and the output respectively:

$$\begin{aligned} \dot{x}(t) &= Ax + Bu \\ y(t) &= Cx + Du \end{aligned} \tag{1}$$

with $x(t)$ the state, $u(t)$ the input and $y(t)$ the output respectively.

Measurands may appear as unknown parameters in the matrices *A* to *D*, or as unknown states.

It is specific for this project (about a design problem) that often a measurand is known, but that there is no explicit description of the scene, in which this measurand has a place. The use of such a description is that it may give a clue for finding a measurement method. Therefore first a model must be created for the scene and than a clue can sought for obtaining a measurement model that determines the unknown measurand. This is a design problem and because an optimal system is sought, the design process involves solving an optimisation problem.

3.2.1 Example: measuring the position of a vehicle

Suppose it is desired to determine the position of a moving vehicle along a straight road. The motion of the car might be described by the following state space model, which has been kept extremely simple for this example:

$$\dot{x}(t) = Bu\,(t) = \frac{w(t)}{R} \tag{2}$$

where $x(t)$ is the position of the vehicle, $w(t)$ is the angular speed of one of the wheels and *R* is its radius.

An output relation is obtained, by measuring the position of the vehicle with (for instance) a camera:

$$y(t) = x_{camera}(t) = C.x(t) \tag{3}$$

where $x_{camera}(t)$ is the measured position of the vehicle in the camera images and *C* is a scaling constant, to be determined separately.

Both from (2) and (3), $x(t)$ can be obtained. Eq. (2) leads to a “dead reckoning method”:

$$x(t) = x(t_0) + \frac{1}{R}\int_{t_0}^{t} w(t)\,dt \tag{4}$$

(3) gives a direct relation between a measurement and the measurand.

The advantage of the dead-reckoning method is that it is extremely fast. However, after some time the estimates of the speed will become less accurate because of drift effects. At the other hand direct measurements have a constant accuracy, but are often relatively slow. Both methods were used during a project concerning a mobile robot [7] and the measurement results were combined with a Kalman filtering technique [8].

This simple example demonstrates that it is imperative to create and describe an environment of the S.U.C. to find a clue for a measurement method for the desired measurand.

3.2.2 Some elements of the solution of a measurement problem

Continuously, combinatorial explosions are threatening while solutions of a measurement problem are being sought. To keep the number of possible solutions within limits, several levels of hierarchy will be introduced with different levels of abstraction. At the top-level the S.U.C. and a candidate measurement system are modelled, without specifying the measurement method explicitly. This generic approach of modelling dynamic systems is treated in [6]. Models may be visualised in terms of bond-graphs. Finkelstein [8] explores a large number of transducers and indicates that they fit into this framework. Thus at the top-level a generic model can be formulated for the S.U.C. and the measurement system that is valid for classes of sensors. The search-tree can now be restricted, by defining criteria for choosing generic models. A criterion might be the complexity of the generic model. In this project it has to be investigated how to define complexity in a sensible way.

Looking back, it can be seen that the scheme of figure 1 can be implemented in a generic model without even defining the domain of interaction between the energy source, the sensor and the measurement system. If we take the example, just given, it would be possible to choose for a direct measurement method (3), or for the incremental method (2). In both cases a complete class of measuring methods and with it an enormous number of sensors could be discarded at once, according to the discarded generic model. Figure 2 sketches a searching process at this level.

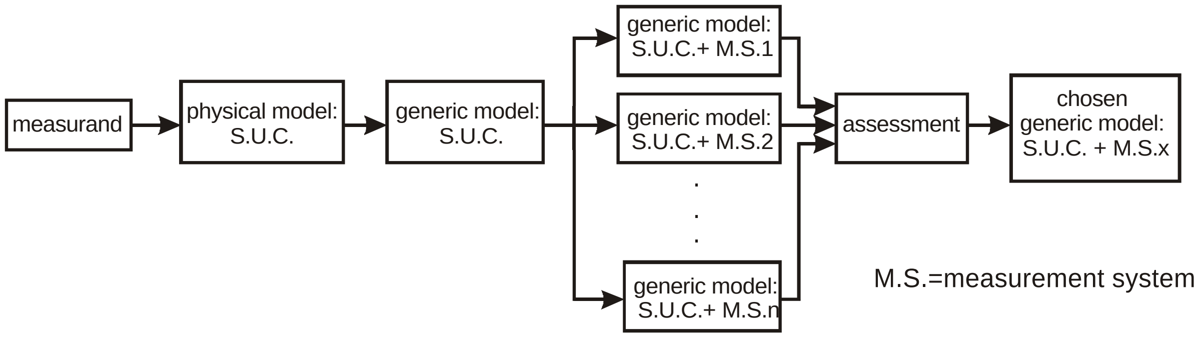

Figure 2. Sketch of the knowledge based system at top-level

It is also possible to introduce sensor fusion at this level. According to [9], two types of sensor fusion can be distinguished

1. Co-operative sensor fusion
   Information from one of a number of different sensors is insufficient for determining a measurand, but the information from the sensors together is precisely sufficient.
2. Competitive sensor fusion
   Information from each of a number of different sensors is sufficient for determining a measurand. Combining information from different sensors can increase robustness and accuracy of the measurement method.

The framework of generic models discussed here allows convenient inclusion of the option of sensor fusion solutions to measurement problems.

3.3 A multi-step approach to sensor selection

Above, generic models have been proposed that introduce a measurement system, corresponding to a System Under Consideration (S.U.C), based on energy streams between the two. Now the generic model of the measurement system must be converted to a specific set of sensors, to be used for the realisation of the measurement system. To keep the search space tractable, this conversion will proceed in a hierarchy of searching and choosing. This means that every time after a search at a certain level, the search tree can be pruned by discarding irrelevant solutions. The following levels are anticipated for the description of the scene and the measurement system:

1. Generic model as described above
2. Energy domain
   At this level, the domain of interaction between the energy source, the S.U.C. and the transducer is chosen.
3. Transduction principle
   According to the above chosen energy domain, it is now known from which domain the transducer should convert a signal to the electrical domain. To find a conversion principle, steps 1 and 2 of this hierarchy may be carried out again at the transducer level. This means that a sensor is being designed. It is also possible to use a database of transduction principles. Finally a combination of the two methods is an option in order to make choices underway. This may reduce the search space.
   At this stage the measurement principle is known. The next step is:
4. Choice of the sensor

Choosing the sensor means to select one from a supplier, according to criteria with respect to performance and costs. The assessment of the solutions is described below.

3.4 Assessment of the solutions

In order to be able to make choices between solutions on the various levels, the solutions must be assessed according to certain criteria. The criteria arise from a set of *user requirements*, to be matched with specifications concerning the solution, given by the user.

On the lowest level of abstraction a sensor has to be specified according to a standard. See for an example 3.5.2, where the ISA-standard is described. A standard should guarantee that all relevant details of a sensor are specified and that all sensors of a certain type are specified in the same way. However it is not sure that all sensor suppliers will be willing to specify their sensors according to the standard. During the selection process it must be taken into account that some specification fields will be lacking for certain sensors.

On a higher level of abstraction specifications will have to be developed, which may be deduced from lower level specifications by means of error propagation. However, also general criteria as for instance the complexity of a solution may be taken into account. On the level of generic models one may want to choose between one of the measurement principles in the example of 3.2.1. Alternatively, the combination (fusion) of more than one may be considered.

Weighing the criteria

The choice between solutions means comparing specifications of different sensors with each other, but also to weigh the various criteria, as accuracy and costs. Thus the user should give requirements on different specification fields, including admissible ranges, and indicate how important they are. A complication arises if not all specifications of a sensor are available. Multi Criteria Decision Making (MCDM) has been described in the literature [10]. The values and the importance of a requirement will have to be expressed in terms, linking up with the way of thinking of the user. Thus expressions like "very important", "not so important", "absolutely necessary" may be more appropriate than numbers like 0.7. Therefore the use of fuzzy criteria may be a good proposition [10].

3.5 The information system

In this section two aspects of the implementation of the sensor selection method in an information system are elucidated. In 3.5.1 a connection is sought between a System Under Consideration (S.U.C.) and a measurement principle. In section 3.5.2 some remarks are made about standards for sensor specifications.

3.5.1 Storage of (hierarchical) models and information in databases

A generic model of a system in which a quantity has to be measured consists at the most abstract level of the two equations for system dynamics and output (see 3.2). The user has to add information to make these equations sufficiently concrete so that a sensible advice on measurement method and sensor can be given. The information added by the user can take one of two forms: (a) parameter specification (concrete values or ranges) and (b) an additional equation that specifies further properties of the system under study. Together, these potential additions span a multidimensional space in which the user has to travel. We will call this space the concretisation space. The concretisation space is a tree. The nodes of the tree are schemes of equations, possibly enriched by parameter settings. The edges between the nodes are operations that allow the user to travel from one node to another. Adding information results in a concretisation operation while removing information results in an abstraction operation. The user interface may bundle several such operations into a single operation if that is allowed (the operations have to form a contiguous path) and if that results in an operation that is “natural” from a user point of view. Such combined operations are not by necessity confined to operations in the same direction (that is, all concretisation or all abstraction): combinations are allowed. Therefore, concretisation space may not appear a pure tree to a user. At the level of the information system, however, concretisation space remains a tree.

The space is only implicitly defined. Every scheme of equations, including the scheme of the two system equations at the top of the tree, defines parameters for which values can be set (or not); likewise, every scheme defines equations that can be added. Equations are stored in a database. Addition of an equation is always followed by a check on consistency. If the check succeeds, the operation is declared complete; if it fails, the operation is undone and the user is warned that he attempted an illegal operation. A bookkeeping scheme keeps track of additions and parameter settings and also records the semantics of the variables used in the equations.

3.5.2 Specification Schemes

A specification scheme for a sensor in general depends on the sensor-type. The Instrument Society of America (ISA) has defined schemes for a number of sensor-types: the SP37 standard [11]. See Table 1 for some sensor-types with their ISA-standard number.

A specification scheme contains a number of required and supplemental fields, which reflect properties of the sensor and contains directives, how to determine them in a standard way. Adaptation of sensor suppliers to such a scheme improves possibilities to compare sensors with one another.

Table 1. Different sensor types with their ISA specification standard

Sensor-type	ISA-standard
Piezo-electrical acceleration sensor	S37.2
Strain-gauge as linear acceleration sensor	S37.5
Piezo-electrical pressure sensor	S37.10
Strain-gauge as pressure sensor	S37.3
Potentiometric pressure-sensor	S37.6
Potentiometric displacement sensor	S37.12
Strain gauge as force sensor	S37.8

4 CONCLUSIONS

In this paper the development of a system is proposed which will support the selection of sensors in order to solve measurement problems. The analysis of the problem leads inevitably to the conclusion that for this selection, a design of the measurement system is necessary at least on a certain global level. A hierarchical framework is proposed, which enables a design on different levels. It is argued that for a good sensor choice not only the measurement system should be modelled, but also the system, which poses the measurement problem. This project focuses on sensor selection, because of restrictions with respect to time and money. However in the future, research certainly will go in the direction of the computer-assisted design of measurement systems.

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