Imprecise Computation Methods in Measurement[1]

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Abstract— **Measurement techniques are traditionally involved in accuracy and the usual aim is to design more and more precise measurement equipment. There are, however, applications where the measurement problem puts strong limits upon the achievable accuracy, permitting thus to use and to gain from various, so called imprecise computational methods.**

For an engineer the most important knowledge is when and how such new tools can be applied, what decisions are left to the user and how to judge the final results. This paper focuses upon these questions. The main properties of various methods are briefly overviewed and their advantages and disadvantaged discussed.

I. Introduction

Classical problem solving methods proved to be sufficiently useful in the area of measurement engineering up to the sixties - seventies. Nowadays measurement science tackled problems of previously unseen spatial and temporal complexity and in a large number of cases traditional designing tools and measurement equipment failed to handle the problems. It became clear that new trends are required for designing, specifying and then implementing successful sophisticated measurement systems.

Until fairly recently most researchers involved in measurement were thinking only in precise measurements, complete knowledge of the domain, and rigorous tools. The problem with this is that for succeeding with high-precision characterizations of complex systems a fundamental prerequisite must be fulfilled: the knowledge and availability of all the basic relations and entities which capture the system description. To reach this a way can be in case of 'well-defined' systems the decomposition of large, complex systems into less complex subsystems and/or elementary components and the explanation of the basic relations and interactions between them.

Another approach can be to break the classical demand for preciseness. Following this direction new possibilities occur and they have a realistic possibility for usefulness in case of 'ill-defined' systems, as well. The basic candidates for these tools are imprecise computational methods with a burden of producing, by definition, imprecise results. Although they compensate this deficiency by increased speed, more balanced usage of computational resources and a better description of the measurement problem.

Section II. deals with complex measurement itself, Section III. with imprecise computational methods, while Section IV. contains a brief overview of the advantages and disadvantages of the various methods discussed.

II. Complex Measurement

If we consider the deeper in the meaning of the expression 'measurement', we will see that today's complex measurement systems are involved in almost all kinds of activities in the fields of engineering. All control problems, system identification problems, industrial technologies, etc. contain some kinds of measurement tasks, when signals, parameters or attributes must be measured, monitored, approximated or determined somehow (Fig.1). Measurement is more than it is meant in the strict sense, so in the following, when talking about it it is interpreted in this wider sense.

As classical problem solving methods have failed to produce 'usable' solutions in many situations the interest of the researchers and engineers has been focused on knowledge representation, information handling, and different ways of expressing uncertainty. All of these led to the a better understanding of experiment in the process of modeling and it became clear that the mathematical apparatus used to specify the measuring procedures must parallel the mathematics of the model. Measurement parted with the purely numerical notion of the information.

The design of measurement systems for smaller scale problems is usually straightforward. If the task becomes more complex, the sound design of the instrumentation becomes problematic. Complex measurement problems are typical examples of ill-defined knowledge intensive problems. A really good planning of the experiments, design of the excitation signals,

[1]This work was supported by the Hungarian Fund for Scientific Research (OTKA) under contract T 014403.

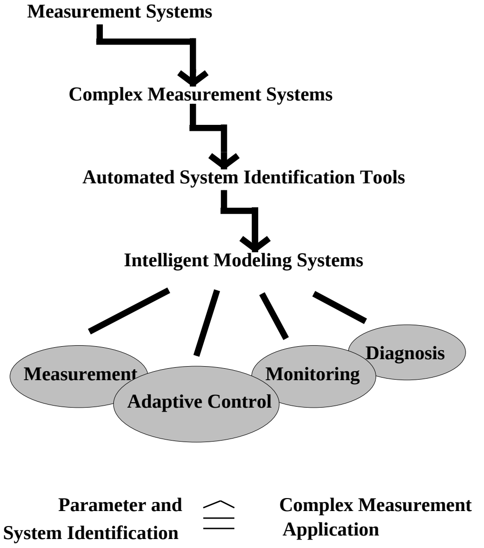

Fig. 1. The hierarchy and applications of measurement and system identification tasks

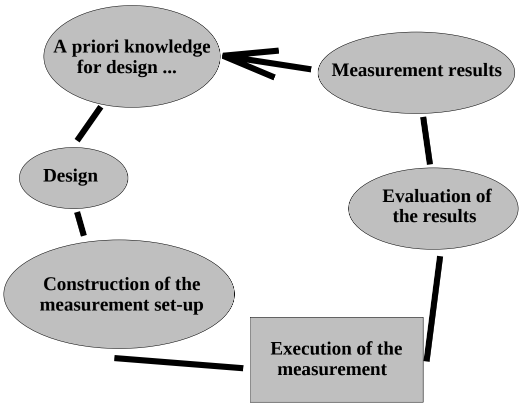

Fig. 2. Measurement as an ill-defined problem

the choice of the suitable information processing and of the measurement devices, etc. requires an extensive insight into:

– the phenomenon under study,
– the consequences of the particular goals,
– the practical limitations arising from the available measurement technical resources.

Of course, we have to face the problem of missing knowledge, otherwise no modeling, no measurement would be necessary. The requisite knowledge of an average user is also questionable. The problem of the missing knowledge can be represented with the following loop (Fig.2):

- We do not know our subject well, so we would like to measure to gain information about it,
- we will get it, if we design our measurement equipment well,
- we design it well if we know how to interact with our subject,
- we will know it, if we know very well our subject and use this knowledge in the measurement procedures.

It must be somehow broken (disregarding the very simple cases), either by the above mentioned decomposition, or by other way e.g. through giving a different formulation of our goals.

Other kind of problems are based on the pure fact that even in an average measurement problem we find quite a number of information (i.e. knowledge) sources, each with its own characteristics, drawbacks, and improved formalisms. Without any exaggeration it can be said that in measurement every kind of uncertainty is present and does influence strongly the outcome of the measurement process. (To get a feeling of the difficulties ahead have a look at Fig.3.) Statical uncertainty is trivial. Physical data is submerged in random disturbances and the gross of the measurement related numerical computations is nothing else but getting rid of those statistical fluctuations.

Computation in modeling (or in measurement) is strongly related to the ontology of the used models. An overprecise computation easily produces results where the improper interpretation gives weight to insignificant details or even artifacts. So the primary quest in measurement is not for accurate results, but results with controlled error.

Deriving and computing models of various phenomena brings another challenge for the computational mechanisms. Many, physically sound models lead to mathematically "unsound" formulations, on the other hand simplified unrealistic physical models appear in an easily computable mathematical form.

In many cases the granularity of the knowledge about the phenomenon is so low, or the span between better defined levels of abstraction in its model is so wide, that the creation of an algorithmically sound mathematical model is out of question. If taught algorithm-less structures are used instead of explicitly designed (analytic or symbolic) algorithms this problem can be solved to a certain extent. Their precision is governed primarily by the information content of the teaching mechanism and is always finite. Still more serious limitation is that the results produced by these tools, are 'noncomputable' in terms of the attributes related to the goal or structures used.

Another source of problems leading to the idea of Imprecise Computation is the ever present reality of implementation. Every computer system (and thus the realization of every computational model) is limited in its resources, let it be memory, time, used power, etc. The primary problem is the timeliness of the system responses, and it is a generally overlooked truth that almost every computer system is a real-time system. Not necessarily hard real-time, but so-called 'soft' real-time system, with the 'graceful degradation' of the produced solutions.

Theories	Tools	Applications
Measurement theory **Signal processing** **Modeling**	**Digital signal processor architectures**	**Medical information systems** **Decision support systems**
Concurrent and real-time systems **Resource management** **Data acquisition** **Scheduling**	**Real-time programming languages** **Real time kernels** **Object oriented programming**	**Industrial process monitoring** **Intelligent measurement systems**
Distributed systems	**Communication networks**	**Virtual measurement systems**
Artificial Intelligence **Knowledge representation** **Problem solving algorithms** **Probabilistic and nonmonotonic reasoning** **Multi level modeling**	**Functional programming languages** **Logic programming languages** **Expert system shells**	**High precision measurement systems** **Automatic design of measurement systems** **Automated off-line and on-line diagnosis**
Fault tolerant systems	**Fault-tolerant HW architectures** **N-version programming**	
Hardware design	**Analog and digital circuits** **Microcomputers, transducers ,** **sensors, etc.**	

Fig. 3. Aspects of today's measurement systems

In typical measurement-like applications (e.g. monitoring, intelligent alarming, fault-diagnosis, system identification, etc.) the real-time characteristics of the task is degraded by the paradox of the 'cognitive overload'. In normal situation (healthy patient, faultless technological process) there is plenty of time to process relatively small amount of data. Crisis time alarms bring a flood of information to be processed quickly, but as precisely as possible.

These problems led to some new ideas in the field of real-time systems. 'Anytime algorithm' is a computation model which can be interrupted anytime and provides a valid, however possibly inaccurate results. The more time such an algorithm can run, the more precise its result will be. Some of the well-known signal processing algorithms (e.g. Kalman-filter) are of anytime character. Others unfortunately not, and quite an insight is needed, if possible, how to transform them into an anytime version.

III. Imprecise Computational Methods

The circumscription of Imprecise Computation (or Soft Computing) has been proposed by Zadeh as: "In traditional - hard - computing, the prime desiderata are precision, certainty, and rigor. By contrast, the point of departure in soft computing is the thesis that precision and certainty carry a cost and that computation, reasoning, and decision making should exploit - whenever possible - the tolerance for imprecision and uncertainty" [1].

Probabilistic Reasoning (PR), Fuzzy Logic (FL), Neural Networks (NN), and Genetic Algorithms (GA) fit this definition nicely, which presents a direction for research.

Fuzzy Logic methods can be comfortably and efficiently used to design intelligent systems on the basis of knowledge expressed in natural language. These systems have been shown to be more successful in many applications (e.g. in control, signal processing, and decision making) than those based on conventional approaches.

Neural Networks are particularly interesting as the bases for the development of parallel architectures. They can be trained or can learn, by themselves, to classify, to recognize patterns, to understand speech, to forecast, to control robots, vehicles, or industrial processes, etc.

Genetic Algorithms and Genetic Programming can solve problems in system identification, classification, control, robotics, optimization, and pattern recognition, as well. They proved to be very useful in the solution of the optimization of nonlinear multivariable systems.

Considering the above definition of Soft Computing, a better clarification of the nature and origin of costs is needed, which would lead to a more relaxed, wider spectrum of soft computing methods. Following this idea we will find that anytime algorithms are also closely related to the very idea of soft computing.

The concept of "imprecise system or computation" covers a task-based, distributed computation, where each task can run at different levels of precision vs., of course, some critical resource, mainly computation time. A global scheduler, familiar with the actual load of the system and the required timeliness of the response, configures the actual accuracy level of each task to reach some global optimum in the quality of the computed results within the given resource limits.

IV. Applications and Criticism on Soft Computing Methods

One area of applications where the measurement task can be severely handicapped by an excessive pursuit of computational accuracy are real-time monitoring and diagnosis problems. Measurement systems in such cases are typically distributed and equipped with concurrent real-time software. Varying information processing load of different system components and changing real-time limits present a formidable challenge to the task schedulers, where any kind of accurate computation, as an aim, is out of question.

Real-time applications led to two basic results related to accuracy. the first are the so called imprecise scheduling methods. An intelligent scheduler, accordingly to the actual time limits, resources and loads, disposes about the accuracy level of each particular task performed within the system. Its overall goal is to make the accuracy of the final results optimal. Another idea is that of any-time algorithms. Any-time algorithms can be interrupted at any time-point and serve admissible results. The later such algorithm is stopped, the better, i.e. the more accurate results it produces. The second area, with the imprecise computation tools being a good if not the only alternative, are those measurement applications, where problems lack well developed analytical description. Analytical models are starting points to design optimal information processing algorithms, or helping tools to select, run and interpret pre-defined methods from algorithm library. When a satisfactory analytical model is missing the quality of numerical results supplied by the traditional numerical algorithms is difficult to judge and often such results are simply meaningless. Models of relaxed accuracy, but more qualitative in nature are interesting alternatives, especially in the field of biomedical, chemical and other 'difficult' engineering tasks.

Fuzzy logic, introducing a novel notion of uncertainty and using logic based inference scheme, can support or even substitute normal numerical algorithms producing strikingly good results. Neural networks, although originated in medical research, from an engineer point of view present powerful nonlinear classification and decision tools. Genetic and other evolutionary algorithms, drawing strongly from biological analogies, yield alternative methods of solving optimization problems.

Fuzzy set theory and fuzzy logic have faced strong oppositions from conventionally oriented theoreticians during the past 30 years (e.g. [10]), as well as, later the other imprecise computational methods. On the other hand many practical applications prove the applicability of these tools. A large number of succesful application of FL and fuzzy reasoning can be found in the world - mostly in Japan. We also have to mention PR applications, like MYCIN expert system, or different working applications based on NN, etc.

All around the world, we find an increasing interest in the theory and applications of SC techniques. Although, it has become evident during the past ten or twenty years that no single approach to the study of cognitive or intelligent processes will succeed in understanding the interactions and no single approach to represent the complex knowledge will fulfill all requirements.

V. Conclusion

The increased complexity of the measurement systems caused classical problem solving methods in many situations to fail to produce 'usable' solutions. This led to focus on knowledge representation, information handling, and different ways of expressing uncertainty. Soft Computing methods are serious candidates for handling many of the theoretical and practical limitations and, in many cases, are the best if not the only alternatives for emphasizing significant aspects of system behavior with a burden of less precision.

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