Teamwork in Intelligent Measurement Systems

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Abstract — Authors investigate how distributed artificial intelligence (DAI) techniques can contribute to the today's complex and distributed measuring systems. The blackboard architecture suits well to the measurement design, where several aspects of the same problem should be considered simultaneously. On the other hand, intelligent agents can help to exploit the emerging knowledge resources in computer networks (like the Internet), and agent cooperation methods can open a promising new perspective to the communication between measuring devices and controllers.

I. INTRODUCTION

The increasing complexity of measurement problems brought into focus the possible advantages of qualitative (i.e. symbolic) processing and reasoning methods. In numerous classes of complex problems problem decomposition became the only way toward a working solution, this, on the other hand, required the presence of interacting problem solving (intelligent) entities.

Such research belongs to the distributed artificial intelligence (DAI), which is concerned with studying the distribution and coordination of knowledge, and in consequence intelligent actions in complex environments. Several industrial applications have already shown the benefits of using DAI methods. These methods, however, were largely neglected in the development of measurement systems. Authors investigate the possible applications of DAI methods both in measurement design and control.

The major research interest in DAI is the distributed problem solving (DPS) which is concentrated on problem decomposition, solution of the subproblems, and the synthesis of an answer [1]. Another important area of the research aims at the cooperation and coordination between intelligent entities. Blackboard systems (BBS) and multiagent systems (MAS) are characteristic examples.

In BBS the basic cooperation is organized around a shared knowledge base (blackboard), where the current state of the problem solving process is stored [2]. The algorithm of cooperation, the representation of the problem are predefined and known to all the system components. Blackboard systems are thus designed for specific problems.

In multiagent systems (MAS) the entities (agents) are autonomous and can differ significantly from each other [3]. Research in this field is focused on how the agents' knowledge, goals, skills, current states and plans can be coordinated to solve a common problem [4,5]. In contrast to the BBS the coordination and the knowledge sharing in MAS are motivated by the tasks. The actual interaction and the spectrum of the participants can vary from a problem to a problem.

Complex measuring systems are obviously distributed. Sophisticated measurement problems lead to a natural physical and conceptual decomposition of tasks and thus to design of distributed measuring systems. Increasing demands amplified the computing and control components of the instruments, up to the point that expert systems became accepted and common parts of measurement systems [6,7]. However, the basic control structures and communication protocols in these systems remained unchanged. Even when expert systems are used to solve the information processing, the measurement controllers are not more intelligent than when HP-IB bus was first introduced [8,9].

Authors present a conceptual arrangement of an intelligent measurement workstation (IMWS), which will be capable of the automated designing and executing complex measurement tasks. The paper shows practical examples of using BBS and MAS techniques in this context. Blackboard architecture suits the task of complex measurement design and control, handling various aspects like accuracy, speed, cost simultaneously, as presented in Chapter 2. Meanwhile - as practical applications show - the agent technology can support information retrieval, filtering, and increasing cooperation between measurement controllers and instruments. Chapter 3 summarizes this area showing already appeared solutions and other ideas of application.

II. BLACKBOARD SYSTEMS IN MEASUREMENTS

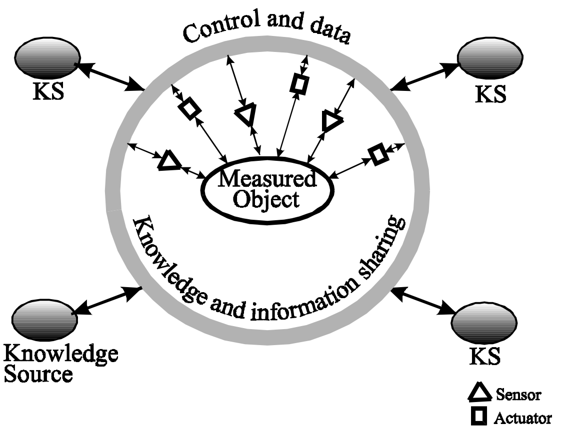
Blackboard systems provide a useful tool for representing heterogeneous and complex measurement problems, providing architecture for both measurement design and control tasks. Designing a measurement set-up for a specific problem requires several aspects to be considered, e.g. choosing among the appropriate tools and methods, deciding about the accuracy, speed and providing the analysis of costs, as a primary trade-off factor.

During measurement various aspects of the real measured objects must be represented [10], cooperating expert systems thus must operate on different aspects of the same problem. This requires shared data and control, which is natural in blackboard systems. Authors investigated several measurement domains (mechanical, acoustic measurements, measurement instrumentation of fermentation, and the like) to characterize the common design methods and knowledge sources which can be implemented in the blackboard frame.

Blackboard data structures store the shared knowledge about the measurement problem including the model of the measured system, current measurement set-up, cost, speed and other properties. The knowledge sources get their information about the current state of the problem from this board, and they also put their results on it.

Fig. 1: Knowledge sources in measurement

These data structures describe not only the whole



problem, but the progress of the problem solving, e.g. the progress of the measurement design, or the measurement itself. They also describe the problem from various aspects, they could contain the same information in several interpretation forms as they are needed by knowledge sources.

There are two principal tasks related to the measurement: measurement design and control of the execution of the measurement.

At first the proper measuring system should be designed, which includes building (or choosing) the abstract model of the measurement, selecting appropriate measuring components (physical devices and processing methods), making cost, accuracy and speed analysis, with respect to the specification and user's expectations.

The second step is actually performing the measurement using the designed set-up. In this step knowledge sources can be used in the evaluation and post processing of the measured data, consulting with the user about the results, or checking the original requirements against the current values.

It is also important that an (advanced) system should support the reconfiguration of the measuring set-up, if required. This means that the two steps of design and execution should be performed cyclically, in an embedded way. The design of the final measuring system will be thus an iterative procedure, because only concrete measurement results can provide more knowledge to improve the system specification and push to the limit the accuracy and other critical parameters of the measurement system. This of course will involve additional knowledge sources for the evaluation of the actual set-up and the model refinement.

In the following we would like to shortly summarize the basic knowledge sources that emerged from studying measurement domains and experiments.

A. Model Builder

This is the basic component of the measurement blackboard structure that supports a priori knowledge acquisition about the problem, and it builds the initial model of the measured system. Its knowledge base contains information about the measurement domain, model skeletons, and methods how to adjust the model skeletons to be fit to the current problem.

B. Experiment Designer

Its task is to design the experiment based on the model provided by the model builder. It specifies the measurement steps in a plan that implement the information acquisition and processing in respect to the user's expectations. Its knowledge base could contain skeleton plans about common measurement tasks. It obtains actual cost, precision, time limit and other information from the shared blackboard. This information is used to tune the skeleton plans.

C. Instrument Database

This knowledge source contains information about measuring devices including technical specifications, operational costs, availability, etc. It helps the experiment designer in choosing the right instruments for performing tasks in the measurement plan. It also supports other knowledge sources with information about the available devices.

D. Algorithm Database

It contains several signal processing algorithm skeletons for different tasks. It is responsible for providing all the necessary information (including accuracy, speed, cost, required hardware devices) about the algorithms. A measurement plan skeleton refers to algorithm skeletons that provide the necessary signal processing steps. These skeletons also should be customized to the current measurement problem.

E. Cost Analyzer

The task of the cost analyzer is to calculate the cost of the current measurement set-up, and to provide this information to other parts. It obtains the necessary cost information from the blackboard, and it also puts its results on it.

F. Time Analyzer

This knowledge source calculates the time cost of the current measurement set-up, and provides this information to the experiment designer. The Algorithm and device base supports this with necessary time data.

G. Precision Analyzer

This analyzer is responsible for calculating the precision based on the current measurement set-up. It combines the accuracy information of instruments, algorithms and methods to obtain the overall measure, which can be used by e.g. the experiment designer to choose among the possible set-ups.

The knowledge sources mentioned so far take part in the design phase of measuring systems. The following experts are needed during the measurement.

H. Experiment Control

The task of this part is to control the designed experiment. It executes the selected plan and handles the events of the measuring system. Its knowledge base contains information about possible events and special instructions about handling these events.

I. Result Interpreter

This expert is intended to help in evaluation and validation of experiments. The experiment results obtained during the execution of the measurement plan should be checked against the initial expectations and constraints. The domain specific knowledge base of this source contains information about the system to be measured and provides hints how to refine the initial model to be more precise and suitable for the measurement task and constraints. It also should support learning that improves the efficiency of the whole system.

Several optional knowledge sources may arise if we consider additional topics like conceptualizing model skeletons from experiments, making inferences from collected results, etc.

III.. USING AGENTS IN MEASURING SYSTEMS

In the case of an isolated intelligent measurement system, all of the system's knowledge is formulated and injected into the system in its designing phase. Measurement controller which is connected to a computer network (corporate network, or the Internet) makes another level of knowledge acquisition and cooperation possible.

This environment, external to the blackboard knowledge sources, can consist of a variety of measurement related agents. Some of them are direct applications of already clarified ideas, others may require reconsideration of the role of the controllers and the instruments used in measurements.

In this chapter agent technologies (like information providers and filters) are presented and suggested areas (measurement expertise agent, agent-like instruments and controllers) are described from the viewpoint of future intelligent measurement systems.

Internet environment gave birth to a new category of systems, so-called intelligent agents [11]. Agents are autonomous, cognitive, reasoning and naturally communicating systems [3]. General idea behind an agent is ordering the service and delegating any responsibility of direct control, rather than monitoring closely the progress of the problem solving (as a real agent is authorized to act on another person's behalf). The truth is that the activity of an intelligent system embedded in a physical environment of Internet dimensions is simply too difficult to analyze and follow.

Until recently typical agent applications were confined to the management of information in the so called Cyberspace (Internet environment), like e.g.:

- data brokers, searching systems, WWW robots, ftp agents, etc. for *information retrieval*,
- Usenet News, e-mail filters as *information filters*,
- electronic libraries, databases as *information providers*,
- other categories like system event monitoring agents or electronic secretaries (e.g. in White House).

Research in agents brought up various notions of agency [3]. For engineering applications the most sound is the so-called weak notion. In the weak notion an agent means a system which is:

- autonomous: operating without direct human control,
- concurrent: executing independently of other agents,
- social: operating in connection to people or other agents,
- reactive: i.e. responsive to the events in its environment,
- proactive: operating purposefully, even if not requested for a particular service.

The idea of an autonomous, reactive and above all proactive system is very appealing. It defines an always-active system which seeks means to fulfil its tasks, enters into cooperation if needed, evades conflicts and which generally attempts to balance the provision of services and the economic management of its own resources.

There are several levels in measuring systems where agent technology can be applied with a success, from the lowest, i.e. device level, to the more abstract information processing levels in the laboratory environment or in a wider computer network.

By treating instruments as agents a more sophisticated measuring configuration can be developed, where in addition to the propagation of data or control signals tasks or complete jobs could be transferred between components. On the other hand, using the emerging Internet measurement resources 'databases' or rather 'knowledge bases' of up-to-date instrument specifications, predefined measurement set-ups, instrument and data processing programs, etc. could be incorporated into the measuring system design. In the following we summarize these possibly fruitful agent application areas.

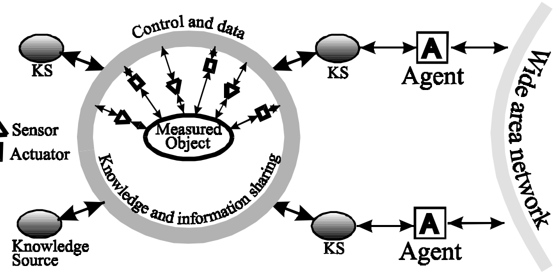


Fig. 2: Agents in measurement

A. Information Providers and Filters

Year 1995 marked the point when measurement related information appeared purposefully and in mass on Internet [13]. Public domain resources contain instrument libraries, ordering information, corporate press releases, catalogues of application notes and typically links to related organizations and databases. Certain vendors became already clearing houses for user written toolboxes and other useful applications. Network resources will possibly develop in the future toward databases of reported measurements, typical set-ups centered around vendor's products, interesting measurement problems, typical test signals, virtual instrument programs, and the like. This kind of information is what searching, mediating and providing agents are about. Client agents resident on system controllers will seek solutions to the measurement problems, agents at vendor sites will support measurement 'virtual reality', e.g. distant measurement and instrument training, courses or expert consultations.

B. Expertise Retrieval

From AI point of view the most interesting topic is the retrieval of measurement technical expertise. Agents should be able to inspect and reason about the description of tools, i.e. software packages, control schemes, instruments. The problem description (measurement task) would be picked at the client's site and then agents would start looking for experts, interviewing them for the possible set-ups, flow of control, or interpretation of the data.

Another possibility is to circulate measurement results together with the description of measurement itself, to seek help in the interpretation of the data. Expertise seeking agents exist still only on paper. The primary bottleneck is not the development of agents, rather a good symbolic formulation of the measurement problem is yet rudimentary.

Close to the previous ideas is the notion of a 'mobile' measurement. Measurement data, obtained already in the past and stored until the development of better signal processing packages, or until a particular development in the theory can be dispatched to places of better expertise or better methodological support. There data can be measured with virtual instruments and interpreted on the spot.

C. System-Controller-as-an-Agent

If the information retrieving agents are relatively easy to develop, agents embedded in the system controllers require more consideration. Measurement system controllers perform at the border of three environments – instruments connected via GPIB (SCPI, [12]) bus, users, and other information systems.

Expert users who know how and would like to exercise direct control over the measurement do not and possibly will never require any support of agent-like features. Controller-as-an-agent approach will be useful rather to an interdisciplinary user investigating the possibility of measurement in his research field but not necessarily at home in today's instrumentation. Such controller would accept a problem, 'discuss' it with the user, then it would seek via other agents the information leading to an adequate specification of the measurement set-up.

In consequence it would be up to the controller to fetch and adapt or automatically generate control command sequences and to interpret the measurement results for possible inconsistency or signs of trouble.

Much of existing measurement expert systems or also recent development in object-oriented organization of real-time measurement scheduling fit well the above considerations. A real issue is a new kind of user interface and a protocol at much more higher level of abstraction. Such protocol should draw from the research on cooperating intelligent systems but it should be also excessively tailored to the specific measurement characteristics.

D. Agent-In-Instrument

Is agent-in-instrument a feasible idea? The communication with instruments is based on the assumption that the controller knows exactly what a particular instrument is able to do. On the other hand, if there are no severe programming errors, instruments will always do as told.

Agent-like instruments would in principle accept description of a task rather than a command. Intelligent instrument, aware of its own functionality, would interpret the problem and would evaluate for the controller or other instruments the prospects of the measurement or the reason why it should refuse the task. In consequence all lower level command sequences would have to be generated within the instrument itself.

Simple instruments do not require this kind of sophisticated design. In complex instrumentation, however, much of know-how is not even contained in the manuals. The best place to confine the instrument related information would be the instrument itself. In consequence, the highest level of the communication would be based on bid-and-contract, rather than on present command-and-execute scheme.

CONCLUSIONS

The distributed nature of complex measurement problems and solutions suggest that DAI techniques would significantly improve measuring systems. Taking advantage of the emerging knowledge bases of networking environments (e.g. the Internet resources) would also be fruitful in these applications.

In this paper we presented how two characteristic examples of the DAI field, blackboard and agent systems could be incorporated into measuring systems to reach these goals and to increase the level of automation.

Blackboard architecture suits well to the measurement design phase, where various aspects of the problem should be considered simultaneously. The agent technology supports on one hand the information retrieval from external sources of knowledge, on the other hand, it can help in specifying a better interface, a better cooperation scheme between the components in the measuring systems, thus making these components more autonomous.

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http://www.hp.com/
"Keithley, Inc., Home page"
http://www.keithley.com/
"Tektronix, Inc., Home Page"
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