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IMPLEMENTATION OF AN AUTO-TUNER USING EXPERT SYSTEM IDEAS

Karl Johan Aström

Abstract

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Contents

1. INTRODUCTION
2. EXPERT SYSTEMS
3. APPLICATIONS TO AUTO-TUNING
4. CONCLUSIONS
5. REFERENCES

1. INTRODUCTION

Simple methods for tuning regulators of the PID type have been proposed by Åström (1981†), Hägglund (1981) and Åström†, 1982 and Hägglund (1983). The methods are based on a few simple algorithms which are combined by heuristic logic. The regulators have been implemented on different computers, Apple II, LSI 11/03 and Vax. Experience has shown that it takes considerable time to structure, code and debug the heuristic logic. In this report it is proposed to base the coding on the methodology developed for rule based expert systems. Although expert systems are much more complex it is believed that the methodology may be applicable also to simple systems of the type discussed in this papers. Only experience can indicate if the approach has some advantages. The expert system methodology is briefly reviewed in Section 2. The application to coding of an auto-tuner is elaborated in Section 3. Some conclusions are drawn in Section 4.

2. EXPERT SYSTEMS

Expert systems were developed to make it possible to obtain reasonable solutions to problems which are too complicated for an exhaustive search of all possible alternatives. See Davis (1982) Barr and Feigenbaum (1982).

Expert systems have been shown to have spectacular performances in some selected application. A special programming methodology has also been developed for expert systems. This methodology may be useful also for more mundane problems as is indicated in this paper.

An expert system may be viewed as consisting of three components: a data base, a collection of rules and a control structure. The data base contains the current knowledge about the problem. The rules describe what actions to take for certain data. The actions are administered by the control strategy. The expert system thus has some resemblance to an automaton. The main difference is that the data base does not represent a proper state since it only contains partial state information.

3. APPLICATIONS TO AUTO-TUNING

It will now be discussed how an auto-tuner like the one discussed in Åström (1981,†), Hägglund (1981) and Åström †, 1982 and Hägglund (1983) can be implemented as an expert system. It is assumed that the reader is familiar with the contents of these references. Let us start by discussing the ingredients.

The data base

The data base should include relevant information about the system. Since knowledge of the critical gain k_c and the critical period t_c are key data for the simple regulators the following data is chosen to belong to the data base.

A0. No prior knowledge

A1. Crude k_c, t_c estimates available

A2. Good k_c, t_c estimates available.

The actions to be taken also depend on how close the measured set point is to the set point. The following data is therefore included.

B0. Do not know

B1. Measured value far from set point

B2. Measured value close to set point.

The reason why B0 is included is that it is hard to tell if the measurment is far from the set point if nothing is known about the disturbances.

The values k_c and t_c are determined from an experiment with relay control. To make such an experiment it is necessary to know the relay amplitude, the hysteresis and the bias. A suitable relay amplitude can be computed from the critical gain. The hysteresis can be determined from the noise level. It is therefore useful to include the knowledge about the noise level in the data base i.e.

C0. Noise level unknown

C1. Noise level known.

To judge the need for tuning it is also useful to have some characterization of the behaviour of the closed loop system.

The following description is therefore introduced

D0. No information available

D1. Unsatisfactory control

D2. Tolerable control

D3. Good control.

The evaluation of performance must be based on the estimate of the noise level. The characterizations given are crude and the separation partly arbitrary.

It is also useful to have a log of historic data for the purpose of diagnosis and learning. An event table and a parameter log are therefore also included in the data base. These are defined as follows.

Table 1 1 Main event table

Event #	Time	Characterization	d_o	e_o	u_o

An entry is made in this table as soon as an event happens.

Table 2 - Operating conditions

Event #	Time	$\bar{u}$	umin	umax	$\bar{y}$	ymin	ymax

An entry in this table is made as soon as the set point changes by more than 3 e_o. The true mean-values of u and y between the set point changes are calculated and stored in the table.

Table 3 - Parameter log

Event #	Time	Scheduling variable if other three no	u_o	y_{ref}	k_c	t_c

An event is entered in this table at each time the parameters k_c and t_c are determined. The control signal and the reference value are also logged as well as the value of a candidate for a scheduling variable.

The operators

The operators are of different types. The decision to "fire" an operator is based on measured process signals and on changes in the data base. Some operators result in changes of the data base others result in control actions or modifications of the control procedure. The operators are listed in Table 1. Detailed descriptions of the operators are given in the appendix.

Table 4 - Operators

Name	Purpose	Data	Result
PID control	This operator performs normal PID control.	Good estimates of k_c and t_c	Control of the process
PID supervisor	To evaluate the performance of the PID regulator	Input-output data under PID control	Changes in the data base
PI control	To bring the system to the set point before tuning	Crude k_c and t_c data	Output curves close to set point
PI supervisor	To evaluate the performance of the PI control	Input-output data under PI control	Changes in the data base
Stability supervisor	To detect if the closed loop system is stable	Input-output data under normal control + crude estimate of t_c	Changes in data base
k_c t_c estimator	To estimate the critical gain and the critical period	Output close to set point and good d_o and e_o	Estimates of k_c and t_c
k_c t_c validator	Validate the estimates of k_c and t_c	Good k_c, t_c estimates	Change in data base
d_o estimation	Determines a good value of d_o	Measured value close to set point crude estimate of k_c	Estimate of d_o
e_o estimation	Determine hysteresis	Control signal constant	

Table 4 - Operators continued

Name	Purpose	Data	Result
Crude estimate	Determine a crude estimate of k_c and t_c	The values of e_o and d_o	Crude estimates of e_o and d_o
Crude estimation supervisor	Supervise crude estimation. Make sure that an oscillation is obtained		
Estimation evaluator	To evaluate the results of the k_c t_c estimation. In particular to find out if PID control may work or if some other control shoulde be used	Good k_c , t_c estimates. Good relay data	Entry in data base
PID evaluator	To find out if PID control is reasonable	Static process gain and k_c	Entry in data base
Static gain estimator	To determine the static gain of the process	Table of operation conditions	

The control structure

In an expert system there is a fairly elaborate control structure which decides how the different rules are 'fired'. In this case we will have a fixed logic instead of a control structure. A simple backward search from the goal gives a suitable logic. This is illustrated in Fig. 1 which shows the major rules and their preconditions.

It is assumed that the system starts in A1 and C1 and either of B1 and B2.

4. CONCLUSIONS

Some ideas on the organization of an advanced auto-tuner have been proposed in this paper. The organization was based on the idea in expert systems. The major difference is that the control structure is a fixed logic. The approach appears to have the advantage that the program is easy to organize and to modify. A systematic design methodology is also obtained. Since information about the operating conditions is stored in tables it is also possible to obtain new functions from the regulator. It is possible to estimate the static gains from Table 2. When the static gain is available it is possible to determine if a control law of the PID-type is suitable or if a more sophisticated regulator should be used. In Åström (1982) it is shown that this decision can be based on the product of k_c and the static gain k. It is thus possible to obtain a system which can find out if the control algorithm is suitable. By scanning Table 3 it is also possible to find out if the process gain changes drastically over the operating range and if the changes are correlated to some scheduling variable. The system thus has the potential of finding out if a gainscheduling is possible and beneficicial.

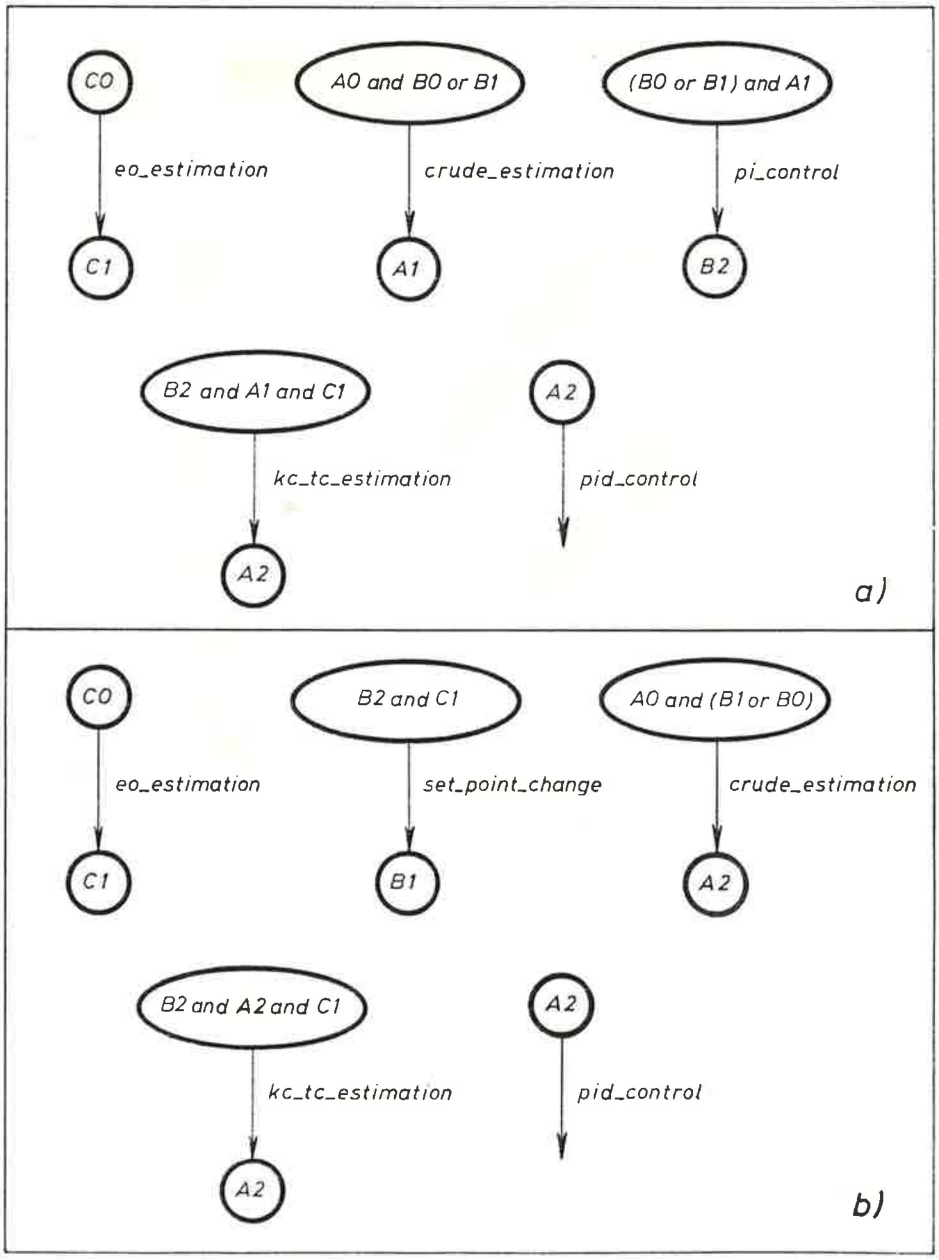

Fig. 1 Partial state-transition graphs for the basic functions of the simple auto-tuner. Graph a) applies when the system starts in state A1, B1, C1 and b) when it starts in A1, B2, C1.

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