Trends in design of digital control systems and applied system identification

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TRENDS IN
DESIGN OF DIGITAL CONTROL SYSTEMS
AND
APPLIED SYSTEM IDENTIFICATION

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Abstract

The lecture covers some important aspects of design of digital controllers. Special emphasis is put on selection of sampling period, design methods and implementation aspects. System identification is briefly discussed in connection with modelling and adaptive controllers.

Introduction

For long time it has been necessary for a control engineer to master analog computing technology. Analog technique has been used to implement and simulate control systems. Today it is equally important to be able to handle digital technique. Computers are today used in an increasing number to implement controllers. The hardware development has made it possible to implement controllers that were impossible to implement a couple of years ago. One example is adaptive controllers. Unfortunately the full potential of the digital technique has not been used by the designers. It is essentially only analog technique that has been translated into digital form. It has, however, been realized that much can be gained by using the full potential of the new technique.

The purpose with the lecture is to point out some of the implications of the development of digital computers. This has consequences for the implementation as well as for the design of the controllers. The lecture will focus mainly on the design methods.

Applications of digital control

The first computer installation in the process industry was made in the end of of the fifties. At that time the computer was a large, expensive, unreliable, part of equipment. The scene has changed drastically over the last twenty years with respect to the hardware and it is a safe guess that the development will continue for still some years. Smaller and larger process control systems are today implemented using computers. Small systems with one or two PID-regulators are often implemented using a microprocessor since this gives a cheaper and more reliable product. However, the user does not notice any difference. The digital PID-controller looks and behaves in the same way as a conventional PID-controller.

For larger systems the picture is quite different for the operator, at least on the surface. A typical DDC (Direct Digital Control) package contains

Arithmetic operations

Logical operations

Linearization and nonlinear functions

Regulators

The regulators are usually different versions of PID-controllers. A trend is that the logical control, such as start, stop and alarm, is integrated with the control functions. Until a couple of years ago these functions were usually separated and even in different equipments. In this type of systems the operator-computer communication is often done using a color display. The operator then has the possibility to choose from a menu of pictures, for instance an overview of the process, a trend curve or a detailed description of one control loop.

In summary there are today a large number of computers that are used to control industrial processes. However, the design philosophy for the control system has unfortunately not changed to the same extent as the hardware has changed.

Digital control theory

The control theory and especially the digital control theory has made much progress over the last twenty years. Much of the theory has, however, not been implemented to the extent that it deserves. There are several reasons for this. One is of course that many of the control problems in the process industry can be solved using simple controllers such that PID-controllers. The PID-controllers can easily be implemented in a computer and the user will not notice in which way the controller is implemented. A second reason is educational. Many control engineers have not taken courses in advanced digital control and feel unsafe when trying to use the new theory. A third reason is that the manufacturer of digital control equipment do not give the user the necessary tool for implementing new ideas. The DDC packages are well suited for PID-controllers and for couplings of simple controllers, but there are usually great difficulties to make something that was not encountered for when the system was designed.

Often digital control applications are done as a translation of an analog control structure. One consequence is then that the digital controller will not give as good performance as the analog controller. To get a good approximation it is necessary to use a fast sampling rate. This will give rise to numerical problems as well as an unnecessary increase in the working load on the computer. Using digital control theory it is however possible to design a controller which can perform as well and even better than an analog controller. What may be achieved by using new digital control algorithms? There are many new possibilities when using a computer to control a process. For instance it is possible to design a controller such that the response has a finite settling time, so called deadbeat controllers. Second using digital control theory it is possible to construct controllers which are using long sampling intervals. Third it is easy to couple different control loops and to change the regulator parameters depending on the working conditions.

Most design of control systems is done for linear systems. The resulting controller is usually linear. In practice it must be surrounded by 'safetynets' which often includes logic and nonlinearities. For instance to make bumpless transfer between manual and automatic mode and to avoid integrator windup. These things are easier to implement in a computer than by using analog technique.

Typical steps in a design procedure are:

Determination of the specifications

Modeling of the process

Choice of control principle, inputs and outputs

Determination of the regulator

Simulation and test of the controller

There are many possibilities when determining the regulators ranging from basic PID-controllers to optimal controllers. One way to unify the design of digital controllers is to look upon the design methods as pole-placement algorithms. Most state space methods and input-output methods can be regarded as pole-placement methods. The main objective of the designer is then to determine where the poles of the closed loop system should be placed. In order to do so it is necessary to understand the relationship between a continuous time system and its corresponding sampled data or discrete time system. This give rise to questions as:

o How will the stability properties of the system change when the system is sampled?

o How will the poles and zeros of the system change?

o Will the sampling influence the controllability and the observability of the system?

o How should the sampling period be chosen?

These and related questions are discussed in the lecture. One important aspect is how to analyze the intersample behaviour of a digital control system. The discrete time description only shows what happens at the sampling points. It is then useful to have a simulation package were it is possible to mix continuous time as well as discrete time systems. Also for the design it is necessary to have good CAD tools for instance to determine controllers and to analyze stability, controllability etc.

System identification

Mathematical models are very useful to summarize the knowledge about a process. Also many of the design methods for controllers require a model of the process and sometimes also of the disturbance acting on the process. The models are often obtained by a combination of physical model building and experiments. It is necessary to have effective estimation algorithms that can be used to analyze the data. Often it is desired that the models can be obtained in real time. This is for instance the case when the estimation routine is used as a part of an adaptive controller.

It is important to emphasize that a process can not be described by one model, but by a hierarchy of models. Simple models are for instance used to to get the main behaviour of the system. The complicated models are used for instance to check the behaviour of the designed controller.

The lecture discusses some trends in system identification such as recursive estimation and properties of different estimation schemes.

The future

Based on the dramatic developments in the past it is tempting to speculate about the future. There are four areas that are important for the development

Process knowledge
Measurement technology
Computer technology
Control theory

The knowledge about process control and process dynamics is increasing. The use of computers also facilitates development of process models. With a computer in the loop it is easy to collect data and to analyse the performance of the system. Also the progress in system identification and data analysis has given new powerful tools.

The development of a control system is often hampered by the lack of measurement devices. There are however many things that can be done using existing techniques. It is for instance possible to combine outputs from different sensors using a model of the process.

The hardware development will probably continue for still some years. It is expected that the microcomputers of the late eighties will have a computing capacity greater than the large mainframes of the late seventies. The trend of decentralization will continue. Better communication between computers will also be developed. Color graphical display will change the ergonometric functions of the computer-operator interface.

The development in software has not been as spectacular. The programming has on the contrary been one of the bottlenecks. This has lead to standardized packages where the user only has to supply some data in order to specify a control loop. This has the consequence that it may be very difficult to make something that was not considered when the software was designed. This situation can be expected to change. New programming tools for real time programming are now available and this will change the programming environment and facilitate experimentation with new control algorithms.

In summary there are many signs that indicate that there will be an interesting development in the application of computers for control of industrial processes.

References

There are many books and papers that cover the field of digital control and system identification. Only a couple of references are given for further reading and references. Digital control theory is presented for instance in:

Franklin G.F. and Powell J.D (1980): Digital Control of Dynamic Systems, Addison Wesley, Reading

Aström K.J and Wittenmark B. (1983): Computer-controlled Systems, Prentice Hall, Englewood Cliffs (to appear)

A survey of computer aided design is given in

Aström K.J. (1983): Computer Aided Modeling, Analysis and Design of Control Systems - A Perspective, Control Systems Magazine, 3, No 2, May 1983, 4-16

Identification methods are discussed in

Goodwin G.C. and Payne R.L. (1977): Dynamic System Identification: Experiment Design and Data Analysis, Academic Press, New York

Ljung L. and Söderström T. (1983): Theory and Practice of Recursive Identification, MIT Press, Cambridge

The latter contains a unified treatment of recursive identification methods.