Papermaking

Adaptive Control

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the time of writing, however, international links operate either with LAPB or with a multiline procedure which also operates on several parallel lines, but which was developed before standardization of the multilink procedure.

X.95 specifies the call progress signals of public data networks—for the packet mode of operation, that is, the meaning of the cause field in clear, restart and reset packets.

X.121 specifies the international numbering plan for public data networks. In other words it describes the internal structure of the address fields used in call-establishment packets. Typically an address for a packet-mode DTE attached to a public packet-switched network is expressed as a one-digit prefix (e.g., 0, followed by a field of four digits to identify the network, and then followed by a few digits to identify the DTE in that network. Each network specifies the number of digits of its DTE address, with the possibility of giving short addresses to the same DTEs and longer ones to others.

9. *Future Prospects*

Although packet switching is now governed by a well-established set of international standards and has become a worldwide communication medium, some development is occurring, mainly in the direction of more interworking with other networks. With the progress made in modems which operate in synchronous mode over the public switched telephone network (PSTN), extensions of X.25 for operation via PSTN access ports are commercially planned. They are being studied by CCITT, in particular for teletex applications (direct communication between text-processing equipment).

Two directions of current research include interworking with local area networks and integration of packet-switching procedures into future integrated service digital networks (ISDNs). ISDNs should bring users an open choice between circuit switching and packet switching so that each is used where it best serves: circuit switching for long, continuous and fast transmission between two devices operating at the same speed; packet switching for slow or for spasmodic traffic, for communications between equipment with different characteristics and for multiplexing large numbers of diverse communications over individual network access ports.

See also: Distributed Computer Systems: An Introduction; Distributed Systems: Synchronization and Interprocess Communication; Switching Networks: General Structures

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R. Despres

Papermaking: Adaptive Control

The advanced control of important quality variables on a paper machine, such as basis weight and moisture content, are of major importance, since improvements of even fractions of a percent can represent substantial savings. The process dynamics include time delays. Operating conditions such as machine speed and the pressure distribution in the dryer sections may vary significantly. Large variations may also occur in the properties of pulp, and this can change drying conditions dramatically. All these variations result in changes in the process dynamics. A regulator which is well tuned at one operating condition and for one paper grade will not be optimal for other grades and other operating conditions. It is possible to compensate for variations in machine speed by gain scheduling, but this is not feasible for the paper grade, which is influenced by many different factors. This makes the paper machine an interesting candidate for adaptive control.

The steady-state control of the quality variables can conveniently be formulated as a minimum variance control problem. By reducing the variances of the quality variables, these may be brought closer to their optimum range, bringing savings in energy and raw materials and increases in production.

It was shown by Åström (1970) that the steady-state dynamics of the process and the disturbances could be described well by the model

$$A(q^{-1})y(t) = B(q^{-1})u(t-d) + C(q^{-1})e(t) \qquad (1)$$

where y is a quality variable (basis weight or moisture content), u is a control variable (pulp flow or steam pressure) and $\{e(t)\}$ is a sequence of independent random variables. Furthermore A, B and C are polynomials of low degree in the backward shift operator q^{-1}. Good results with minimum variance controls based on identified model were also reported.

The model (1) is in a form which is well suited for the application of self-tuning regulators. Industrial feasibility studies of basis weight and moisture control using a simple self-tuner based on minimum variance control and least-squares estimation were carried out by Borisson and Wittenmark (1974) and Cegrell and Hedqvist (1975). There exist substantial disturbances which excite the process persistently, and thus good

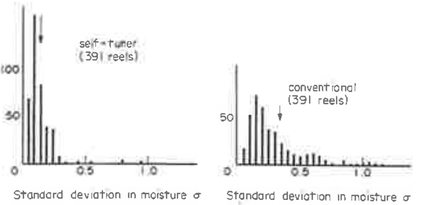

Figure 1
Histogram for standard deviation in moisture for a self-tuner and a conventional fixed gain regulator (Fjeld and Wilhelm 1981)

parameter estimates can be obtained and simple exponential forgetting of past data works well. Commercial paper machine controls have also been equipped with self-tuning controllers (Fjeld and Wilhelm 1981). The performance improvements obtained in comparison with conventional control are illustrated in Fig. 1.

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Parabolic Systems

Any partial differential equation where the solution u is a function of a one-dimensional variable t (the time, generally) and of a second variable x (multidimensional, generally), and which may be written (explicitly or implicitly) in the form

$$\frac{du}{dt} + D(u(t,x),t,x) = g(t,x) \qquad (1)$$

may be called a parabolic equation if $u \to D(u,t,x)$ is an elliptic operator, where partial derivatives of second order with respect to x occur. We shall see that Eqn. (1) is "well posed" if the initial value is given, and if boundary conditions (at the boundary of the domain of x) are given.

We present in this article only the linear case (where $D(\cdot,t,x)$ is linear for any t), after giving the best-known example of such equations, the heat equation. Finally we study variational inequalities, which are linear parabolic equations in a domain with a free boundary.

1. *The Heat Equation*

The heat equation is the "model" of linear parabolic equations. We present here this equation in a general case and we give explicit results in the simple case where the evolution domain is the whole space.

Let Ω be an open set of $\mathbb{R}^d$ modelling a heat conductor body. Assume that the initial temperature of the body is equal to $f(x)$ for all x in Ω; that the boundary is maintained at the temperature $\psi(t,x)$ at time t and position x; and that there is a distributed heat source whose density with respect to time and space is a function $g(t,x)$. Then the evolution of the temperature $u(t,x)$ of the body at time t and position x may be modelled by the following equation (where $t>0$):

$$\frac{\partial u}{\partial t} - m(x)\sum_{i=1}^{d}\frac{\partial}{\partial x_i}\left(M(x)\frac{\partial u}{\partial x_i}(x)\right) = g(t,x), \quad x\in\Omega \qquad (1a)$$

$$u(t,x) = \psi(t,x), \quad x\in\partial\Omega \qquad (1b)$$

$$u(0,x) = f(x), \quad x\in\Omega \qquad (1c)$$

where m and M are strictly positive functions describing the conductivity of the body. This kind of equation is studied in Sect. 2, (Eqn. (1) is a nonhomogeneous Dirichlet boundary condition).

Assume now that $\Omega = \mathbb{R}^d$ (then (1b) has to be dropped) and $m = M = 1$. Then (1) may be written in the very simple form

$$\left.\begin{aligned}\frac{\partial u}{\partial t} - \sum_{i=1}^{d}\frac{\partial^2 u}{\partial x_i^2} &= g(t,x)\\ u(0,x) &= f(x)\end{aligned}\right\} \qquad (2)$$

This is a Cauchy problem.

Proposition 1. *If f and g are in $L^\infty(\mathbb{R}^d)$ and $L^\infty([0,+\infty)\times\mathbb{R}^d)$ respectively, there exists a unique bounded solution u of (2).*

Indeed, let

$$p = p(t,x,\xi) = (4\pi t)^{-d/2}\exp[-(x-\xi)^2/4t] \qquad (3)$$

This function is called Green's function associated with the Laplacian in $\mathbb{R}^d$. It may be seen that p is a solution to

$$\left.\begin{aligned}\frac{\partial p}{\partial t} - \sum_{i}\frac{\partial^2 p}{\partial x_i^2} &= 0\\ p(0,x) &= \delta(x-\xi)\end{aligned}\right\} \qquad (4)$$

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