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High-gain adaptive control: an overview

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A wide range of control theory deals with the problem that, for a *known* plant, a controller has to be designed in order that the feedback system achieves a prespecified control objective. The fundamental difference between this approach and that of *adaptive control* is that the *plant is not known* exactly, only structural information is available. The aim is therefore to design a single controller which can be applied to a variety of systems belonging to a certain class. The control law has to be designed so that the controller learns form the behaviour of the system, and based on this information, it adjusts its parameters. This area has been intensively studied over the last 40 years. See [1,32] for survey articles.

Up to the end of the 1970s, most adaptive control mechanisms would attempt to identify or to estimate certain parameters of the plant, and then design a feedback controller on the basis of this information. Here an overview is given on adaptive controllers which are not based on any parameter identification or estimation algorithm, see also [10]. The objective is not to obtain information about the plant, but simply to control the unkown plant or process.

We consider the class of linear, time-invariant systems of the form

$$\left.\begin{array}{rcl} \dot{x}(t) & = & Ax(t) + Bu(t) \quad ,x(0) = x_0 \\ y(t) & = & Cx(t) \end{array}\right\} \qquad (1)$$

where

(i) $(A, B, C) \in \mathbb{R}^{n \times n} \times \mathbb{R}^{n \times m} \times \mathbb{R}^{m \times n}$ and n are unknown,

(ii) (A, B, C) is stabilizable and detectable,

(iii) $C(sI_n - A)^{-1}B$ has no zeros in $\{s \in \mathbb{C} | Res \geq 0\}$,

(iv) $\sigma(CB) \subset \{s \in \mathbb{C} | Res > 0\}$ [or $\det CB \neq 0$].

If output feedback of the form

$$u(t) = -ky(t)$$

is applied, then we obtain a closed-loop system

$$\dot{x}(t) = [A - kBC]x(t) \qquad ,x(0) = x_0. \qquad (2)$$

Assumption (ii) guarantees that the unstable modes can be controlled and observed. (iii) is essentially a generalization of the minimum phase condition to multivariable systems. In other words, the zero dynamics are exponentially stable. Thus for k tending to $+\infty$ the poles of (2) tend to the zeros of (1) and the remaining poles go off to infinity. Finally, (iv) ensures that the remaining poles tend to $-\infty$. (A modified feedback has to be applied if the weaker assumption $\det CB \neq 0$ holds true.)

So far the system will be asymtotically stable for k 'large enough'. However k has to be found adaptively. In the seminal work of [29,33,41] the following simple adaptive control strategy has been introduced

$$\left.\begin{aligned} u(t) &= -k(t)y(t) \\ \dot{k}(t) &= \|y(t)\|^2 \qquad , k(0) = k_0 \in \mathbb{R}. \end{aligned}\right\} \tag{3}$$

Now the time-varying gain $k(t)$ is increasing as long as $\dot{x}(t) = [A - k(t)BC]x(t)$ is unstable. Until finally the system becomes stable, $k(t)$ converges to a finit limit, and $x(t)$ tends to 0.

This simple adaptive control strategy (with slight modifications) is universal in the sense that it works for whole classes of minimum phase systems. It is the underlying idea for many generalizations of the class (i)-(iv) and many different control objectives.To name but a few references:
Linear systems: [2,12,13,15,25,26,33,41]
Infinite dimensional systems: [5,6,19,21,22,23,24]
Nonlinear systems: [16,18,35,36,37,38]
Robustness: [7,20,23,27,34]
Perfo~~r~~rmance: [9,12,27]
Higher relative degree: [3,4,10,17,27,30,31]
Stability of the final system: [11,14]
Tracking [8,16,21,25,27,28,29,40]

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