Chapter 15
Self-Tuning Control Systems: A Review of Developments

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ABSTRACT

A concise technical overview of some of the key ‘landmark’ developments in self-tuning control (STC) are presented. The notion of two coupled sub-algorithms forming the basis of STC together with enhancements to produce adaptive on-line procedures is discussed as well as the potential limitations of such schemes. The techniques covered include optimal minimum variance, sub-optimal pole-placement and long range model-based predictive control. Based on the experiences of the authors in the industrial application of STC, extensions of the standard linear model-based approaches to encompass a class of bilinear model-based schemes, are proposed. Some on-going developments and future research directions in STC for bilinear systems are highlighted. These include the requirements for combined algorithms for control and fault diagnosis and the need for models of differing complexities.

INTRODUCTION

The general aim of the chapter is to provide the reader with an overview of some of the key developments in the field of linear model-based STC. It also includes an introduction to some of the definitions that allow the classification of the resulting STC forms. The definition of STC as being one form of adaptive control which requires two coupled sub-algorithms, one for on-line estimation of a discrete-time mathematical model of a plant and the other for control law design and implementation, is presented. The notion of repeatedly updating the model parameters via recursive estimation is introduced. Whilst reference is made to authoritative texts on the subject, a brief review of recursive least squares and Kalman filtering is given, together with extensions to enhance the adaptivity of the schemes. Then, three main categorisations of control law design are considered in the order of their historical development, namely: optimal d-step ahead control.
strategies (where \( d \) is defined later), sub-optimal pole-placement control strategies and long range model-based predictive control. The above developments are based on assuming a linear model representation for the system to be controlled. Various extensions and refinements have been proposed, and the chapter will provide the details of some of these developments, particularly those of the authors and their colleagues.

In particular, research conducted by the first author has shown that it is often found that the online parameter estimation algorithms can produce wildly varying estimations in cases when STC is applied to nonlinear systems. In such cases, the self-tuning principle may become violated, and an extension of the above STC strategies to deal with a class of bilinear systems has been considered. Adopting such a bilinear model representation potentially allows STC to be applied to a wider range of systems for which the notion of linearisation at a point is replaced by that of bilinearisation over a range. A review of some the more recent developments in the area of STC assuming a bilinear model representation is therefore included. Finally, a section containing concluding remarks is given which resumes the overall coverage of the chapter.

A discussion on future open research directions in which the notion of a combined approach for realising control and fault diagnosis and the need for different model complexities is presented in a section on additional reading.

BACKGROUND: TECHNICAL REVIEW OF SELF-TUNING CONTROL

This chapter on ‘Self-tuning Control Systems: A Review of Developments’ aims to inform the reader of the major developments and historical landmarks in the topic up to the present day. The earliest reference dates back to the first International Symposium on Self-Adaptive Flight Control in 1959 which was held at what is now the Wright-Patterson Air Force Base, Dayton, Ohio, USA (Gregory, 1959), where the concept of ‘self learning’ control was first proposed. However, due to the lack of available technology at that time, in terms of reliable computer hardware and software, it was a decade before this concept was to re-emerge. In fact it re-emerged under the name of self-tuning control (STC) in the 1970s and was notably driven in those earlier years by Kalman (1960), Peterka (1970), and Astrom and Wittenmark (1973), who are now recognized as the early pioneers in this field. The major breakthrough by Astrom and Wittenmark (1973) with the optimal d-step ahead minimum variance (MV) self-tuning regulator/controller (STR)/STC in which convergence was proved for the simplest case was perhaps the first landmark which led to a positive resurgence and increased interest in the subject. This was followed in 1975 by the development due to Clarke and Gawthrop (1975) with the generalised minimum variance (GMV) STC in which constraints on control effort could be implemented to achieve a realizable control system. This led naturally to the incremental forms of MV and GMV STC, in which inherent integral action is automatically achieved.

The reader will be reminded that a model is only an approximation, however sophisticated it may appear, and that all models are developed and used for purpose and convenience. In fact, the notion of ‘models for purpose’ will feature as an underlying thread throughout the chapter, with models for the purpose of control being necessarily simpler in structure than some of their counterparts, e.g. those for fault diagnosis. The above MV and GMV schemes belong to a family of control systems which can be described as Linear Quadratic Gaussian (LQG) since the assumed plant model is linear, the cost function to be minimized is quadratic and the noise affecting the output of system is assumed to be Gaussian. The resulting MV and GMV controllers were developed initially for the auto-regressive with
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