

# Preface

Time delay always arises in engineering models, where the rates of change of state variables depend both on present and on past state variables of the system. Control processes with feedback delay, regenerative machine tool chatter, wheel shimmy models including the elastic contact between the tire and the road, car-following traffic models with the reaction time of the drivers, human motion control with reflex delay, can be mentioned as examples. The analysis of these systems requires the characterization of their local behavior around a desired position or a desired (possibly periodic) path. Such properties can be described by stability charts that present the stability of the linearized system in the plane of the system parameters. These stability charts provide a useful tool for engineers, since they present an overview on the effects of system parameters on the local dynamics of the system.

The main differences between systems with and without time delay is that time delay produces an infinite-dimensional dynamics as opposed to the finite-dimensional dynamics of delay-free systems. For simple time-delay systems, stability charts can be derived analytically. However for complex systems, for instance, when the time-delay effect is coupled with parametric excitation, only numerical techniques can be used.

The scope of this book is to present a numerical technique, called the semi-discretization method, for the stability analysis of linear time-periodic time-delay systems, which is also an essential tool in the study of periodic motions of non-linear time-delay systems. Semi-discretization is a well-known technique used, for example, in the finite element analysis of solid bodies, or in computational fluid mechanics, where the corresponding partial differential equations are discretized along the spatial coordinates only, while the time coordinates are unchanged. In case of time-delay systems, semi-discretization results in the discretization of delayed terms only, while the actual-time-domain terms are not discretized. In this way, the infinite-dimensional system is approximated by a finite-dimensional one.

The structure of the book is as follows. Chapter 1 gives some introduction to linear time-delay systems. Chapter 2 deals with the construction of the stability charts for some fundamental delay-differential equations. The semi-discretization method is presented in Chapter 3 including higher-order methods, rate convergence esti-

mates, and numerical issues. The semi-discretization method is applied in Chapter 4 to some Newtonian examples with different delay types, such as single point delay, multiple delays, distributed delay, and time-periodic delay. Finally, Chapter 5 presents real-world mechanical engineering applications. Turning and milling processes are considered with varying spindle speed, resulting in time-periodic time delays. Then, the so-called act-and-wait control concept is introduced, and it is analyzed through applications to the stick-balancing problem and to a force-control process with feedback delay. It is shown that the inclusion of waiting periods in the control rule may have a stabilizing effect. This provides the surprising conclusion that doing nothing and rather waiting for the response of a previous action might be a superior control strategy for systems with feedback delay. Finally, the stick-balancing model with reflex delay is investigated in the case of parametric forcing at the stick's base. The book concludes with an appendix that contains Matlab codes for the semi-discretization of the examples presented in Chapter 4.

The book is designed for graduate and PhD students as well as for researchers working in the fields of mechanical, electrical, and chemical engineering, control theory, biomechanics, population dynamics, neurophysiology, even climate research in which time-delay models occur.

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