Preface

Although the origin of reset control systems goes back to 1958 with the founding work of Clegg, the subject is still in its infancy. The seminal works of Horowitz and coworkers in the 1970s were the first attempts to build a synthesis theory for basic reset compensators such as the Clegg integrator or the FORE (first-order reset element), but the lack of a control theory, approaching basic questions such as well-posedness and stability, for several decades has put aside of the mainstream further developments in reset control, both in theory and applications. It is not until the late 1990s that reset control starts to develop with the works of Chait, Hollot and coworkers, giving a significative impetus to the field. In the meantime, the area of hybrid control systems and impulsive control also give numerous results, having clear connections with reset control. For the last decade, a number of international groups have been working actively on reset control, and fortunately, reset control has started to be seen as an attractive control design technique with a significant potential for practical control applications.

The first direct contact of the authors with reset control was in September 2000, when Isaac Horowitz was visiting our group in Spain. We were actively working in nonlinear QFT at that time, that uses linear compensation, and in several fruitful discussions he gave us clear arguments for the many benefits of using nonlinear/reset compensation to attack the "nonlinear tiger" and also to overcome fundamental limitations of LTI systems. We started to seriously work on reset control in 2006, and since then our goal has been to develop a formal theory to cover basic theoretical aspects, and also to define simple compensator structures and tuning rules for them, with the focus on some practical problems, including applications in process control and teleoperation, and in general systems with time-delays.

The first chapter of the book is an introduction to reset control systems, pursuing two objectives. The first objective is to give a quick and simple description of what a reset control is, and to provide basic explanations on why and when it is convenient to use this strategy. This objective is covered by the first two sections and is summarized in this key idea: *a reset control is a simple nonlinear control technique very effective for linear plants subject to fundamental design limitations*. The second objective of the chapter is to give a brief survey on the literature on analysis and design of reset control systems. The historical perspective begins with the early ideas on reset control, including the popular Clegg integrator and the first-order reset element (FORE) introduced by Horowitz and coworkers. In addition, the first series of rigorous results on analysis and design of reset controllers using a state-space description are given, including full reset and partial reset compensators. In addition, relationships between reset control and the wider field of impulsive and hybrid control systems will be analyzed from different points of view.

In Chap. 2, a definition of a reset control system, or a reset system in general, is given. In general, as it is common in impulsive systems, reset systems may exhibit different types of solutions, in particular having complex patterns such as beating, deadlock, and Zenoness. In control practice, this type of behavior is considered pathological and thus several conditions will be given for reset control systems to be well-posed. On the other hand, important properties of reset systems may be derived by analyzing the reset instants that correspond to a given initial condition. These patterns will be also analyzed, and their relationship with the observability and reachability of the base linear system will be shown.

Chapter 3 is devoted to the stability problem of reset control systems with finite-dimensional base systems. The stability problem is addressed from different, complementary points of view: (i) internal or Lyapunov stability, (ii) external or input–output stability with passivity analysis, and (iii) stability by the describing function method. Internal stability techniques are subdivided into techniques giving rise to stability conditions that do not depend directly on the reset instants (reset-times independent), or alternatively, are reset-times dependent. The first case is obtained directly using continuous time Lyapunov functions (that gives rise to the so-called H_β condition), while the second case (reset-times dependent) requires a discretization at the after-reset values and a subsequent discrete-time Lyapunov analysis. Then, the input–output $\mathscr{L}_2$ stability is studied, and a number of results are presented in connection with passivity and dissipativity properties of reset feedback loops. Finally, the standard describing function tool is used for approximately predicting the appearance or absence of oscillations.

Stability of time-delay systems under reset control is approached in Chap. 4. Since reset control is able to overcome fundamental limitations, and time-delay is one source of such limitations, then it is of great interest to study the problem of delayed reset systems. The stability is addressed by choosing an appropriate Lyapunov–Krasovskii functional, and by imposing that the functional should decrease in the continuous and reset modes. The resulting conditions take the form of linear matrix inequalities, and, depending on the chosen functional, these LMIs can be delay-dependent or delay-independent. In both cases, those LMIs, derived from time-domain stability conditions, are translated into equivalent frequency-domain conditions by means of adequate tools, like the Kalman–Yakubovich–Popov lemma, or passivity techniques. From the latter frequency-domain conditions, useful interpretations are exhibited regarding the achieved robustness, in terms of scaled small-gain or positive realness of certain subsystems. Finally, several examples illustrate the application of the stability conditions, showing the potentials of reset control when applied to time-delay systems.

In Chap. 5, reset compensation has been used to overcome limitations of LTI compensation. In this chapter, a new reset compensator, referred to as PI + CI, is introduced. It basically consists of adding a Clegg integrator to a PI compensator, with the goal of improving the closed loop response by using the nonlinear characteristic of this element. It turns out that by resetting a percentage of the integral term in a PI compensator, a significant improvement can be obtained over a well-tuned PI compensator in some relevant practical cases, such as systems with dominant lag and integrating systems. The main goal is the development of PI + CI tuning rules for basic dynamic systems in a wide range of applications, including first- and higher-order plus dead time systems. In addition, a number of design improvements such us the use of a fixed or variable reset band, the integration with QFT, and the use of a variable reset percentage are discussed.

Finally, in Chap. 6, several practical applications of reset control systems will be developed, all based on the PI + CI compensator: a temperature control system of a heat exchanger, a bilateral teleoperation control system, and finally, a temperature control of a solar collector field. The first two applications have been tested by means of experiments in plants, while the third has been tested by using a (well-proven) simulator of the field.

This book is a compendium of the several works developed by our groups in the last five years. These works have been performed in collaboration with Joaquín Carrasco, Angel Vidal, Alejandro Fernández, Juan Ignacio Mulero, Sebastián Dormido, José Carlos Moreno, Manuel Berenguel, and Arjan van der Schaft. In fact, they are responsible for many parts of this book. The authors also acknowledge the support of ‘Ministerio de Ciencia e Innovación’ (Spanish government) under the joint projects DPI2004-07670, DPI2007-66455, and DPI2010-20466.

Thus, the book has been planned as a means to systematize and make available to a wider audience a number of publications that are disseminated over several journals and conference proceedings. It is intended for control researchers interested in a solid introduction to reset control, including the several approaches available in the literature, and also for control engineers interested in application of simple and efficient control techniques that may overcome fundamental limitations of the universally used PI/PID compensators.

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