Preface

Stabilization and output regulation are two central design problems in nonlinear control theory and applications. Stabilization refers to the process of designing a feedback control law for a controlled plant such that certain invariant manifold of the closed-loop system is stable in a broad sense. A motion trajectory and an equilibrium point of a dynamic system are special cases of an invariant manifold of the dynamic system. Output regulation, on the other hand, aims to design a feedback control law for a controlled plant subject to some exogenous signal such that certain invariant manifold of the closed-loop system is stable and, in addition, the output of the plant asymptotically approaches a given reference input determined by the exogenous signal. Thus, the output regulation problem is more demanding than the stabilization problem. Both the disturbance and the reference input of a control system can be viewed as the exogenous signal. Thus, the output regulation problem is also referred to as asymptotic tracking and disturbance rejection problem, or servomechanism design problem. In comparison with some other methods dealing with asymptotic tracking and/or disturbance rejection problem, a celebrated feature of the output regulation problem is that the control law is required to be able to handle a class of exogenous signals generated by a dynamic system called exosystem.

The output regulation problem arises from mathematically formulating practical control problems such as vibration suppression of high speed trains, disturbance rejection for flight vehicles, landing of aircraft on carriers under severe weather condition, and coordination and manipulation of robots. Thus this problem has attracted the attention of the control community for several decades and it has also been a driving force for the advancement of modern control theory and applications.

The output regulation problem was first studied for the class of linear time-invariant systems by Davison, Francis, and Wonham, to name just a few. The main tool for dealing with the output regulation problem is the internal model principle. By this principle, the output regulation problem of a given plant can be converted into the stabilization problem of the augmented system composed of the given plant and a well-defined dynamic compensator called internal model. The well-known
integral control can be viewed as a special case of the internal model principle when the exogenous signals are constant.

Since the early 1990s, the research on the output regulation problem has been focused on nonlinear systems. The problem has attracted the attention of numerous researchers from the world. By the time of the mid-2000s, the research on the nonlinear output regulation problem had achieved a degree of maturity. In addition to numerous research papers, four monographs on this topic were published.


It is noted that the main tool for studying the output regulation problem in the first three books [1–3] is the internal model design approach. An internal model is a dynamic compensator which together with the given plant constitutes a so-called augmented system. An internal model is conceived such that the stabilization solution of the augmented system leads to the solution of the output regulation problem of the original plant. Thus, this design framework has made a connection between the stabilization problem and the output regulation problem. In contrast, the book [4] studied the problem using a convergent dynamics approach. In particular, a system is designed to have the property that all its solutions “forget” their initial conditions and converge to each other. The convergent steady-state solution is uniquely defined by an exosystem. Jacobian analysis of nonlinear systems was applied to achieve the convergent property.

Since the mid-2000s, the scope of research on the output regulation problem has experienced a tremendous expansion along several directions summarized as follows. First, several new methods for constructing more general internal models have been developed. These new internal models have led to the solution of the output regulation problem for more general nonlinear plants and exosystems on one hand, and, on the other hand, have generated several new types of robust stabilization problems for more complex nonlinear systems, thus leading to some interesting results and techniques for global stabilization of uncertain nonlinear
Second, in order to handle uncertainty in exosystems, arbitrarily large exogenous signals and uncertain parameters, or unknown control direction, several adaptive control techniques have been incorporated into the original design framework for the output regulation problem, thus leading to the so-called adaptive output regulation problem. Third, extensive efforts have been made to solve real world practical control problems by output regulation theory. Some recent examples are asymptotic tracking of Chua’s circuit, spacecraft attitude control, speed control of surface mounted motor, robust regulation of hyperchaotic Lozenz system, etc.

Given the rich new results of the nonlinear output regulation theory and applications obtained in recent years, and the need for studying the state-of-the-art techniques for handling the stabilization problem and the output regulation problem of nonlinear systems by graduate students and researchers in both academia and industries, we bring this book to readers. The book can be used as a textbook for graduate students in all engineering disciplines and applied mathematics. It can also be used as a reference book for both practitioners and theorists in broad areas of electrical engineering, aerospace engineering, mechanical engineering, and chemical engineering. Readers are assumed to have some knowledge of the fundamentals of linear algebra, advanced calculus, and linear systems.

The authors seek to strike a balance between the theoretical foundations of the output regulation problem and practical applications of the theory. The treatment is accompanied by many examples, including practical case studies with numerical simulations based on MATLAB. The book was typeset using LaTeX.

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