Chapter 7
Modeling, Model Reduction, and Control of a Hands-Free Two-Wheeled Self-Balancing Scooter

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ABSTRACT

Designing a two-wheeled self-balancing scooter involves in the synergistic approach of multidisciplinary engineering fields with mutual relationships of power transmission, mass transmission, and information transmission. The scooter consists of several subsystems and forms a large-scale system. The mathematical models are in the complex algebraic and differential equations in the form of high dimension. The complexity of its controller renders difficulties in its realization due to the limit of iteration period of real time control. Routh model reduction technique is employed to convert the original high-dimensional mathematical model into a simplified lower dimensional form. The modeling is derived using a unified variational method for both mechanical and electrical subsystems of the scooter, and for the electronic components equivalent circuit method is adopted. Simulations of the system response are based on the reduced model and its control design. A prototype is developed and realized with Matlab-Labview simulation and control environment.

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INTRODUCTION

In general, the mechanical engineering design focuses on the analysis of motions, forces or torques to figure out its variables such as displacements, velocities or forces. The mechanical products were developed with simple feedforward and feedback control systems by using analog/digital devices to manipulate designed variables to achieve certain control functions and performances. With the introduction of digital computers into their control systems, the industrial products became multidisciplinary, and their comprehensive functionalities were executed with mechanical and electrical systems and achieved much higher precision of their motions. Starting in early 1980s, more and more industrial products have been migrating to mechatronic products. Nowadays, mechatronic products possess smart mechanisms driven by local actuators, which are integrated with sensors, and operated by embedded microprocessors coded with artificial intelligence, operational laws, as well as arithmetic and logic computations. The mechatronic systems have functionalities via the task-driven reconfigurable and flexible precision mechanisms. (Zhang, Nawrocki and Li, 2018)

As for the formulation of mechatronic systems, generally speaking, a machine set is mainly composed of two categories: power-generating machine and power-consuming machine. The power electronics delivers the manipulated input of energy flow into the power-generating machine, such as a DC motor, while the drivetrain builds the connection between the power-generating machine and power-consuming machine, obtaining the desired energy output measured by corresponding sensors. Basically, three types of energy flows are handled: electrical energy, mechanical energy and hydraulic energy. If this system is integrated with information processing subsystem bridging the input and output, automatically handling data based on the manipulated variables and measured variables in a feedback or feedforward way, a mechatronic system is constructed.

The terminology mechatronics was coined by Tetsuro Mori in 1969, by combining the mecha- from mechanical and –tronics from electronics to describe the electronic control systems for mechanical factory equipment built by Yaskawa Electric Corporation. Different literatures gave several definitions for this new terminology, and all of them pointed out that mechatronics is of multidisciplinary engineering. To our best understanding, it is more proper to interpret mecha- as mechanism instead of mechanical for the term mechatronics. The first generation of mechatronic systems, such as anti-lock braking systems, cameras, printers and disk storage, were developed by integrating the mechanical system, sensors, actuators and microcontrollers. The vital element of such a system is integration, consisting of both horizontal integration from various disciplines and vertical integration from design to manufacturing. Thus, a simultaneous engineering is recommended for