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New Trends in Robot Control

Springer

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Preface

The current book *New Trends in Robot Control* publishes the latest developments in the field of robotic and control, presented informally and with high quality. The content of the book is very interesting and attractive as it covers a wide range of technologies and control techniques including advanced robotic systems such as robot manipulators, system network, underactuated robotic system, autonomous drilling system, UAV-type drones, vehicular networking and connected vehicles, and vision process control. The intent is to cover the theory, applications, and perspectives on the state-of-the-art and future developments relevant to the field of robotic and other related areas, as embedded in the fields of control engineering, as well as the paradigms and methodologies behind them. The chapters of this book are designed for graduate students, researchers, educators, engineers, and scientists requiring theories, methods, and applications of mathematical analysis. Each chapter provides an enrichment of the understanding of the research discussed along with a balanced effort in theories, methods and applications, and also contains the most recent advances made in an area of robotic. This book is made of four distinct parts. In total, there are 19 chapters in this book, and they are organized as follows:

The first part of this book focuses on applications of control theory on robot manipulators, and comprises seven chapters:

The chapter "Tuning of Fractional Order Controller and Prefilter in MIMO Robust Motion Control: SCARA Robot" investigates the quantitative feedback theory in combination with fractional order controller to control multivariable systems. A new analytic tuning method of fractional order controller is proposed and aims at ensuring stability and robustness of the MIMO system.

The chapter "Flexible-Link Manipulators: Dynamic Analysis and Advanced Control Strategies" contains advanced studies in dynamic modeling and nonlinear control strategies applied to flexible-link robotic manipulators. The control strategy tackled in this chapter utilizes the classical nonlinear PD with fuzzy and gain scheduling controllers. The robustness of the obtained performance is then further improved involving a novel fractional order fuzzy PD (FOFPD) controller that uses non-integer order differentiator operators in the fuzzy PD controller by fine-tuning

the gains of the FOFPD using the particle swarm optimization algorithm. The stability of the closed-loop system is shown to be bounded input-bounded output.

The chapter "Autonomous Trenchless Horizontal Directional Drilling" reports mathematical aspects of drilling and trenches technology and provides an online control scheme for real-time optimization of the drilling parameters and control of steering system to minimize the deviation from the target borehole trajectory of the pilot hole and maximize Rop. Nonlinear model for the drilling process was developed using energy balance equation. The proposed controller design problem is formulated as an optimization problem where an objective function is considered to minimize tracking error and drilling efforts.

The chapter "Stabilization of Second Order Underactuated System Using Fast Terminal Synergetic Control" investigate the control of a class of underactuated mechanical systems using fast terminal synergetic control (FTSC) to guarantee the finite time convergence and the stability of the underactuated system. Hierarchical procedure has been utilized for the design of the finite time type controller.

The chapter "Sliding Mode Fault Diagnosis with Vision in the Loop for Robot Manipulators" investigates the problem of fault diagnosis (FD) for industrial robotic manipulators within the framework of sliding mode control theory. The control scheme for fault detection is complemented by a low-cost vision servoing architecture allowing the design a fault-tolerant control strategy in case of sensor faults. The effectiveness of the proposed FD architecture has been carried out in simulation on a realistic simulator as well as experimentally on a COMAU SMART3-S2 anthropomorphic robot manipulator.

The chapter "L_1 Adaptive Control of a Lower Limb Exoskeleton Dedicated to Kids' Rehabilitation" presents a comparison study of different adaptive controllers developed to control robotic orthoses used for kids rehabilitation. It is shown that among the proposed adaptive controllers, the performance of L1 adaptive control scheme prevails over the other approaches. The developed controllers were validated through different scenarios and simulations.

The chapter "Exoskeletons Control via Computed Torque for Lower Limb Rehabilitation" presents similar robotic system that aids deficient kids ability to walk. An exoskeleton 2-DoF robotic system is therefore considered in this chapter whereof two types of PID controllers have been proposed, in particular the PID based on feedback linearization and the PID adaptive feedback linearization have been tested and compared.

The second part of the book presents most advanced techniques on controlling and navigating autonomous vehicles and includes six chapters:

The chapter "Intelligent Control for an Uncertain Mobile Robot with External Disturbances Estimator" presents a control approach for the trajectory tracking problem of nonholonomic wheeled mobile robot (WMR) that efficiently copes simultaneously with model uncertainties and external torque disturbances. The novelty of this approach is the ability to completely compensate for the uncertainties and external torque disturbances without the requirement of torque measurement. In this approach, a kinematic backstepping controller is proposed to achieve perfect velocity tracking. Then, a robust dynamic adaptive control

algorithm with two update laws is developed to estimate and compensate the dynamic uncertainties and the unmeasured external torque disturbances. The design of the update laws uses only position and velocity measurements and is derived from the Lyapunov method.

The chapter "Adaptive Event-Triggered Regulation Control of Nonholonomic Mobile Robots" investigates the design of an adaptive-regulation control of a mobile robot in the presence of model uncertainties with event-based feedback control. The neural network with two layers are utilized to estimate the uncertain dynamics of the mobile robot. The control inputs is then developed with event-sampled measurement update. The Lyapunov's method is utilized to develop an event sampling condition and to demonstrate the regulation error performance of the mobile robot.

The chapter "Optimal Lane Merging for AGV" addresses the generation of an optimal constrained trajectory for lane merging tasks. The developed algorithm ensures a safe and a less fuel consumption for autonomous driving. The security is established with the restriction of both the lateral and the longitudinal AGV's position inside a safe zone while accomplishing a lane change to overtake an obstacle or to follow a lead vehicle.

The chapter "Finite Time Consensus for Higher Order Multi-agent Systems with Mismatched Uncertainties" tackles another aspects of robotic filed, which is networking and connected agents. This chapter presents a finite time distributed consensus problem for a class of robotic system represented by a higher order multi-agent system (MAS). The chapter considers agents when they are potentially affected by mismatched uncertainties and continues the design of a distributed controller combining the integral sliding mode technique and the finite time disturbance observer. Allowing to neglect the effect of mismatched uncertainties during the sliding mode. Stability analysis of the MAS is conducted using strict Lyapunov functions.

The chapter "Path Planning for a Multi-robot System with Decentralized Control Architecture" studies the path planning problem of a group of autonomous Wheeled Mobile Robots (WMR) in a cluttered environment. The problem of coordinating the motion of multiple WMR is tackled from the point of view of finding local minima of artificial potential field imbricated into a decentralized architecture to coordinate the movement of WMR that consists of combining three techniques which are the potential field, the neighborhood system, and the notion of priority between the robots. The approach is validated by simulation resorting to different possible scenarios.

The chapter "Which is Better for Mobile Robot Trajectory Optimization: PSO or GA?", Two optimization approaches for path planning of mobile robot have been proposed and compared. These approaches are the Particle Swarm Optimization and the Genetic Algorithms. The two approaches are then merged together seeking for optimal parametrization of the Dynamic Variable Speed Force Field. Authors' opinion has been provided to decide which of the two methods is the best for path planning of mobile robot.

The third part is concerned about recent developments on autonomous unmanned vehicles and drones, particular interest is brought to control of quadrotor-type aerial vehicles. This part is made of four chapters:

The chapter "Dynamic Modeling of a Quadrotor UAV Prototype" presents two methods to determine the dynamic model of a quadrotor UAV. In a first attempt, a mathematical model is developed to describe the quadrotor dynamics with six degree of freedom, using Euler–Lagrange formalism. The unknown model parameters are then obtained using calculations and experimental tests. In the second attempt, the roll system is estimated using closed-loop identification method and frequency domain analysis. The simulation results are compared with practical responses.

The chapter "Model-Based Fault Detection of Permanent Magnet Synchronous Motors of Drones Using Current Sensors" discusses simple low-cost and effective scheme for the detection of the most common faults in drone actuators which are the permanent magnet synchronous motors (PMSM). The scheme is based on a modeling stage which only requires the current measurements from a fault-less motor. From this, a simplified transfer function of the motor is derived. Then, the output of this model and a healthy motor are used as arguments of simple tests to detect the occurrence of a set of characterized faults in the target motor. The setup of the scheme and the development of the tests are straightforward. The faults considered in this work are inter-turn short-circuit, changes in friction constant and flying off propeller, and other less common faults. Experimental results show that these faults are accurately detected and characterized by the proposed scheme.

The chapter "ENMPC Versus PID Control Strategies Applied to a Quadcopter" investigates the trajectory tracking control problem for an unmanned aerial vehicle (UAV). Two continuous-time strategies of control are presented to solve this control problem. The first technique is based on cascade proportional-integral-derivative (PID) controllers, while the second utilizes the explicit nonlinear model predictive control (ENMPC) technique. Numerical comparison study is conducted to show the effectiveness of these two approaches and to emphasize the advantages of the ENMPC over the cascade PID strategy.

The chapter "Robust and Adaptive State Estimation of UAV Quadrotors with a High Gain Approach" studies the problem of joint states and external aerodynamic disturbances as well as the problem of adaptive estimation of quadrotor systems. Two configurations of the quadrotor are studied: in the first configuration, the dynamics of longitudinal and angular velocities are corrupted by unknown time-varying disturbances and in the second one, the quadrotor system is subject to constant unknown parameters. For the two latter cases of study, only positions and angles are available for measurements. To this end, the problem of observer matching condition is developed to solve both robust and adaptive estimation problems using first-order sliding mode observer in cascade with a high gain observer to reconstruct both the states and the unknown disturbances of the quadrotor system in the case of time-varying disturbance and adaptive observer in cascade with the same high gain observer to reconstruct both the states and the unknown parameters.

The fourth and last part of this book includes two chapters and emphasis on the importance of microsensors and actuators being used in robotics:

The chapter "Compound Fractional Integral Terminal Sliding Mode Control and Fractional PD Control of a MEMS Gyroscope" proposes a compound fractional order integral terminal sliding mode control (FOITSMC) and fractional order proportional-derivative control (FOPD-FOITSMC) for the control of a MEMS gyroscope. In order to improve the robustness of the conventional integral terminal sliding mode control (ITSMC), a fractional integral terminal sliding mode surface is applied. The chattering problem in FOITSMC, which is usually generated by the excitation of fast un-modeled dynamic, is the main drawback. A fractional order proportional-derivative controller (FOPD) is employed in order to eliminate chattering phenomenon. The stability of the FOPD-FOITSMC is proved by Lyapunov theory.

The chapter "Highly Sensitive Polymer/Multiwalled Carbon Nanotubes Based Pressure and Strain Sensors for Robotic Applications" is dedicated to illustrate the recent progress and development in wearable tactile sensors based on polymer nanocomposites for robotic applications, where capacitive pressure sensor and high sensitive and flexible piezoresistive strain sensor were realized. To effectively test these sensors, they were placed in different locations in the hand like fingers and palm for precision and power grasping in addition to gait analysis in a humanoid robot.

The editors are grateful to the contributors for their timely cooperation and patience while the chapters were being reviewed and processed. The editors also thank the editors and supporting staff at Springer for their timely cooperation in bringing out this book. We hope that all the contributors and the interested readers benefit scientifically from this book and find it stimulating in the process.

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