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BOOK REVIEW

Underwater Robots: Motion and Force Control of Vehicle-Manipulator Systems. 2006 (2nd Edition). Gianluca Antonelli (Authour), Springer Tiergartenstrasse 17, 69121 Heifelberg, Germmany (Publisher), price USD 118. This is the second edition of the book first published in 2002. The book is organized into10 chapters and an appendix.

Chapter 1 entitled 'Introduction' presents a short outline about the scope of underwater vehicle technology, and the motivation behind its development. Some examples of recent researches of underwater vehicle technology by various research groups around the world are also presented briefly in this chapter. The theory, which the mathematical model of vehicle's motion is based on, is presented in Chapter 2 under the title 'Modeling of Underwater Robots'. Subjects discussed in this chapter is divided into 10 sections: Rigid Body Kinematics and Dynamics, Hydrodynamics Effects, Gravity and Buoyancy, Thrusters' Dynamics, Underwater Vehicles' Dynamics in Matrix Formula, Kinematics of Manipulators with Mobile Base, Dynamics of Underwater Vehicle-Manipulator Systems, Contact with Environment, and Identification. Starting with the theory of rigid body's kinematics, the chapter discusses the expressions of attitude representation by Euler angles and by Quaternion, and provides the conversion formula to convert one to the other. The discussion about rigid body's kinematic is concluded with a presentation of 6-DOF (degree of freedom) kinematics. All expressions about translational and rotational motion of a rigid body are expressed in compact expressions. Discussion about rigid body's dynamics follows with the derivation of Newton-Euler formulation to express rigid body's translational and rotational motion.

Proceeding into the next section, discussion about hydrodynamic effects includes added mass and added moment of inertia, damping effects, and current effects. The discussion is limited to simple cases, as much in context of automatic control design. Further discussion regarding more complex cases is referred to references. Chapter 3 of [1] presents more thorough exposition on the calculation of added mass and moment of inertia, wind and current effects, and shallow water effects. Discussion about gravity and buoyancy presents formulation of how these two environmental forces affect the vehicle's dynamic. Like the discussion about hydrodynamic effects, discussion about thruster's dynamics is also limited to simplified modeling of thruster's dynamics, where thruster's theoretical and experimental analysis is left in references. These five sections are then concluded in the following section with the formulation of underwater vehicle's dynamic equation in matrix form, which covers all 6-DOF of the vehicle.

The discussion then proceeds with the kinematics of manipulators followed by their dynamics with underwater vehicle as a composite system. Contact between manipulators and environment is modeled afterwards. Simplified model is used to describe their interaction. Further discussion regarding interactions between manipulators-vehicle and environment is referred to references. The last section of this chapter is entitled 'Identification'. Here, the author describes about how dynamic parameter of underwater structure identification is considered as challenging task, so difficult that identification results are still limited to one and few DOFs, no significant result has been achieved in identification of full model underwater vehicle-manipulator systems. Discussion ends with overview of various works in underwater vehicle-manipulator system identification.

In chapter 3, various approaches of 6-DOF autonomous underwater vehicle controller design are discussed. Combinations between Earth-Fixed-Frame/Vehicle-Fixed-Frame and Model-Based/Non-Model-Based controller, including Model-Based controller with current compensation and Jacobian-Transposed-Based controller, are comprised. Qualitative comparison among them is presented afterwards, followed by results of numerical simulations.

Chapter 4 begins with concept of fault detection and fault tolerance, their philosophy and motivation. List of possible failures on autonomous underwater vehicles is listed. In the next section, fault detection strategies used in various researches are discussed. A model-based fault detection scheme whose objective is to isolate horizontal motion actuators' failures is presented. In this scheme, thruster's output is compared with its estimated value from an extended Kalman filter to detect incoherent behavior to the model's dynamic. Similar to this approach is using a sliding-mode observer in place of the extended Kalman filter. Another approach is by direct mismatching thruster's voltage between measured value and desired value computed by the thrust control matrix to detect failure. Another approach, a rule-based failure detection scheme also discussed briefly, where failure detection procedure involves certain task execution depending on mission phase. The rule-based failure detection scheme also used to isolate respective failure by a fuzzy inference system. In an autonomous underwater vehicle system, a rule-based fault detection procedure is equipped in every subsystem (Power, Communication, Propulsion, Navigation, and Guidance) coordinated by a Global Diagnoser. Such architecture is distributed on a redundant network of multiple coupled processors to ensure system's reliability. Some example research cases are presented. Another approach is called data-driven approach, where fault detection is performed by validating measured values with a 6-DOF simulation data. Another model-based detection called integrated heterogeneous knowledge is discussed briefly. This approach uses a multi-dimensional correlation analysis whose objective is to increase confidence level in fault detection. Also in discussion is neuro-symbolic hybrid system, a fault detection scheme with learning capability. The discussion also includes a systematic quantitative approach to maximize mission-and-return success probability. 'Quantitative' here means many redundant sensors on each system's variable to ensure measuring reliability.

The discussion about fault tolerance in the next section begins with a highlight on relationship between how tolerant a thruster-driven underwater vehicle with whether it is over-actuated or not. Example cases discussed next, always involve over-actuated underwater vehicles. The first case's strategy is to eliminate all coupling from the failed thruster and remap the vehicle's force and moment to the remaining working thrusters. Next case is a task-space-based fault tolerant control with redundant actuation. Next, a model-based fault tolerance scheme on sensor system is discussed where an emulated measuring output is used in comparison with that from the real sensors. Error between them is calculated and failed sensor is disconnected from the whole system for the rest of the mission.

Chapter 5 presents experiments on dynamic control of a 6-DOF autonomous underwater vehicle. Experimental set-up and some experimental results on dynamic control of a 6-DOF autonomous underwater vehicle and on fault tolerance to thruster's fault are presented.

Chapter 6 is about kinematic control of underwater vehicle-manipulator systems. The first section discusses the motivation and nature of the problem and previews several approaches to obtain solution. In the next section, an algorithm to minimize hydrodynamic drag is presented. Problems concerning joint constraints are addressed afterwards. Singularity-Robust Task Priority, a control approach that can achieve effective coordinated motion of the vehicle-manipulator is discussed in the following section, complemented with simulation results. And finally, kinematic control using fuzzy technique is presented, complemented with results of simulation of 4 study cases.

Chapter 7 begins with an overview of dynamic control approaches in some study cases. The following sections discuss various control techniques: Feed-forward Decoupling Control, Feed-back Linearization, Non-linear Control with Composite Dynamics, Non-Regressor-Based Adaptive Control, Sliding Mode Control, Adaptive Control, Output Feedback Control, and Virtual-Decomposition-Based Control.

By feed-forward decoupling control, controls of vehicle and manipulator's arm are achieved independently. Vehicle-manipulator coupling effect is estimated and fed-forward to vehicle thrusters to compensate it. Experimental results are presented for this technique. The feed-back linearization technique is a model-based control system, where the vehicle-manipulator is treated as linear system. The non-linear control with composite dynamics is a model-based control system with consideration of different bandwidth characteristics between the dynamics of the vehicle and of the manipulator. The non-regressor-based adaptive control is a control technique where controllers for the vehicle and for the manipulator are developed with a kinematic control approach with different bandwidth and independent one to the other. The sliding mode control is a non-linear control with variable structure that switches according to current system's position in state space. The controller's objective is to bring the vehicle-manipulator system's trajectory toward the controller's switching condition. Stability analysis and simulation results for this control technique are presented. The adaptive control here is a proportional-derivative controller with modifiable gains to compensate plant's varying or unknown parameters. Stability analysis and simulation results are also presented for this technique. The output feedback control is model-based controller designed with an observer forming up a controller-observer scheme. Implementation issues of this controller scheme are discussed. Stability analysis and simulation results of some study cases are also presented. The virtual-decomposition-based control is a control scheme with modular structure which simplifies control application to systems with large number of links. This scheme replaces one high-dimensional problem with many low-dimensional ones. Stability analysis and simulation results are also presented.

Chapter 8 begins with general overview about underwater vehicle-manipulator systems interaction control problems. Factors that must be taken into consideration in designing interaction control scheme are presented. It also discusses some control schemes that have been proposed for this problem. The discussion begins with a controller, based on hierarchy of interacting subsystem, designed to run on two 7-DOF manipulators to perform a cooperative task. It continues with impedance control scheme to achieve desired impedance at the end effectors. Then it proceeds with a discussion about external force control scheme. The discussion involves solving of inverse kinematics problem, stability analysis, robustness analysis, case of end effector's loss of contact with the environment during task, implementation issues, and simulation results. Discussion about explicit force control ends the chapter.

Discussions in chapter 9 are about coordinated control schemes for autonomous underwater vehicles in group. The following sections discuss the kinematic control problem on group of autonomous underwater vehicles. The control approach is by designing different generic tasks which each controls specific state variable of the whole group, then stacking them together as a task vector according to task priority framework. Another approach is by applying obstacle avoidance strategy to the task priority framework. Results of simulation test of the scheme are presented. A picture of experimental set-up for the scheme is also presented.

The appendix contains mathematical model of unmanned underwater vehicle and underwater vehicle-manipulator systems used throughout the book.

Assessment

Throughout the book, all mathematical expressions are written in compact forms. This is very convenient especially when describing motion inter-coupled in its multi-degree of freedom. Notations and symbols are carefully used and listed beforehand as to not making any inconsistencies. When discussing rigid body's kinematics and dynamics, however, the author only uses a few illustrations. For learner readers who are to familiarize themselves with subjects in robotics, this can be a bit of a challenge for them. Overall, compared to related books on the underwater robotics, Antonelli's *Underwater Robots: Motion and Force Control of Vehicle-Manipulator Systems* is more structured and easier to read than [2] and more coherent than [3].

The book provides a large amount of references in its discussions on theory, accomplished work, and example cases, giving its readers an opportunity to enrich their insights about the subject. References used throughout the book are indexed at the end of the book. Since their amount is so large, it would be beneficial for the reader if all references are indexed chapter-wise, or any other categorical way.

In conclusion, undoubtedly any researchers and scientist working on the area of underwater robotics will benefit from reading the book and gain valuable insights and a greater understanding of the challenges of and viable solutions to design, testing and operation of underwater robots for various missions and applications.

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