Preface

Kinematically redundant manipulators are those having more degrees of freedom (DOF) than required to perform a given end-effector primary task. One fundamental issue in operating such a robot system is the redundancy-resolution problem (or so-called inverse kinematics problem). An inverse-kinematics scheme is called repetitive if it maps closed paths in the task space (i.e., cyclic sequences of tasks) to closed trajectories in the configuration space (i.e., cyclic sequences of configurations). Nonrepetitive problem is that the joint angles may not return to their initial values after the end-effector traces a closed path in its workspace. Nonrepetitive problem results in a joint-angle drift phenomenon and may induce a problem that the manipulator's behavior is hard to predict; it is then less efficient to readjust the manipulator's configuration after every cycle.

In this book we present four typical motion planning schemes. One of them is online repetitive motion planning (RMP) scheme, or so-called cyclic motion generation (CMG) scheme, and its proof based on neural dynamic methods is given in detail. Then, some other optimization schemes, which can be viewed as the extensions of the RMP scheme, are developed and investigated for the purpose of repetitive motion planning. Furthermore, we unify them as quadratic programs (QPs). Moreover, some important QP solvers (including neural networks and numerical algorithms) are employed to solve the resultant QPs. Computer-simulation results based on various robotic models demonstrate the effectiveness of the proposed RMP schemes. For substantiating the physical realizability of the RMP schemes via QP formulation, one of the RMP schemes is applied to an actual planar six-DOF robot manipulator (or to say, robot arm). More specifically, we have the following organization.

In Chap. 1, we first discuss the importance of the RMP research and review the recent results on RMP. Then we present three kinds of manipulators. Their Jacobian matrices are derived in detail for further discussion, simulations, and experiments.

In Chap. 2, an optimization scheme is first presented and investigated for online RMP of redundant robot manipulators. Then, three extended schemes are developed for the purpose of RMP. These four schemes are finally reformulated and unified as QP problems with different definitions of the same coefficients.

In Chap. 3, we employ the well-known gradient-based neural network (GNN) and Zhang neural network (ZNN) approaches to analyze and prove the repetitive motion performance index.

One of state-of-the-art recurrent neural networks (RNN) is dual neural network (DNN). It can solve QP in real time. The DNN is of simple piecewise linear dynamics and has global (exponential) convergence to optimal solutions. In Chap. 4, we present such a DNN and its design method.

In addition to DNN, another type of neural network has been widely used in recent years, i.e., primal–dual neural network (PDNN). This kind of network includes mainly a traditional primal–dual neural network, a linear variational inequality (LVI) based PDNN, and a simplified LVI-based PDNN, presented in Chap. 5.

Different from the neural-network-based QP solvers, the numerical algorithms as QP solvers are very important as well, especially in the real-time kinematic resolution via today's digital computers. In Chaps. 6 and 7, we present numerical algorithms 94LVI and E47, respectively.

In Chaps. 8, 9, and 10, we present computer simulation examples based on planar multilink manipulators, PUMA560, and PA10 robots to demonstrate the effectiveness of the presented RMP scheme and the corresponding QP solvers.

To demonstrate the hardware realizability and efficacy of the QP-based methods for solving the nonrepetitive problem, Chap. 11 gives a repetitive motion planning and control (RMPC) scheme, and realizes this scheme on a physical planar six-DOF push-rod-joint (PRJ) manipulator. To control the real PRJ manipulator, this scheme considers variable joint-velocity limits and joint-limit margins. To decrease the model disturbance and computational round-off errors, this scheme also considers the position-error feedback. Then, the scheme is reformulated as a QP problem. Due to control via a digital computer, a discrete-time QP solver, termed piecewise linear equation (PLE) based numerical algorithm (i.e., numerical algorithm 94LVI), is presented to solve the QP problem. For comparison, both of the nonrepetitive and repetitive motions are performed on the six-DOF PRJ manipulator to track square, B-shaped, and circular paths. Theoretical analysis and experimental results validate the physical realizability and effectiveness of the RMPC scheme. Position-error analysis further verifies the accuracy of this scheme.

In summary, the book solves the nonrepetitive motion problem, which has stood in the areas of robotics and control for 30 years (specifically, since the work of Klein and Huang in 1983). The QP technique is exploited in this RMPC research with rich verification of simulations and experiments, while the traditional methods relate to pseudoinverse-type solutions. Now, the door to the industrial applications of redundant manipulators is completely open, as the difficult nonrepetitive motion problem has been solved truly, systematically, and methodologically. Without doubt, this book can be extended. Any comments or suggestions are welcome. The authors can be contacted via e-mails zhynong@mail.sysu.

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