SOME PROBLEMS OF MANIPULATOR MOTION CONTROL

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Introduction

The purpose of manipulator control is to maintain the dynamic response of a computer-based manipulator in accordance with some prespecified system performance and desired goals. In general, the dynamic performance of a manipulator directly depends on the efficiency of the control algorithms and the dynamic model of the manipulator. The control problem consists of obtaining dynamic models of the physical robot arm system and then specifying corresponding control laws or strategies to achieve the desired system response and performance.

Application of dynamic models

Robot arm dynamic deals with the mathematical formulations of the equations of robot arm motion. The dynamic equations of motion of a manipulator are a set of mathematical equations describing the dynamic behavior of the manipulator. Such equations of motion are useful for computer simulation of the robot arm motion, the design of suitable control equations for a robot arm, and the evaluation of the kinematic design and structure of a robot arm. The actual dynamic model of an arm can be obtained from known physical laws such as the laws of newtonian and lagrangian mechanics. This leads to the development of dynamic equations of motion for the various articulated joints of the manipulator in terms of specified geometric and inertial parameters of the links. Conventional approaches like the Lagrange-Euler (L-E) and the Newton-Euler (N-E) formulations can then be applied systematically to develop the actual robot arm motion equations. These motion equations are equivalent to each other in the sense that they describe the dynamic behavior of the same physical robot manipulator. However, the structure of these equations may differ as they are obtained for various reasons and purposes. Some are obtained to achieve fast computation time in evaluating the nominal joint torques in servoing a manipulator, others are obtained to facilitate control analysis and synthesis, and still others are obtained to improve computer simulation of robot motion.

The derivation of the dynamic model of manipulator based on the L-E formulation is simple and systematic. Assuming rigid body motion, the resulting equations of motion, excluding the dynamics of electronic control devices, backlash, and gear friction, are a set of second-order coupled nonlinear differential equations. The L-E equations of motion provide explicit state equations for robot arm dynamics and can be utilized to analyze and design advanced joint-variable space control strategies. Unfortunately, the computation of the dynamic coefficients requires a fair amount of arithmetic operations. Thus, the L-E equations are very difficult to utilize for real-time control purposes unless they are simplified.

As an alternative to deriving more efficient equations of motion, attention was turned to develop efficient algorithms for computing the generalized forces/torques based on the N-E equations of motion. The derivation is simple, but messy, and involves vector crossproduct terms. The resulting dynamic equations, excluding the dynamics of the control device, backlash, and gear friction, are a set of forward and backward recursive equations. This set of recursive equations can be applied to the robot links sequentionally. The most significant result of this formulation is that the computation time of the generalized forces/torques is found linearly proportional to the number of joints of the robot arm and independent of the robot arm configuration. With this algorithm, one can implement simple real-time control of a robot arm in the joint-variable space. The N-E formulation results in a very efficient set of recursive equations, but they are difficult to use for deriving advanced control laws.

Another approach for obtaining an efficient set of explicit equations of motion is based on the generalized d'Alembert principle to derive the equations of motion which are expressed explicitly in vector-matrix form suitable for control analysis. In addition to allowing faster computation of the dynamic coefficients than the L-E equations of motion, the G-D equations explicitly identify the contributions of the translational and rotational effects of the links. Such information is useful for designing a controler in state space. Furthermore, the G-D equations of motion can be used in manipulator design. The computational efficiency is achieved from a compact formulation using Euler transformation matrices (or rotation matrices) and relative position vectors between joints.

The computation of the applied forces/torques from the generalized d'Alembert equations of motion is of order $O(n^3)$, while the L-E equations are of order $O(n^4)$ [or of order $O(n^3)$ if optimized] and the N-E equations are of order $O(n)$, where n is the number of degrees of freedom of the robot arm.

Conclusions

Current industrial approaches to robot arm control treat each joint of the robot arm as a simple joint servomechanism. The servomechanism approach models the varying dynamics of a manipulator inadequately because it neglects the motion and configuration of the whole arm mechanism. These changes in the parameters of the controlled system sometimes are significant enough to render conventional feedback control strategies ineffective. The result is reduced servo response speed and damping, limiting the precision and speed of the end-effector and making it appropriate only for limited-precision tasks. Manipulators controlled in this manner move at slow speeds with unnecessary vibrations. Any significant performance gain in this and other areas of robot arm control require the consideration of more efficient dynamic models, sophisticated control approaches, and the use of dedicated computer architectures and parallel processing techniques.

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