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Design optimization on the drive train of a light-weight robotic arm

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ABSTRACT

A drive train optimization method for design of light-weight robots is proposed. Optimal selections of motors and gearboxes from a limited catalog of commercially available components are done simultaneously for all joints of a robotic arm. Characteristics of the motor and gearbox, including gear ratio, gear inertia, motor inertia, and gear efficiency, are considered in the drive train modeling. A co-simulation method is developed for dynamic simulation of the arm. A design example is included to demonstrate the proposed design optimization method.

1. Introduction

The drive train is the core part of a robot system, with significant impact on the cost and performance of the whole system. To achieve a light-weight design, drive train optimization plays a key role. A number of methods for motor and gear selection in mechatronic systems have been proposed. Pasch and Seering [1] studied maximizing the system acceleration by optimal selection of transmission ratio. van De Straete et al. [2,3] proposed a general method of motor and gearbox selection for optimization of servo drive system. The method automates the solution procedure for the servo drive design problem by virtue of the normalization of torques, velocities, and transmission ratios. Cetinkunt [4] proposed an optimization approach of balancing the high speed and precision in servo systems. Cusimano [5,6] presented a procedure for optimal selection of an electrical motor and transmission. Roos et al. [7] proposed a method of finding the best motor/gear ratio combination for any given load with respect to weight, size, peak power, torque and efficiency. The methods above are applicable to the design of a single joint combining a motor and a gearbox, and they do not address the discrete nature of the selection process.

For the design of robotic drive train consisting of multiple joints, the challenge is that not only the characteristics of motor and gearbox at a single joint, but also the dynamics of the robot should be taken into account, the latter varying with the selection of components and link dimensions. Furthermore, the optimization procedure adopted has to be capable of handling discrete design variables because the transmission is typically composed of commercially available components. Very few methods are available for the optimization of the entire drive train of a robot under constraint of available components. A method for the optimum selection of robot actuators was proposed in [8], with objective to minimize the total mass of all the actuators under torque and temperature constraints. Pettersson and Ölvander [9] reported recently a method of design optimization, in which drive train for two joints were optimized for an industrial manipulator. The method is not applicable to selection of components from a catalog. An evolutionary approach of optimization on robot configurations was reported in [10]. A simulation environment called Modelica with robot optimization characteristic was presented in [11], where the parameters of a controller can be tuned by a multi-criteria parameter optimization method to improve the system dynamics. DLR's 7-dof (degrees of freedom) torque-controlled light-weight robotic arm was built with customized motors and gearboxes to achieve a low weight [12]. Methods of robot optimization can also be found in [13–15], among others.

In this paper, an optimization method for drive train design of a light-weight robotic arm is proposed. The method is applicable to serial robotic arms, aiming at minimizing the arm weight. In the method, the optimization is carried out with a prescribed trajectory of the end-effector, generated within the robotic arm's workspace. Moreover, the inverse kinematic analysis was conducted in ADAMS to verify that the trajectory is within the joint space. A dynamic model of the robotic arm is developed, upon which an optimization problem is formulated. A non-gradient optimization method, namely, the Complex [16], is implemented to run the optimization. The method is implemented on a co-simulation platform, where robotic dynamics is determined using MSC.ADAMS™, and the complex optimization is performed in Matlab™.

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