## Abstract

This dissertation is concerned primarily with investigating the influence of friction and backlash on the dynamics and control of trajectory following robots. Existing industrial robots have bearings and gears within joints. These elements exhibit a nonlinear behavior of friction and discontinuity in the transmitted input torque to the link during backlash. Their effects on the dynamic performance of a robot can be quite significant. Realistic designs of driving systems should consider the minimization of the effect of these nonlinearties and the transmitted reaction . Efficient control methods that are based on more accurate dynamic model result in better accuracy in the dynamic response of the robot.

This work addresses three important area of robotics: modeling, design, and control. A dynamic model for a general robot with a driving system, including friction and backlash, is developed. The dynamic model is capable of handling prismatic joints as well as revolute joints, up to six degrees of freedom. The effect of gear parameters on friction is investigated. A mathematical procedure of calculating joint friction is developed. Different cases of backlash, with associated friction and transmitted reactions are investigated. Newton-Euler recursive relations for computing the actuating torques are modified to include a driving system with friction and backlash.

Design requirments and arrangements of the driving system is proposed to minimize the number of mathematical operations, and to minimize the transmitted reactions. The effect of speed ratio and gear size on friction is investigated, and a design of driving system for minimum friction is proposed. A shifting in the starting time of backlash, shortening its duration, and eliminating backlash are investigated.

An efficient method for dynamic computation with the complete dynamic model is introduced. A new way to determine end-effector to joint, and joint to end-effector differential transformations, is introduced and implemented on the Stanford arm.

Efficient control methods, based on the complete dynamic model, are proposed and their performance is evaluated and compared with a conventional method and with a more recent control approach.

A computer program written in FORTRAN is employed to investigate the effect of friction and backlash on the performance of the robot using the complete dynamic model, and using various control schemes. Computer simulations have been made to investigate several types of friction, different values of backlash, and the effect of payload on friction and backlash. The results demonstrate the neccessity for improving the dynamic model to include friction and backlash.

Simulation results of the present investigation include the following plots:

1. the effect of various types of friction on trajectory deviation,
2. the effect of different values of backlash on trajectory deviation,
3. the effect of different values of backlash with friction on trajectory deviation,
4. the effect of payload on backlash and friction,
5. comparison of performance under the improved dynamic model and the conventional model,
6. comparison of performance of different control methods for several sources of deviation.