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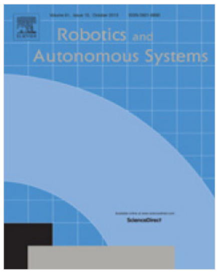

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Flat Control of Industrial Robotic Manipulators

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Abstract

A new approach to tracking control of industrial robot manipulators is presented in this paper. The highly coupled nonlinear dynamics of a six degrees of freedom (6-DOF) serial robot is decoupled by expressing its variables as a function of a flat output and its derivatives. Hence the derivation of the flat output for the 6-DOF robot is presented. With the flat output, trajectories for each of the generalised coordinates are easily designed and open loop control is made possible. Using MATLAB/Simulink S-functions combined with the differential flatness property of the robot, trajectory tracking is carried out in closed loop by using a linear flat controller. The merit of this approach reduces the computational complexity of the robot dynamics by allowing online computation of a high order system at a lower computational cost. Using the same processor, the run time for tracking arbitrary trajectories is reduced significantly to about 10 seconds as compared to 30 minutes in the original study(1). The design is taken further by including a Jacobian transformation for tracking of trajectories in cartesian space. Simulations using the ABB IRB140 industrial robot with full dynamics is used to validate the study.

Keywords: Industrial robots, Six degrees of freedom robot, Differential Flatness, Trajectory planning, Tracking control

1. Introduction

The development of industrial robots has been advanced in the last decade. This is mainly due to increase in the complexity of tasks that they execute. The controller which is a major component of robots has received a lot of attention from robotic researchers. This is because it has a direct impact on their performance and could inhibit their deployability and applicability in certain areas(2; 3; 4). Many control techniques have been proposed for modern industrial robot manipulators including the classical PID, Computed torque, feedback linearization, inverse dynamics, neurofuzzy, model predictive control etc. More recently, robot control methods have been model based which simply relies on the mathematical model of the robot.

Model based control has been applied in trajectory tracking tasks(5; 6; 7). However, the computational requirements of these model based systems are quite high as it is required to solve very large equations in their controls. Despite fast computer processor speeds, effective control algorithms become very computationally expensive with high run times and in some cases impossible to achieve. Most researchers in dealing with trajectory robot tracking applications have had to work with lower order robotic dynamics such as in wheeled robots(8; 9; 10), parallel robots(11) and underactuated robots(12; 2; 9) in proposing their control algorithms. Underactuating robotic manipulators reduces the order from a high degree of freedom (DOF) to a lower one. As the number of degree of freedom increases, the computational complexity of computing the control also increases. We refer to chapter 6 of(13) where the computational complexity of the 6-dof robot dynamics is discussed.

In this study, a 6-dof robot is modeled using the Newton-Euler approach. The computations done with the MAPLE software resulted in very long dynamic equations, literally running into several pages. The mere size of the equations can be a challenge to the control engineer in terms of the computing time. The equations are also nonlinear which adds to the burden. In these scenarios, classical control techniques fail due to the fact that they require long times for solutions to be obtained. This study presents a technique of tracking a 6 DOF without the use of underactuation or such other assumptions that would have first reduced the complexity of the problem.

One nonlinear control strategy that is gaining popularity among robotic researchers is the differential flatness based control(14; 15; 16; 17; 18; 19). It has been applied to control mobile robots(20; 10; 8), UAVs, UGVs(21), flexible robots(22), underactuated planar robot(23; 24; 12; 25) and so on. Differential flatness is known to be well suited for the problem of trajectory generation and tracking(20; 19; 26). With differential flatness, the trajectories (position, velocity, acceleration and jerk) of a nonlinear system can be easily interpolated by defining a smooth curve with initial and final conditions. The state and control variables can then be reconstructed without having to integrate the system equations(19).

This paper focuses on using this strategy for trajectory control of the ABB IRB140 6-DOF industrial robot with full dy-

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