SIMULATION STUDY OF AN ADVANCED CONTROL STRATEGY FOR A PUMA LIKE ROBOT MANIPULATOR

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ABSTRACT

The work of this project concerned with the presentation of an integrated mathematical model of the robot manipulator. The model of the system considered comprises the mechanical part of the robot manipulator, the actuators, as well as the gear trains. The formulation results in nonlinear time varying state equations, which represent a more realistic model of the robotic system. Decomposition and reduce the integrated model of the robot manipulator into a system with bounded uncertainties is presented. The Integral Sliding Mode Controller applied to a three degree of freedom PUMA like robot manipulator actuated by DC motors. It is shown that the robot manipulator utilizing the presented controller is practically stable and tracks a reference trajectory if a given sufficient condition is satisfied. The controller performance is evaluated through the simulation using MATLAB/SIMULINK. The performance of Integral Sliding Mode Controller is to be compared with an Independent Joint Linear Control.

ABSTRAK

Projek ini membincangkan tentang model berrepadu untuk pengolah robot. Sistem model yang dibangunkan merangkumi banagian-bahagian mekanikal robot, pemancu dan juga berk. Kaedah pemodelan sebegini menghasilkan persamaan kaedah berubah dengan masa yang juga merupakan model yang lebih realistic untuk robot. Model berrepodu pengolah robot diburaikan kepoda system dimana wujudnya ketidak pastian sempadan. Kawalan ragam gelincir kamiran diaplikasikan pada PUMA robot yang mengandungi 3 darjah kebebasan yang mengerakkan motor DC. Dapat dibuktikan bahawa pengawal yang di gunakan oleh pengolah robot adalah stabil dan boleh mengikut kebendak trjektori jika memencehi syarat. Keupayaan pengawal akan dinilai dengan bantuan perisian matlab/simulink. Keupayaan di antara kawalan ragam gelincir kamiran dengan kawalan lelurus bebas lipatan di bandingkan.

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SYMBOL	DESCRIPTION

1. UPPERCASE

A(,*,*)*	*3N x 3N* system matrix for the intagrated robot manipulator model
A	*3N x 3N* system matrix for the augmented dynamic equation of the actuators
$\Delta A(*,*)$	matrix representing the uncertainties in the system matrix
B(*,*,*)	*3N x N* input matrix for the intagrated robot manipulator model
B	*3N x N* input matrix for the augmented dynamic equation of the actuators
$\Delta B(*,*)$	matrix representing the uncertainties in the input matrix
C	*N x 3N* constant matrix of the Integral Sliding Surface
$\tilde{C}(*,*,*)$	*N x N* coffeicient matrix related to the accelaration vector in the derivative of the manipulator link dynamic equation
D(,*,*)*	*N x 1* vector of Coriolis and centrifugal forces

$\bar{D}(*,*)$ — $N\,x\,\sum_{i=1}^{N} i$ matrix related to *D(*,*,*)* vector

$\hat{D}(*,*,*)$ — *N x N* matrix related to *D(*,*,*)* vector

$\tilde{D}(*,*,*)$ — *N x N* coffeicient matrix related to the velocity vector in the derivative of the manipulator link dynamic equation

E(*,*) — a continuous function related to $\Delta B(*,*)$

F — *3N x N* load distribution mattrix for the augmented dynamic equation of the actuator

G(,*)* — *N x 1* vector of gravitational forces

$\hat{G}(*,*)$ — *N x N* matrix related to the vector of gravitational forces *G(*,*)*

H(*,*) — a continuous function related to $\Delta A(*,*)$

$I_{11}^{i} + I_{22}^{i} + I_{33}^{i}$ — Moment of inertia at the center of gravity for the *ith* link with respect to x-, y-, and z-, respectively

J_{mi} — moment of inertia for the *ith* motor (Kgm^2)

K_i — linear feedback gain matrix for the *i*th sub-system

L_i — armature inductance for the *ith* joint (H)

M(,*)* — *N x N* vector inertia matrix of the manipulator linkage

R_i — armature resistance for the *ith* joint (Ω)

$\Re^N$	*N*-dimensional real space
T(*)	*N x 1* vector of deriving forces/torques applied by the atcuator at the deriving point on each link of the manipulator
$\dot{T}(*)$	derivative of the manipulator torque *T(*)* with respect to time
U(*)	*N* x 1 control input vector for an *N* degree of freedom robot manipulator
W	*3N x N* rate of load distribution matrix for the augmented dynamic equation of the actuators
X(*)	*3N x 1* state vector for the intagrated robot manipulator model
X_d	*3N x 1* desired state trajectory vector for the integrated robot manipulator system
Z (*)	*3N x 1* error state vector between the actual and the desired states of the overall system
$(*)^T$	transpose of (*)
$\|\| (*) \|\|$	Euclidean norm of (*)

2. LOWERCASE

a_{ij}	*ij*th element of the integrated system matrix *A*(*,*)
b_{ij}	*ij*th element of the integrated input matrix *B*(*,*)
g	gravity acceleration (m.s^2)
k_{ti}	torque constant for *ith* motor (Nm/A)
k_{vi}	back emf constant for *ith* motor (V/rad/s)
l_i	length of the *i*th manipulator link (m)
m_i	mass of the *ith* manipulator link (kg)
t	time (second)

3. GREEK SYMBOLS

α	norm bound of continuous function *H*(*)
β	norm bound of continuous function *E*(*)
θ	joint displacement (rad)
$\dot{\theta}$	joint velocity (rad/s)
$\ddot{\theta}$	joint acceleration (rad/s^2)
θ_d	desired joint angle (rad)

$\dot{\theta}_d$	desired joint velocity (rad/s)
$\ddot{\theta}_d$	desired joint acceleration (rad/s^2)
σ	Integral sliding manifold
ξ	parameters of the manipulattor such as payload which belong to finite region of allowable parameter value
τ	time interval for manipulator to move from a given initial position to a final desired position (seconds)

LIST OF ABBREVIATIONS

DC	Direct Current
DOF	Degree of Freedom
IJC	Independent Joint Control
ISMC	Integral Sliding Mode Controller
PUMA	Programmable Universal Machine for Assembly
SMC	Sliding Mode Control
VSS	Variable Structure System

CHAPTER 1

INTRODUCTION

1.1 Overview

Robotics research is highly interdisciplinary requiring the integration of control theory with mechanics. The term robot has been applied to a wide variety of mechanical devices. An important class of robots are the manipulator arms, such as the PUMA robot. These manipulators are used primarily in materials handling, welding, assembly, spray painting, grinding, and other manufacturing applications. Robot manipulators are basically multi-degree of freedom positioning devices. The robot, as the plant to be controlled, is a multi-input/multi-output, highly coupled, nonlinear dynamic system.

To achieve higher speed and accuracy for robot manipulator over a wide range of application, the control technique needs to be improved. In general, the dynamic performance of a robot manipulator is directly dependent on the efficiency of the control algorithm and dynamic model of the robot manipulator. Thus the robot manipulator control problem consists of determining the mathematical model of the robot manipulator system and specifying the corresponding control strategies based on these models so that the desired system response and performance is achieved.

The main challenges in the motion control problem are the complexity of the dynamics, and uncertainties, both parametric and dynamic. Parametric uncertainties arise from imprecise knowledge of the dynamics, while dynamic uncertainties arise from joint and link, actuator dynamics, friction, sensor noise, and unknown environment dynamics.

An application of integral sliding mode control (ISMC) based on variable structure system for a three degree of freedom PUMA like robot manipulator is described in this project. This technique suppresses the uncertainties due to parametric variations, and variable payloads.

1.2 Objective

The objectives of this project are as follows:

1. To give a unifying framework for the formulation of the complete mathematical dynamic model of a DC motor actuated revolute robot manipulator in state variable form. The integrated robot manipulator model with joint angle, velocity and acceleration chosen as state variable. The formulations result in nonlinear time varying state equations.

2. To decompose an integrated nonlinear dynamic model of the PUMA like robot manipulator into a system with bounded uncertainties.

3. To control the three DOF PUMA like robot manipulator using Integral Sliding Mode Controller.

4. To compare the performance of Integral Sliding Mode Controller with conventional linear state feedback controller.

1.3 Project Scope

The scopes of this project are:

- Three DOF Permanent Magnet armature controlled DC motor driven PUMA like Robot manipulator as described in [1].
- Simulation work using MATLAB/Simulink as platform.
- Integral Sliding Mode Controller as described in [2].
- Comparison of Integral Sliding Mode Controller with conventional linear state feedback controller

1.4 Research Methodology

The project work consists of three main stages:

- Decomposition of the integrated dynamic model into an uncertain system based on the bounded of the angle, velocity, acceleration, and the payload.
- Two approaches for controlling PUMA Robot
  - First approach utilizing Integral Sliding Mode Controller.
  - Second approach utilizing conventional linear state feedback controller.
- Perform simulation of the two controllers in controlling a three DOF PUMA Robot manipulator using Matlab/Simulink as the platform.

1.5 Literature review

Various advanced and sophisticated control strategies have been proposed by numerous researchers for controlling the robot manipulator such that the system is stable as well as the motion of the manipulator arm is maintained along the prescribed path. Some of the control approaches considered in the literature will be presented briefly.

Several control algorithms for robot manipulators based on the variable structure theory have been reported in the literature [3], [4]. Variable structure systems are characterized by a discontinuous feedback control law induces the sliding mode in which the system trajectory lie on the switching surface, which result in insensitivity to parameter variation and disturbances. It is this insensitivity property that enables the elimination of the interactions among the joints of the robot manipulator. The control algorithm does not require an accurate knowledge of the physical parameters of the manipulator, the bounds of the parameters are sufficient to construct the controller Young [3]. However, the discontinuous control law is very difficult for realization in practice and discontinuous controller results in chattering effects of the control signal. To reduce the chattering effects due to the discontinuous control inputs [4] replaced the discontinuous feedback control law with an approximated continuous feedback control law.

Adaptive self-tuning control proposed by [5], used an autogressive model to fit the input-output data from the robot manipulator. The method does not require a detailed mathematical model of the robot manipulator. And the resulting system is insensitive to the changing configurations of the manipulator and variations in the load. However, the dynamic of the manipulator is required to be linearized. Thus, the technique results in a poor system performance over wide range of tasks.

Sliding mode techniques are one approach to solving control problems and are an area of increasing interest. In the formulation of any control problem there will typically be discrepancies between the actual plant and the mathematical model developed for controller design. This mismatch may be due to any number of factors and it is the engineer's role to ensure the required performance levels exist despite the existence of plant/model mismatches. This has led to the development of so-called robust control methods. However this approach is decreasing the order of the system dynamics, may produce undesirable result in certain application. Other alternative must be introduced to increase the order of the closed-loop dynamics [2].

To overcome the problem of reduced order dynamics, a variety of the sliding mode control known as the Integral Sliding Mode Control has been successfully applied in a variety of control. Different from the conventional SMC design approaches, the order of the motion equation in ISMC is equal to the order of the original system, rather than reduced by the number of dimension of the control input. The method does not require the transformation of the original plant into the canonical form. Moreover, by using this approach, the robustness of the system can be guaranteed throughout the entire response of the system starting from the initial time instance [2].

1.6 Layout of Thesis

Chapter 2 deals with the formulation of the integrated dynamic models of revolute robot manipulator. The state space description of the actuator dynamics (DC motor) in form of $\theta(t), \dot{\theta}(t)$ and $\ddot{\theta}(t)$, which are the joint angle, velocity, and acceleration respectively. Derivation of the integrated dynamic model for a three DOF PUMA like Robot manipulator with $\theta(t), \dot{\theta}(t)$ and $\ddot{\theta}(t)$ the joint angle, velocity, and acceleration respectively as state variable is developed.

Chapter 3 presents the controller design using integral sliding mode control. A PUMA like robot manipulator is treated as an uncertain system. Based on the allowable range of the position and velocity of the robot arm operation, the model comprising the nominal and bounded uncertain parts is computed. Then, the centralized control strategy for robot arm based on Integral Sliding Mode Control (ISMC) and also linear state feedback controller are described.

Chapter 4 presents the simulation results of the proposed controllers. The effectiveness of changing the controller parameters as well as the payload on the robot manipulator tracking is presented. Tuning algorithm is presented to assure that the desired tracking response is achieved. The performance of both controllers were evaluated by simulation study using Matlab/Simulink. For the comparison purposes, simulation study on Independent Joint Linear Control is also presented.

Chapter 5 summarizes the results of the research studies. Recommendations and suggestions for future work are also presented.