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Identification of a Hydraulic Manipulator

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ABSTRACT

General purpose controllers or controllers commanding systems which operate at varying conditions need a system identification routine which is applied to yield a response model of the system and adapt itself accordingly. This paper describes the application of the least squares identification technique to identify the response of a hydraulic robot manipulator. The hydraulic servo system is assumed as a second order linear system and modelled by the second order linear difference equation. Constant coefficients of the difference equation are obtained by the application of the least squares technique to minimise the error between the discrete position data resulting when actuated by a pseudo-random binary command signal and what the model generates. Manipulator and model responses to a given trajectory following task are presented.

INTRODUCTION

Mathematical model of a system can be determined on the basis of physical laws by Lagrange, Hamilton and Newton-Euler formulations or by energy methods. However, it can be difficult to determine some parameters such as masses, inertias, dimensions, etc. without stopping and dismantling the system. An alternative approach is then to assume a simpler model in which parameters are determined by probing the system with a certain input command profile and relating the response and the command to obtain good fit between the input and output data. The electrohydraulic servo system have found a large field of application in industrial robotics because of distinct advantages like high power-to-weight ratio, high system stiffness and good repeatability. Exact differential equations of motion of robot systems are highly complicated. On the other hand modeling of hydraulic servo drive systems could be quite complex and difficult to simulate [1,7]. Exact differential equations of motion defining the manipulator and the control circuits have acceleration, velocity and position dependent terms, which can be assumed constant in all engineering purposes, and hence can be modeled by the difference equation identification technique. The aim in the gross motion control of a manipulator is to make the end effector follow a specified trajectory. A time series model in form of difference equations is convenient in applying estimation schemes such as the least squares algorithm and calculate the constant coefficients of the empirical model.

In this paper, model identification techniques are applied to a manipulator where each joint is driven by hydraulic actuators controlled by electrohydraulic servo valves, to show the applicability of the least square identification method to generate a model for it. Only 2 degrees of freedom, one revolute and one prismatic are considered which form a dyad working in the vertical plane, where effect of gravity is constantly present to produce steady state errors.

REPRESENTATION OF A DYNAMIC SYSTEM BY THE LINEAR DIFFERENCE EQUATION

Response $y(k)$ of a linear second order system commanded by a single input $u(k)$ is characterized by the general n 'th order difference equation as:

$$y(k) + a_1 y(k-1) + \dots + a_n y(k-n) = b_0 u(k) + b_1 u(k-1) + \dots + b_n u(k-n)$$

or

$$y(k) + \sum_{j=1}^n a_j y(k-j) = \sum_{j=0}^n b_j u(k-j) \quad (1)$$

where k is an integer index counting the discrete time steps and n is the order of the difference equation. k is the independent variable, and a_j and b_j are constant coefficients. Normally the order of the equation should be kept as high as possible to increase its sensitivity.

MODEL IDENTIFICATION BY LEAST SQUARES

A linear system can be modeled by difference equations, transfer functions and variable state equations which are useful in modern control [5,6,9]. The system can be described by an n 'th order difference equation of constant coefficients as in equation (1). Defining the input-output vector $x(k)$, having $2n+1$ elements as:

$$x(k) = [-y(k-1), \dots, -y(k-n), u(k), \dots, u(k-n)]^T \quad (2)$$

and the vector θ , containing the system parameters totaling to $2n+1$ elements as:

$$\theta = [a_1, a_2, \dots, a_n, b_0, b_1, \dots, b_n]^T \quad (3)$$

then the least square equation becomes:

$$y(k) = x^T(k)\theta + e(k) \quad (4)$$

where $e(k)$ is a vector of errors which is to be minimized. Normally, to find the elements of vector θ , $2n+1$ experimental readings of input and output are required. Numerical values obtained in this way may not provide a good correlation of input and output throughout the whole range of operation. N many measurements can be recorded where N is an integer much greater than $2n+1$, and obtain θ by the least squares estimation. Parameter θ then can be estimated as:

$$\theta_{\text{est}} = (xx^T)^{-1} x^T y \quad (5)$$

Application to a hydraulic servo system

Hydraulic servo systems have a large field of application in robotics as they provide large amounts of power with simplicity in control. Hydraulic phenomena is difficult to model and simulate. In most applications empirical equations are used instead of exact equations of flow [1]. Dynamics of the servo-valve itself is of 4th order or more [7]. On the other hand, Their repeatability is extremely good. Once a conforming mathematical model is set, it can be used to model the system effectively in a broad range of operating conditions. Although a realistic model of a hydraulic servo could be quite complicated, it will have mass and inertia dependent, velocity and displacement dependent components. Force components like that of viscous damping, the proportional and derivative components of the controlled actuation force are of this type. Higher order terms are generally negligible, hence assuming such a system to be of second order and linear has firm grounds of justification. With this assumption a hydraulic servo system can be effectively identified by the least square method.

Identification test on a single degree of freedom system

To show the applicability of the least square identification method to generate a model for a single degree of freedom hydraulic servo system, the input sequence $\{u(k)\}$ in form of a Pseudo-Random Binary Signal (PRBS) of amplitude 1 volt and discrete time interval arbitrarily $T = 0.45$ seconds is applied to the horizontally oriented prismatic axis of a hydraulic heavy duty robot, a picture of which is seen in Figure 1.

while the other degrees are constrained. 127 successive command steps of random polarity are given and position responses are recorded at the end of each time interval T .

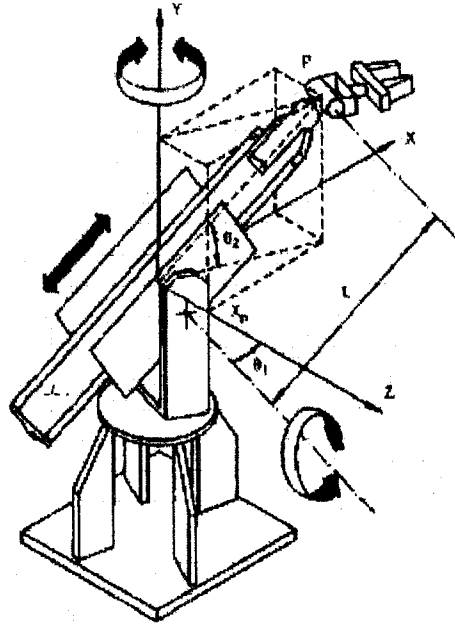


Fig.1 RRP Configuration hydraulic manipulator. This topology, due to its robustness, is widely used in the design of heavy duty manipulators.

At the end of identification, a second order model in the following form

$$y(k) = -a_1 y(k-1) - a_2 y(k-2) + b_0 u(k) + b_1 u(k-1) + b_2 u(k-2) \quad (6)$$

is sought for. To find the five unknown coefficients, a minimum of five equations are required which needs to be simulation easily solved. A greater number will enable a better fit with the least square method. T and total number of successive steps can be changed arbitrarily provided that no aliasing problems occur and the coefficients calculated will be theoretically be the same. In [3] a working program which digitally produces the PRBS excitation is given. The parameter set for the hydraulic system under consideration is estimated at the end of least squares fitting as:

$$L = [-0.7305, 0.0979, 0.0028, -0.8193, 0.4302]^T \quad (7)$$

and the corresponding difference equation model comes up as:

$$y(k) = 0.7305y(k-1) - 0.0979y(k-2) + 0.0028u(k) - 0.8193u(k-1) + 0.4302u(k-2) \quad (8)$$

The hydraulic servo system under consideration is actuated by a servo valve with proportional position control. Amplifier gain is arbitrarily set to a moderate value to provide a smooth operation. The recorded response of the servo to PRBS and the profile of equation (8) to the same signal are plotted together in Fig.2. The fit of the curves is satisfactory for all practical purposes, and hence it can be concluded that equation (8) can be used to model the response of the servo under consideration. To show the applicability of the model to a curve following problem, commands to follow a curve are given both to the hydraulic servo and the model of equation (8). The result shown in Fig. 2 also indicate that this method provides a good and consistent dynamic response model.

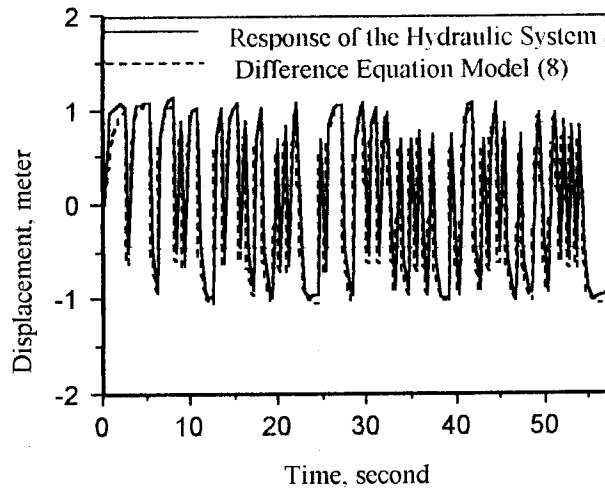


Fig. 2 Recorded response of the hydraulic servo system to a PRBS and that of the difference equation model defined by equation (8).

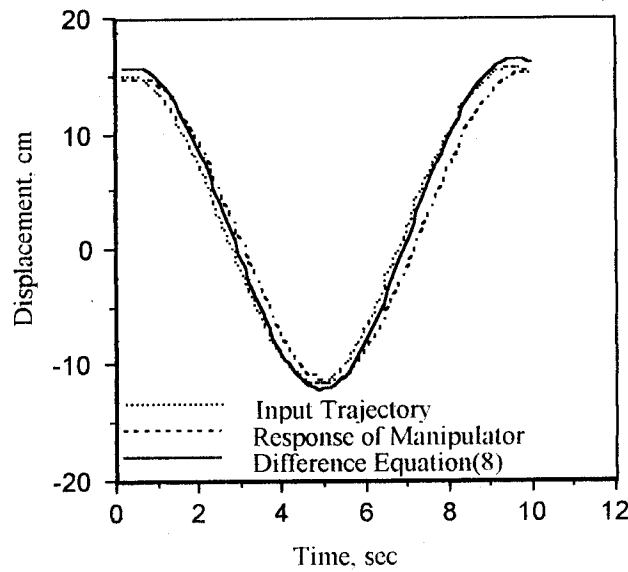


Fig. 3 System and model responses to a curve following task.

Identification test on a two degrees of freedom system

To generate the two joint model coefficients for the manipulator under consideration, with the assumption of independent joint dynamics, a Single-Input, Single-Output (SISO) model is used for each joint i , $i = 1, 2$. A linear difference time series model can be set as:

$$y_i(k) = a_{i1}y_i(k-1) + a_{i2}y_i(k-2) + b_{i0}u_i(k) + b_{i1}u_i(k-1) + b_{i2}u_i(k-2) \quad (9)$$

The input sequences $\{u_1(k), u_2(k)\}$ in the form of a PRBS [3] of amplitude ± 0.5 Volts and discrete time interval $T = 0.5$ second are applied to the revolute and prismatic degrees of freedom. Firstly, input sequence $u_1(k)$ is applied to the manipulator revolute joint servo, elevation angle denoted as θ_2 and the estimated parameter set is obtained as:

$$\theta_{2_est} = [-0.91861, 0.189189, 0.00856, 0.65686, -0.391934] \quad (10)$$

Secondly, the input sequence $u_2(k)$ is applied to the manipulator prismatic joint servo denoted as L , yielding the estimated parameter set as:

$$L_{est} = [-0.621336, 0.052292, 0.022577, 0.866682, -0.459428] \quad (11)$$

Corresponding difference equation models in terms of the joint variables come up as:

$$\begin{aligned} y_1(i) &= 0.91861y_1(i-1) - 0.189189y_1(i-2) \\ &\quad + 0.008561u_1(i) + 0.65686u_1(i-1) - 0.391934u_1(i-2) \\ y_2(i) &= 0.621336y_2(i-1) - 0.05229y_2(i-2) \\ &\quad + 0.02257u_2(i) + 0.86668u_2(i-1) - 0.459428u_2(i-2) \end{aligned} \quad (12)$$

To test the model, revolute and prismatic degrees of the manipulator are actuated to trace a circle of radius 50 cm, center at coordinates $X = 90$ cm, $Y = -10$ cm with respect to a right handed cartesian frame with Y axis vertically up and origin at the point of intersection of the revolute and prismatic axes. Similarly, same inputs to trace the circle is introduced to the model of equation (12) and response of the manipulator and the model equations are plotted in Fig.4 which shows a good fit.

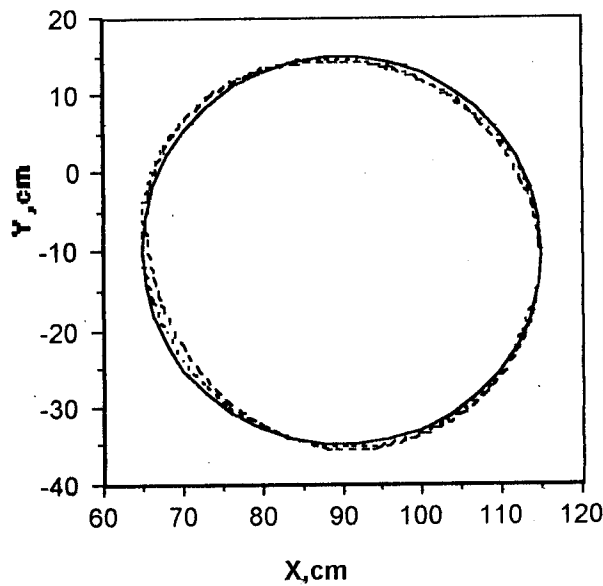


Fig.4 Recorded response of manipulator (-----) and response of difference equation (.....) to the input trajectory (-----). Responses of the manipulator and the model defined by equation 12 to trace a circular track. Degrees of freedom are assumed decoupled. As actuators are powerful and control system stiff, coupling effects are minimal.

CONCLUSIONS

The profile of motion in tracing the trajectories of Fig.3 and Fig.4 are quite slow, variation of command signals well beyond resonant frequencies, where the system is expected to behave well normally. At higher operation speeds, dynamic effects become more predominant and machine starts lagging the commands and distort the expected motion. To see how the models respond to faster motions, frequency response tests were carried out [4]. The models respond very well to changing frequencies, in accordance to the real system up to the first resonance point. For higher frequencies, discrete time interval becomes unable to provide a continuous profile and problems of aliasing emerge. As machines are required to operate with their DC bandwidths, the difference equation models can effectively describe a realistic response of the system they model within their DC bandwidth.

Least square system identification technique is simple, and computation time required is practically nil. In a general purpose control software, this method can effectively be used for system identification. The work presented in this paper is a part of a general purpose manipulator independent robot control software to identify the characteristics of any possible manipulator connected.

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