Trajectory Tracking Control for a 7-Arms Robot Manipulator

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Abstract

This paper proposes a trajectory tracking control method based SPO (sliding perturbation observer) for a 7-arms robot manipulator. The 7-arms robot manipulator is designed to assemble small parts or packaging in industrial manufacturing. System dynamics modeling is introduced at first. The dynamics of this 7-arms robot is difficult to determine precisely caused by its uncertainties and many nonlinear terms through mathematical analysis. An experimental identification process using signal compression method is applied to divide the linear term from integrated dynamics with non-linear terms and uncertainties. Estimation of the non-linear terms and uncertainties for compensating the real dynamics is obtained by SPO. Controller sliding mode control is designed based on estimation perturbation.

Keywords: manipulator, robust controller, sliding mode control, perturbation observer.

1. Introduction

Multi-axis robot arm are wildly used for industrial area, such as parts assembly, automatic welding in vehicle manufacturing, pre-arrangement etc. Usually, those kinds of robots are requested for an accurate trajectory tracking. However, caused by those multi-axis arms the traditional controller without consideration of dynamics such as PID is not proper. Many robust controllers based on system dynamics model are designed with robust performance. In [1], a linear control logic LQR is combined with PID to control a flexible manipulator. Sliding mode control (SMC) is the most used one. The designed nonlinear control input which restrains the error states within sliding surface that ensures an outstanding performance for a nonlinear system. In [2], a robust controller SMC based SMCSPO is designed to control a hydraulic manipulator with showing an excellent performance in tracking. Before designing and applying the above mentioned controllers, system dynamics is necessary modeled at first. In this research, a 7 arms manipulator is designed to simulate the assembling work which mainly focus on trajectory tracking. The dynamics of this manipulator is modeled using signal compression method [3]. Signal compression method uses an equivalent impulse signal which is obtained from an similar impulse signal filtering by a time delay filter, then given as a tracking reference to the object system. This identification process is introduced at first in this paper. However, as same as mostly used identification method, signal compression method only estimates the divided linear terms without any reflection from nonlinear terms in original system dynamics. Therefore, compensation for the nonlinear terms and uncertainties which are not identified is necessary. Kalman fiter can estimate uncertainties which is well known caused by its high accuracy in low frequency area [4]. SPO has the similar algorithm with kalman fiter, but derived from state space, which also has outstanding estimation performance in low frequency area [5]. In this paper, we use the SPO to observe the perturbation which contains the nonlinear terms in dynamics, identification errors, uncertainties and disturbance. The estimated perturbation is used for designing a robust controller such as sliding mode control. This paper is organized as following: signal compression method for system modeling is introduced in section 2, the perturbation design is shown in section 3, we conclude this work in section 4.

2. Dynamics Modeling

Signal compression method is used for dynamics identification. In this method, an equivalent impulse signal is generated to implement on an objective system as the desired trajectory. The equivalent impulse signal is obtained by passing a time delay filter from a designed impulse signal. The expanded impulse signal is available to apply on the real system. Then, the response output is filtered by the inverse of the time delay filter. The result after the inverse time delay filter is supposed as the real response which is from the origin impulse signal to the linear system. The system can be modeled when we change the model dynamics to match the correlation with the output signal from real experiment. This logic is shown in figure. 1.

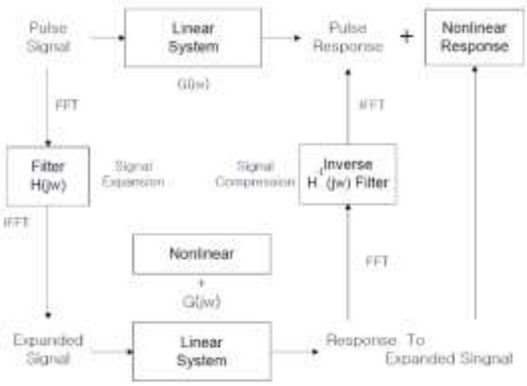

Fig. 1. Signal Compression Method Logic.

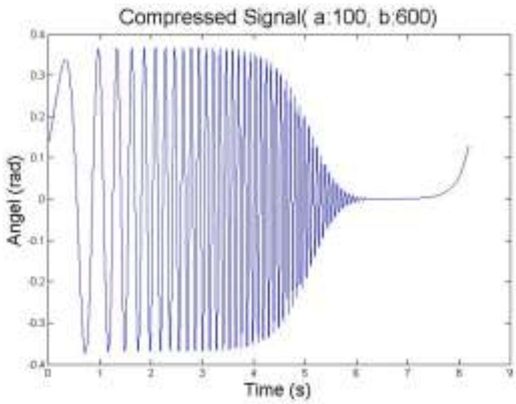

Fig. 2. Expanded Impulse Signal.

The expanded signal is shown in figure.2. It obtained from the designed impulse signal in Eq.(1) passed by an time delay filter with following function in Eq.(2):

$$
\begin{aligned}
&P(n) = 60\exp[-(\frac{n}{a})^{12}],\ 0 \le n \le N/2-1 \\
&P(n) = 0,\ n = N/2 \qquad (1) \\
&P(n) = P(N-n),\ N/2+1 \le n \le N-1
\end{aligned}
$$

$$
\begin{aligned}
&H(n) = \exp[-\frac{12n^2}{b}\,j],\ 0 \le n \le N/2-1 \\
&H(n) = 0,\ n = N/2 \qquad (2) \\
&H(n) = H(N-n),\ N/2+1 \le n \le N-1
\end{aligned}
$$

The robot manipulator are shown in figure.3. The experiment of signal compression method is accomplished with an simple P controller (Kp=10) which logic is shown in figure(4).

Fig. 3. Real System .

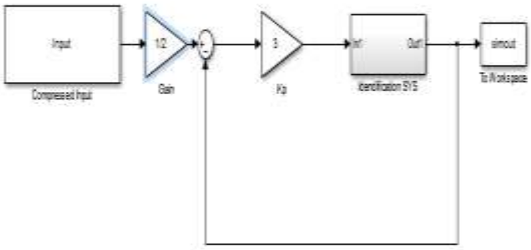

Fig. 4. Expanded Impulse Signals.

The output from compression signal of link7 is shown in Fig .5. In Fig . 6, the result of real system output passed by the invers filter of Eq. (2) and model result with same process are shown. All links modeling result are shown in Table.1 with the assumption of their dynamics are a simple 2 order linear system.

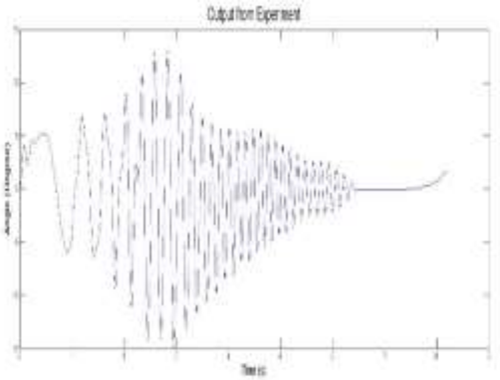

Fig. 5. Real System Response(link7).

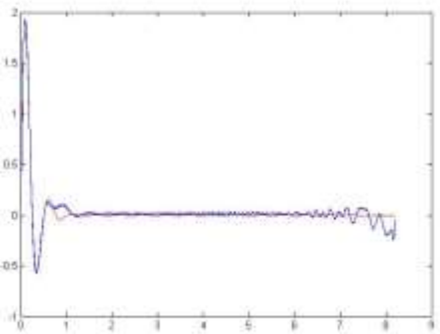

Fig. 6. Correlation of Real System Response with Modeled System Response Result(link 7).

Table 1. Result of Medeling

	ζ	ω_n	2nd order.Model
1	0.642	6.864	$\frac{4.711}{s^2+8.813s}$
2	1.521	2.937	$\frac{0.8626}{s^2+8.934s}$
3	0.324	7.628	$\frac{5.819}{s^2+4.943s}$
4	0.61	5.521	$\frac{3.048}{s^2+6.736s}$
5	0.346	12.469	$\frac{15.55}{s^2+8.629s}$
6	0.37	13.21	$\frac{17.45}{s^2+9.775s}$
7	0.35	12.502	$\frac{15.63}{s^2+8.751s}$

3. Controller

In this section, we define the perturbation in a mathematic equation. Before defining perturbation, the dynamics of a general robot system is normally defined as

$$\ddot{x}_j = f_j(\mathbf{x}) + \Delta f_j(\mathbf{x}) + \sum_{i=1}^{n}[(b_{ji}(\mathbf{x}) + \Delta b_{ji}(\mathbf{x}))u_i] + d_j(t)$$
$$j = 1,\dots,n. \qquad (3)$$

where $\mathbf{x} \overset{\Delta}{=} [\mathbf{X_1 ... X_n}]^{\mathrm{T}}$ is the state vector and $\mathbf{X_j} \overset{\Delta}{=} [x_j, \dot{x}_j]^{\mathrm{T}}$. The terms $f_j(\mathbf{x})$ correspond to linear driving terms while $\Delta f_j(\mathbf{x})$ corresponds to the nonlinear driving terms, their parameters, dynamic modeling, and dynamic uncertainties. The components b_{ji} and Δb_{ji} represent the elements of the control gain matrix and their uncertainties, while d_j is the external disturbance and u_j is the control input. It is assumed that the terms f_j and b_{ji} can be obtained after system identification. Perturbation is introduced simply in the introduction that contain the nonlinear terms in dynamics, identification errors, uncertainties and disturbance as shown in Eq. (4).

$$\Psi_j(\mathbf{x}, t) = \Delta f_j(\mathbf{x}) + \sum_{i=1}^{n}[\Delta b_{ji}(\mathbf{x})u_i] + d_j(t). \qquad (4)$$

The observer contains states are shown in Eq. (5).

$$\dot{\hat{x}}_{1j} = \hat{x}_{2j} - k_{1j}\,\mathrm{sat}(\tilde{x}_{1j}),$$
$$\dot{\hat{x}}_{2j} = \alpha_3 \bar{u}_j - k_{2j}\,\mathrm{sat}(\tilde{x}_{1j}) + \hat{\Psi}_j,$$
$$\dot{\hat{x}}_{3j} = \alpha_{3j}^2(\bar{u}_j + \alpha_{3j}\hat{x}_{2j} - \hat{x}_{3j}),$$
$$\hat{\psi}_j = \alpha_{3j}(\alpha_3\hat{x}_{2j} - \hat{x}_{3j}). \quad (5)$$

The stability of SPO is proved in [6]. The perturbation estimation is used to design a robust controller. In here, we use sliding mode control with its combination of SPO.

4. Experiment and Conclusion

The experiment is designed for trajectory tracking on the Windows based RTX software (real time operating system). The application interface is made from MFC API and shown in Fig. 7. It also can plot the movement of link 7.

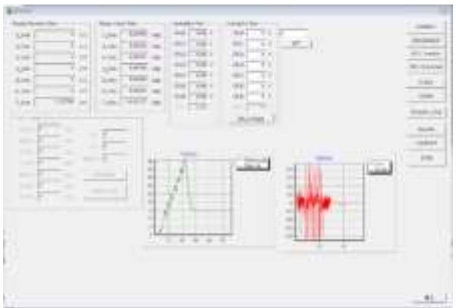

Fig. 7. Real Time Tracking Result Using SMCSPO for link 7.

In Fig. 8, the reference trajectory of link 2 with blue line and real trajectory with red line are presented. The error between them is shown in Fig. 9.

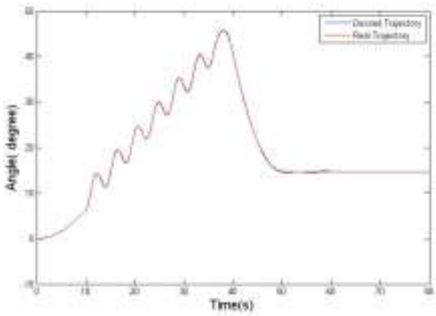

Fig. 8. Tracking Result Using SMCSPO of link 2.

The tracking error shows within the limit about 0.3 degree. It verifies the sliding mode control with proposed perturbation estimation has outstanding performance fora multi-arm robot which dynamics is obtained by signal compression method approximately.

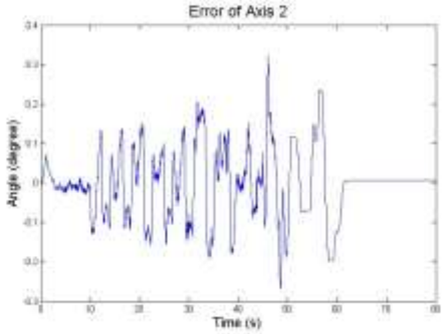

Fig. 9. Error in Tracking Result of link 2.

Acknowledgments

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