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Variable Structure Control in Excavator Robot

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Abstract

This work evaluates the use of Variable Structure Control or Sliding Mode techniques to control excavator robot. The VSC techniques have been studied with success to control robots, this depends on characteristics of stability and robustness of VS controller also for non linear, discontinuous and non well modeled systems. A centralized controller has usually a large cost and consuming time for calculus, while a decentralized control of every joint is more flexible, less expensive and allows a more stable control of actuators.

We consider a decentralized variable structure control of joints, including the actuator dynamics, and we consider also the possibility to adapt the control dynamics on the system disturbs.

1. INTRODUCTION

The excavator is a very complex machine, hard to model completely as its operating environment, an excavator robot needs so an adaptive, robust and intelligent controller to work as well.

For this purpose we evaluate the Variable Structure Control (VSC), because this technique is robust and suitable for non well modeled, non linear and discontinuous systems, besides, it is used for both centralized and decentralized control.

The centralized controller needs long time of calculus and expensive hardware, the decentralized controller can divide calculus for every subcontroller, it is more flexible, and in same time it has a stable control of joint actuator.

In industrial robotics the decentralized control is used widely, but PD controller isn't stable for large variations of inertia and load, and its needs accurate modelling of the system. The earthmoving machines have large variations of inertia and load, many difficulties to be modeled exactly, moreover, the actuator system is formed by asymmetrical hydraulic cylinders and valves with many non linearitys, different gain for both push directions, and problems for speed near to zero when they are controlled by symmetrical hydraulic valves.

The future design of construction machines seems to predict the distributed control system, hydraulic power included, using serial data bus, where every joint is a node of this network, provided with a controller for the actuator and its valve control. (Fig.1)

For this reason and other again, we evaluate the use of Distributed Variable Structure Control, including actuator dynamics.

2. MODELLING

The manipulator dynamics with n joints is described by a system of differential equations of second order, where $M(\theta)$ is the $n x n$ inertia matrix, $N(\theta)$ is the

$$\boldsymbol{M}(\theta)\ddot{\theta}+\boldsymbol{N}(\theta,\dot{\theta})+\boldsymbol{G}(\theta)+\boldsymbol{H}(\dot{\theta})=\boldsymbol{T}$$

vector of centrifugal and Coriolis torques, $G(\theta)$ is the vector gravity torques, $H(\theta)$ is the vector of friction torques.

In the decentralized control every joint is considered as subsystem of manipulator, coupled to other subsystem by coupling torques, this one allows to rewrite the previous equation in the following form, pointing out by D_i the disturbs.

$$M_{ii}(\theta)\ddot{\theta}_i(t)+D_i(\theta,\dot{\theta},\ddot{\theta})=T_i(t) \rightarrow D_i(\theta,\dot{\theta},\ddot{\theta})=\left|\sum_{j=1}^{n} m_{ij}(\theta)\ddot{\theta}_{ij}(t)\right| n_i(\theta,\dot{\theta})+g_i(\theta)+h_i(\dot{\theta})$$

We refer to the mechanism with slider and the asymmetrical hydraulic cylinder in fig. 2, given the function $g(\theta)$ of dependence of piston speed on angular speed of respective link, we have the following relatioships.

$$\dot{x}=\dot{\theta}g(\theta) \qquad T=Fag(\theta)=(A_1p_1-A_2p_2)ag(\theta) \qquad E=V_0/\beta \qquad m=A_2/A_1$$

$$\theta(s)=\frac{\dfrac{k_v}{A}i(s)-\dfrac{k_c}{A}\left(\dfrac{E}{k_c}+1\right)D}{s\left(\dfrac{s^2}{\omega_n^2}+2\dfrac{\zeta}{\omega_n}s+1\right)}$$

$$A'=\begin{cases} A_1g(\theta)(1+m^2) & i>0 \\ A_2g(\theta)[m^2/(1+m^2)] & i<0 \end{cases} \qquad A''=\begin{cases} A_1(1+m^2)ag^2(\theta) & i>0 \\ A_2[m^2/(1+m^2)]ag^2(\theta) & i<0 \end{cases}$$

These relationships, where the angular displacement of link depends on the i control current of servovalve, include the dynamic equation of joint plus the the dynamic equation of actuator, controlled by symmetrical valve. The k_v flow-current and k_c flow-pressure coefficients of servovalve linear model have been carried out from its commercial rating, while the valve dynamics is given as a first order transfer function.

3. THE VS CONTROLLER

In the decentralized control, every subsystem can be controlled as an indipendent system, therefore, every joint can be controlled by a VSC.

We consider a dynamic system in the following form, where $u(t)$ is the control imput, $X(t)$ is the state, $b(X,t)$ is control gain, $d(t)$ is the disturbance.

$$x^{(n)}=f(X,t)+b(X,t)u(t)+d(t)$$

Slotine [3] puts the switching function $s(X)$ in the form, where $X\text{-}X_d$ is the error. $S(t)=s(X,t)=0$ is the time-varying sliding surface.

$$s(X,t)=\left(\frac{d}{dt}+\lambda\right)^{(n-1)}\tilde{x} \qquad \lambda>0 \qquad \tilde{X}=X-X_d=[\tilde{x},\cdots,\tilde{x}^{(n-1)}]^T$$

Defined ε as the maximum possible X deviation from the surface or boundary layers, we have the boundary layer "thickness" as $\varphi=\lambda^{p-1}\varepsilon$.

A sufficient condition to drive the system on the sliding surface, or positive invariance of $S(t)$, is to choose the control low u such that, i.e. s^2 is a Lyapunov function.

$$\frac{1}{2}\frac{d}{dt}s^2(X,t)\leq-\eta\,|s| \qquad \eta>0 \qquad \Rightarrow \qquad \dot{S}\,sgn(s)\leq-\eta$$

Given the system $X^{(n)}=f(X,t)+Bu+d(t)$, and letting $k(X,t)=F(X,t)+D(X,t+v(t)+\eta\geq\eta>0$ where $F(X,t)\geq|\Delta f(X,t)|$, $|d(t)|\leq D(X,t)$, $|x_d^{(n)}(t)|\leq v(t)$, and replacing $sgn(s)$ with $sat(s/\psi)$, we can obtain the following form of control low.

$$u=-\hat{f}(X,t)-\sum_{p=1}^{n-1}\binom{n-1}{p}\lambda^p\tilde{x}^{(n-p)}-k(X,t)\mathrm{sat}(s/\varphi)$$

The function $k(X,t)$ and sat help to reduce the chattering problems of VSC.

4. CONTROLLER DESIGN

From the dynamic relationship of arm-actuator system we note two terms, the first one shows the transfer function $\theta(s)/i(s)$, while the second one represents the disturbance. The two "structural" poles of the arm-actuator system have a frequency very highest of the cut servovalve frequency, therefore we have modelled the arm-actuator-servovalve system as second order system, where the τ cut frequency is the same frequency of servovalve.

$$\omega_n=\sqrt{\frac{(A_1+A_2)^2ag^2(\theta)}{JE}} \qquad \zeta=\frac{k_c}{2E\omega_n}$$

$$\theta(s)=\frac{Ki(s)}{s(1+\tau s)}$$

For a position controller the sliding function becames

$$S(\Theta,t)=\lambda\tilde{\theta}+\tilde{\theta}^{(2)}$$

and we obtain the following control low, where $U{=}Ki$ and $\alpha\equiv K(X,t)$.

$$U=\theta_d^{(2)}-\lambda\tilde{\theta}^{(1)}-\tau\theta^{(1)}-\alpha sat(\frac{S}{\varphi}) \quad \text{with } S(x,t)=0 \quad \rightarrow \quad \tilde{\theta}^{(1)}=-\lambda\tilde{\theta}_1$$

If λ_{max} is the larghest possible value of λ, we must have $k_{max}/\varphi\leq\lambda$, which fixes the best attainable traking precision ε by the *balance condition.*

$$\lambda\varphi=k_{max} \qquad \Rightarrow \qquad \lambda^{n}\epsilon=k_{max}$$

The disturbances can be carried out by

$$d(\theta,t)=T-T_d=[A_1p_1-A_2p_2]ag(\theta)-J\ddot{\theta}$$

where p_1,p_2,θ and its derivatives are measurable or obtained by it.

As $d(\theta,t)$ is included in $k(X,t)$, varying $k(X,t)$ we can vary λ in accordance with the balance condition. In this way it is possible to adapt the control low.

5. RESULTS

The DVSC tecnique has been applied to join control of the excavator boom. We have chosen to test only the angular position control of this joint, because the used servovalves are slow, but the VSC counterbalances also the gravity force which is included in disturb term.

The system response depends widely on the dynamics of the switching function, having λ cut frequency, the best results have been obtained for cut frequency of switching function near the dynamics of the servovalves. A more high λ cut frequency could be near the sampling frequency of a possible digital control, that we can think as unmodelled part of the system. These results are shown in fig. 3, note the symmetrical shape of the control action.

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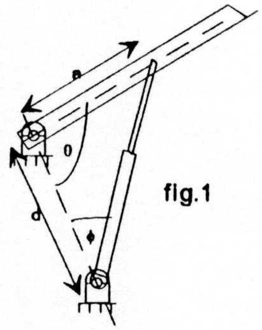

fig.1

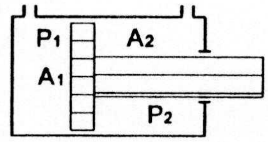

fig.2

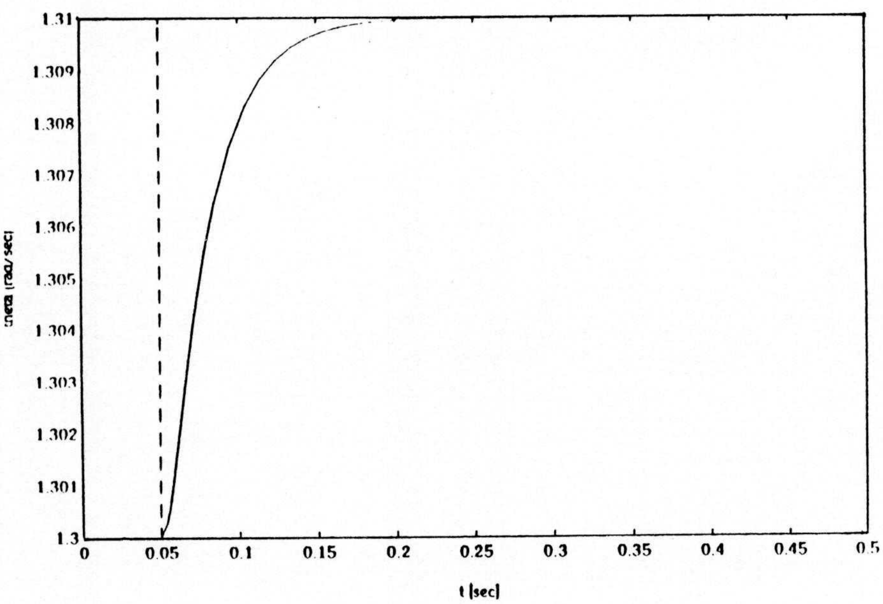

fig.3a

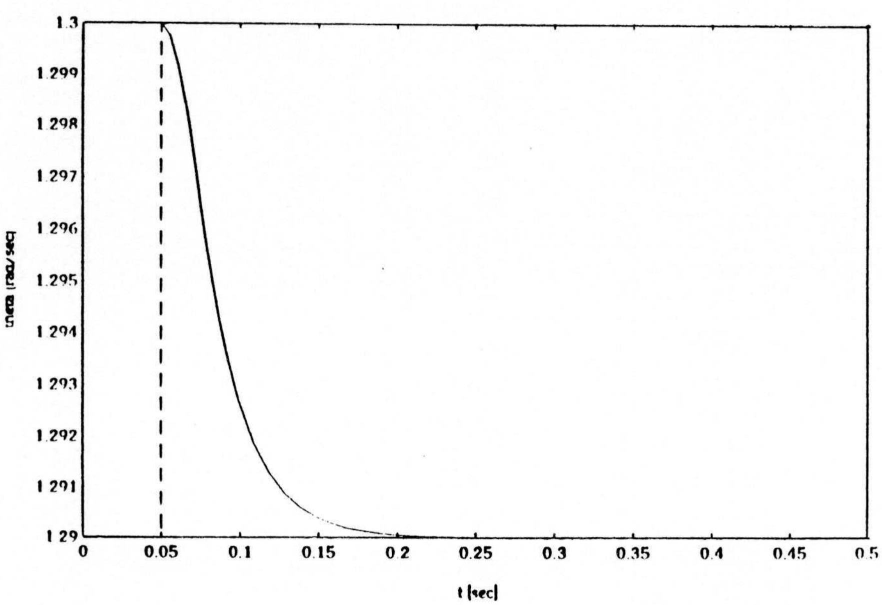

fig.3b