Velocity Control of an Electro Hydraulic Servosystem by Sliding Mamdani

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Abstract: This paper addresses new hybrid approaches for velocity control of an electro hydraulic servosystem (EHSS) in presence of flow nonlinearities and internal friction. In our new approaches, we combined classical method based-on sliding mode control and Mamdani networks. The control by using adaptive networks need plant’s Jacobean, but here this problem solved by sliding surface. It is demonstrated that this new technique have good ability control performance. It is shown that this technique can be successfully used to stabilize any chosen operating point of the system. All derived results are validated by computer simulation of a nonlinear mathematical model of the system. The controllers which introduced have big range for control the system.

Keywords: Electro Hydraulic, Mamdani networks, Strict Feedback, Sliding mode, Sliding Surface.

1 Introduction
The EHSS is used in many industrial applications, because of its ability to handle large inertia and torque loads and, at the same time, achieve fast responses and a high degree of both accuracy and performance [1, 2].

Depending on the desired control objective, an EHSS can be classified as either a position, velocity or force/torque EHSS. Therefore, control techniques for electro-hydraulic servo system have been widely studied over the past decade; the details of these systems are given in the reference [3]. In [8] an intelligent CMAC neural network controller using feedback error learning approach introduced which is very complex, and [3] presents methods based on feedback linearization and backstepping approaches, that have good performances but the controller designing is not very simple procedure, in [9] authors proposed a simpler method than other methods based on Lyapunov stability approach but the results in this new hybrid approaches are very better and faster than other mentioned methods.

The paper is organized like this: In section 2, the EHSS and its nonlinear mathematical model are described. In section 3, issues related to the sliding mode design and Mamdani network are discussed in some detail. In section 4, system properties and the relation of new method and simulation results describe and section 5 is the conclusion part.

2 System Description

A scheme of an electrohydraulic velocity servosystem is shown in Figure 1. The basic parts of this system are: 1. hydraulic power supply, 2. accumulator, 3. charge valve, 4. pressure gauge device, 5. filter, 6. two-stage electrohydraulic servovalve, 7. hydraulic motor, 8. measurement device, 9. personal computer, and 10. Voltage- to- current converter.

Figure 1: Electrohydraulic velocity servosystem.
rotational motion of the motor shaft. It is assumed that the motor shaft does not change its direction of rotation, $x_3 > 0$. This is a practical assumption and in order to be satisfied, the servo valve displacement $x_3$ does not have to move in both directions. This assumption restricts the entire problem to the region where $x_3 > 0$.

If the state variables are denoted by:
- $x_1$: hydro motor angular velocity
- $x_2$: load pressure differential
- $x_3$: valve displacement

Then the model of the EHSS is given by:

$$
\begin{align*}
\dot{x}_1 &= \frac{1}{J} \{- B_n x_1 + q_n x_2 - q_n C_f P_s \} \\
\dot{x}_2 &= \frac{2 \beta_s}{T_o} \{- q_n x_1 - C_m x_2 - C_j W x_3 \sqrt{\frac{1}{\rho} (P_s - x_2)} \} \\
\dot{x}_3 &= \frac{1}{T_e} \{- x_3 - K_s u \} \\
y &= x_1
\end{align*}
$$

(1)

where the nominal values of parameters are:
- $J = 0.03 \text{kgm}^2$: total inertia of the motor and load referred to the motor shaft,
- $q_n = 7.96 \times 10^{-7} \text{m}^3/\text{rad}$: volumetric displacement of the motor,
- $B_n = 1.1 \times 10^{-3} \text{Nms}$: viscous damping coefficient,
- $C_f = 0.104$: dimensionless internal friction coefficient,
- $V_c = 1.2 \times 10^{-4} \text{m}^3$: average contained volume of each motor chamber,
- $\beta_s = 1.391 \times 10^9 \text{Pa}$: effective bulk modulus,
- $C_j = 0.61$: discharge coefficient,
- $C_m = 1.69 \times 10^{-11} \text{m}^3/\text{Pa.s}$: internal or cross-port leakage coefficient of the motor,
- $P_s = 107 \text{Pa}$: supply pressure,
- $\rho = 850 \text{Kg/m}^3$: oil density,
- $T_o = 0.01 \text{s}$: valve time constant,
- $K_s = 1.4 \times 10^{-4} \text{m}^3/\text{s}$: valve gain,
- $K_x = 1.69 \times 10^{-3} \text{m}^2$ for valve flow gain,
- $W = 8.9 \times 10^{-5} \text{m}$: surface gradient.

The control objective is stabilization of any chosen operating point of the system. It is readily shown that equilibrium points of system are given by:

$$
\begin{align*}
x_{1N} &= \text{Arbitrary constant value of our choice.} \\
x_{2N} &= \frac{1}{q_n} \{ B_n x_{1N} + q_n P_s C_f \}
\end{align*}
$$

(2)

With very simple linearization we can find out that the system is minimum phase which allows application of many different design tools. In [4], Alleyne and Liu developed a control strategy that guarantees global stability of nonlinear, minimum phase single-input single-output (SISO) systems in the strict feedback form by using a passivity approach and they later used this strategy to control the pressure of an EHSS.

3 Mamdani Sliding Mode Controller

3.1 Mamdani Networks

The field of fuzzy sets and logic was first introduced by Lotfi Zadeh [10, 11], and fuzzy control was first introduced by E. Mamdani [12, 13]. Mamdani’s networks are embedded in a two parts, premise and consequent. The output units implemented a weighted sum of hidden unit outputs. The input into an Mamdani network is nonlinear while the output is linear. The output of the Mamdani network with product inference engine and singleton defuzzifier for single output is:

$$
\phi_i(x) = \prod_{i=1}^{n} \exp \left( \frac{-\|x - \vec{c}_i\|^2}{2\sigma_{\alpha}^2} \right), \quad i = 1, 2, \ldots, l .
$$

(3)

The output of the network is:

$$
y = \sum_{i=1}^{m} m_i \left( \frac{\phi_i(x)}{\sum_{i=1}^{l} \phi_i(x)} \right) = M^T \Phi, \quad j = 1, 2, \ldots, m .
$$

(4)

Where $x \in \mathbb{R}^n$ and $y \in \mathbb{R}^m$ are input vector and output vector of the Mamdani network, respectively, and $\Phi = [\phi_1, \phi_2, \ldots, \phi_l]^T$ is the rule firing vector. $n$ is the number of membership function for each input and $l$ is number of rules, $M = [m_1, m_2, \ldots, m_l]$ is the center vector of the consequent part, $\vec{c}_\alpha$ and $\sigma_{\alpha}$ are centers and variance of the premise parameters, respectively. The adjustable parameters of Mamdani networks are $M$, $\vec{c}_\alpha$, and $\sigma_{\alpha}$. The symbol of adjustable parameters of Mamdani networks introduced as $W$.

3.2 Mamdani Network Sliding Mode Controller

Sliding mode control (SMC) is a variable structure control utilizing a high-speed switching control law to drive a system state trajectory onto a specified and user chosen surface, so called sliding surface,
and to maintain the system state trajectory on the sliding surface at subsequent times [14]. In this paper, the sliding surface on the phase plane can be defined as:

\[ e_i = x_i - x_{i1} \]
\[ S = \left( \frac{d}{dt} + \lambda \right)^2 e_i = \ddot{e}_i + 2\dot{e}_i + \lambda^2 e_i \quad (5) \]

The sliding variable, \( S \), will be used as the single input signal for establishing a Mamdani network model to calculate the control law, \( u \). Then for the single-input and single-output case in this paper, the output of the controller based on Mamdani networks is:

\[ u = \sum_{i=1}^{l} \eta_i \phi(S) = M^{*} \Phi \quad (6) \]

Where \( l \) is the number of rules and the \( u \) is the final close-loop control input. In order to combine the advantages of sliding mode and adaptive control schemes into the Mamdani Networks, an adaptive rule is introduced to adjust the weightings between hidden and output layers networks.

Based on the Lyapunov theorem, the sliding surface reaching condition is:

\[ V = \frac{1}{2} S^2 \Rightarrow \dot{V} = SS < 0 \quad (7) \]

If a control input \( u \) can be chosen to satisfy this reaching condition, the control system will converge to the origin of the phase plane. Adaptive law is used to adjust the weightings for searching the optimal weighting values and obtaining the stable convergence property. The adaptive law is derived from the steep descent rule to minimize the value of \( SS < 0 \) with respect to \( W \). Then the updated equation of the weighting parameters is:

\[ W_{n+1} = W_{n} - \eta \frac{\partial S}{\partial W} W_{n} W_{n} \quad (8) \]

\[ W_{n+1} = W_{n} - \eta S \frac{\partial S}{\partial W} W_{n} W_{n} \quad (9) \]

\[ \frac{\partial S}{\partial W} = \frac{\partial S}{\partial u} \frac{\partial u}{\partial W} \quad (10) \]

and from equation (5) we have

\[ \dot{S} = \ddot{e}_i + 2\dot{e}_i + \lambda^2 e_i \Rightarrow \dot{S} = \ddot{x}_i + 2\dot{x}_i + \lambda^2 x_i \quad (11) \]

form equations (1) we can find that:

\[ \frac{\partial \ddot{x}_i}{\partial u} = 0 \quad \frac{\partial \dot{x}_i}{\partial u} = 0 \quad \frac{\partial x_i}{\partial u} \neq 0 \quad (12) \]

so

\[ \frac{\partial S}{\partial u} = \frac{\partial \dot{x}_i}{\partial u} \quad (13) \]

finally we can find updating rule as follow:

\[ W_{n+1} = W_{n} \frac{\partial S}{\partial W} W_{n} W_{n} \quad (14) \]

It is clear that we do not need any identifier for EHSS.

4 Simulation Results

In this section, simulation results are presented. Figure (1) illustrated the state response when the controller used.

Figure (2) is shows the change of sliding surface we can see that this surface very fast equal to zeros. These results in compare with [3, 8 and 9] are very fast and so simpler in design. Our controller is adaptive and its structure is simple too. The fastest result in [1, 2, and 3] is 3 sec but here we track desired in less than 2.5 sec.

Figure 1: Simulation results of system, obtained using sliding RBF controller.

Figure 2: Sliding surface variation during control process.

5 Conclusion

This paper introduced Mamdani sliding mode method for control the EHSS system which is one of the very useful systems in industrial applications.
In this paper, a new Mamdani sliding mode control method for EHSS is proposed, which combines the merits of adaptive, fuzzy, and sliding mode control. Based on the Lyapunov stability theory, a sliding mode controller based on the Mamdani network is designed for stabilization of EHSS system to the desired point in the state space. Simulation results show that the proposed controller is able to control EHSS very better than other methods. The chattering phenomenon of conventional switching type sliding control does not occur in this study.

References