ADAPTIVE MULTI-AGENT CONTROL OF LEATHER MANUFACTURING PROCESSES BY USING SMITH PREDICTOR

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The conventional control systems used in leather manufacturing proven their inefficiency due to their centralized architecture, being a critical point of failure that impose operational bottleneck. Multi-agent systems (MAS) represent a viable alternative for making a system agile, providing flexibility and modular development of the control system. A MAS represents a more natural way in dealing with complex distributed problems due to their characteristics autonomy, social ability, mobility, modular development. Agents part of the MAS are distributed geographically and communicate one with another via a network. Each node of the network is represented by an agent that represents a manufacturing resource. Communication between agents generates delays that can affect functionality of the system. This paper presents an adaptive multi-agent control system used on leather manufacturing processes which is based on Smith predictor. The proposed adaptive control strategy based on Smith predictor aims to eliminate the negative effects generated by communication delays between agents on production system performance. Communication delays are modeled as pure delay elements. The proposed control strategy has an estimator for the communication delays and these estimates are used to adjust the controller, specifically to adapt its parameters to the new values of communication delays. Simulation results are presented and they demonstrate the performance improvement when the proposed control strategy is used.

Keywords: leather industry, agent architecture, smith predictor, multi-agent systems, leather manufacturing.

INTRODUCTION

Conventional automation systems based on staled centralized control model proven to be an inefficient solution for dealing with the complexity and the diversity of the leather manufacturing operations (Guta and Dumitrache; Guta *et al.*, 2013; Hanchevici and Guta, 2012). These concentrate all control functions within a single central controller that is rigid, not provide agility, flexibility, being a critical point of failure that impose operational bottleneck.

The problem of effective tannery automation has numerous variable such as raw material diversity, discontinuity of the technological process, time-variance and non-linear behavior of the manufacturing operations, lack of mathematical models that accurately express the reality. The traditional solutions did not offer expected results to the above mentioned problem. In this situation adoption of multi-agent system (MAS) solution that extends the functionality of an existing automation system represents a viable solution (Guta and Dumitrache).

Guta *et al.* (2013) emphasize the superiority of the MAS technology for leather industry in comparison with conventional solution. Its superiority is mainly in terms of agility, flexibility, modular development, fault tolerance, robustness.

MAS technology is used for solving complex problems that are difficult or even impossible to solve by a centralized system (Wooldridge, 2009; Paolucci and Sacile, 2004). A MAS is composed of a society of autonomous entities (software agents) distributed geographically that represents the manufacturing entities (mainly resources). These agents are sociable, have a partial knowledge or view of the manufacturing system, interact one with another sharing knowledge and delegating task. Thus the result of agent interaction is an emergent behavior that is similar to that of humans, proper for solving complex problem (Guta, 2014; Monostori *et al.*, 2006). The agents part of a MAS are distributed across the whole tannery and communicate one with another via an industrial network or even wireless. During their communication acts through message exchange, communication delays can occur.

The paper addresses the issues generated by the variant communication delays which can occur in MAS used for the control of the leather manufacturing processes.

PROPOSED CONTROL STRATEGY

In this paper is proposed a multi-agent control strategy for linear SISO (single input – single output) systems which have variant communication delays. This control strategy is based on Smith predictor. The communication delays between the agents are modeled as pure delay elements. The control strategy used for fixed communication delays is presented in Figure 1.

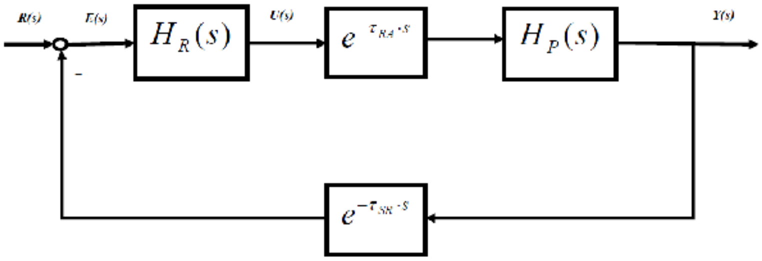

Figure 1. The control strategy used for fixed communication delays (Hanchevici, 2013)

where:

- R(s) represents the set-point for the closed loop system;
- E(s) is the error of the closed loop system;
- U(s) represents the control computed by the control agent;
- Y(s) denotes the controlled parameter;
- $H_R(s)$ is the mathematical model of the control agent;
- $H_P(s)$ represents the mathematical model of the plant;
- $e^{-\tau \cdot s}$ represents the mathematical model of the communication delays. $e^{-\tau_{RA} \cdot s}$ is the mathematical model of the communication delay between the control and actuation agents, and $e^{-\tau_{SR} \cdot s}$ is the mathematical model of the communication delay between the sensing and control agents.

The control strategy presented in Figure 1 is used for the case when the communication delays between agents are fixed. If the communication delays are variant, then is used the proposed control strategy presented in Figure 3.

In Figure 2 is described how it is used the Smith predictor. The controller H_R* is designed for the case when the communication delays are placed outside the control loop.

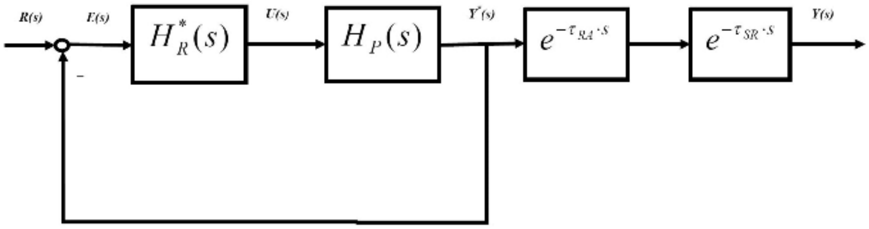

Figure 2. The control strategy which has the fixed communication delays placed outside the loop (Hanchevici, 2013)

The dependency between them is expressed by (1):

$$H_R(s)=\frac{H_R^*(s)\cdot e^{-\tau_{SR}\cdot s}}{1+H_R^*(s)\cdot H_P(s)\cdot\left(1-e^{-\tau_{RA}\cdot s}\cdot e^{-2\cdot\tau_{SR}\cdot s}\right)} \tag{1}$$

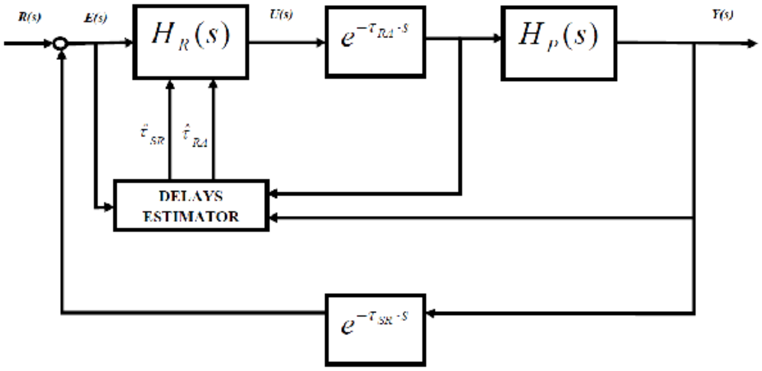

Figure 3. The control strategy proposed for variant communication delays

In the proposed control strategy is used an estimator for the communication delays. During every sampling time, the DELAYS ESTIMATOR is used to estimate the current values for the communication delays and these values are used to tune the control agent. The tuning represents changing the values of the controller's parameters according to the current values of the communication delays.

CASE STUDY

For this study the control of one parameter was considered, namely the pH value. This SISO (Single Input Single Output) system is non-linear and it can be approximated by the rational s-transfer function (2):

$$H_P(s) = \frac{K_P}{T_P \cdot s + 1} = \frac{1}{10 \cdot s + 1} \qquad (2)$$

It is designed a control agent considering fixed communication delays, and it is tested in different cases when the communication delays are variant.

In Figure 4 is presented the influence of variant communication delays over the control, and in Figure 5 is presented the influence of the same delays over the output of the closed-loop multi-agent system.

By analyzing these responses, we can see that the performances of the closed-loop multi-agent system are worse in terms of overshoot. This mismatch is generated by the fact that when the variant communication delays appear, the controller designed for the case when the communication delays are fixed is not able to perform as requested and the performances of the closed-loop multi-agent system are getting worse.

In order to prevent the decrease of performances of the closed-loop multi-agent system, we have adopted the control strategy presented in Figure 3.

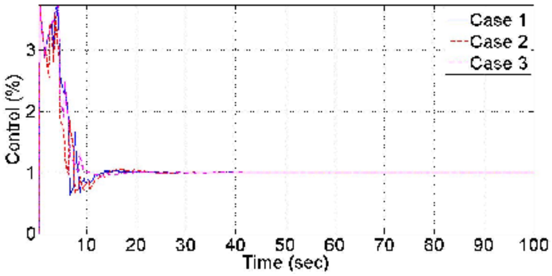

Figure 4. Simulated control analysis when is used the same controller and the communication delays are variant

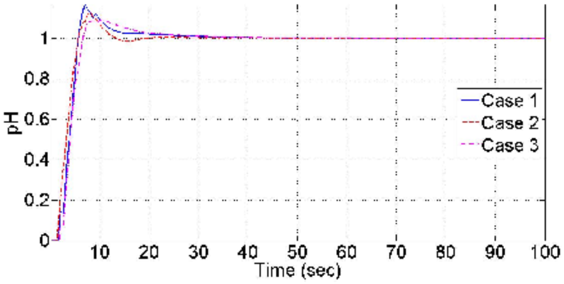

Figure 5. Simulated output analysis when is used the same controller and the communication delays are variant

In this study have been considered the following cases (Table 1):

- Non-adaptive represents the performances of the closed-loop multi-agent system obtained when the communication delays were variant between 0 and 2 seconds, and the controller was designed considering fixed communication delays;

- Adaptive represents the performances of the closed-loop multi-agent system obtained when the communication delays were variant between 0 and 2 seconds, and is used the proposed control strategy.

Table 1. Simulation study analysis

		Overshoot (%)
Non-adaptive	Case1: τ_{max}=2.0 sec	16.8
	Case2: τ_{max}=2.0 sec	12.9
	Case3: τ_{max}=2.0 sec	9.1
	Case4: τ_{max}=2.0 sec	19.9
	Case5: τ_{max}=2.0 sec	19.2
Adaptive	Case1: τ_{max}=2.0 sec	0.0
	Case2: τ_{max}=2.0 sec	0.0
	Case3: τ_{max}=2.0 sec	0.0
	Case4: τ_{max}=2.0 sec	0.0
	Case5: τ_{max}=2.0 sec	0.0

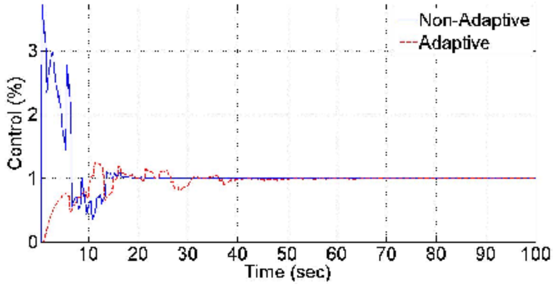

Figure 6. Simulated controls both situations with variant communication delays (case S5)

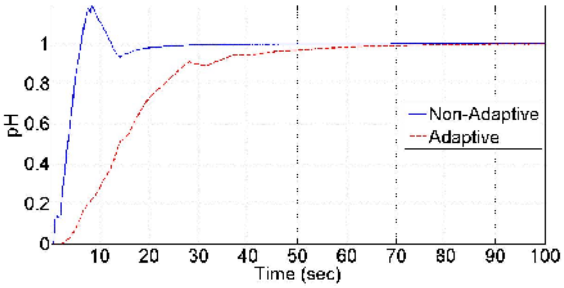

Figure 7. Simulated responses for pH value control in both situations with variant communication delays (case S5)

In Figure 6 are presented the controls, and in Figure 7 are presented the outputs of the closed-loop multi-agent system for two cases with variant communication delays. In the first case (Non-Adaptive) is used the control strategy described in Figure 1, and in the second case (Adaptive) is used our proposed control strategy (Case 5).

By analyzing the responses presented in Figures 4, 5, 6, and 7 we can see that the performances, in terms of overshoot, of the closed-loop multi-agent system are improved when is used our proposed control strategy.

CONCLUSIONS

The paper pointed out the advantages of MAS technology in leather manufacturing in comparison with conventional control solutions. A thing that stands out is the fact that during the communication between agents, delays occur that affects the functionality of the system. The paper presented a solution that mitigates the negative effects caused by variant communication delays. An adaptive multi-agent control strategy was proposed for non-linear single input single output systems affected by variant communication delays. The proposed control strategy uses an estimator for the communication delays, and these values are used to tune the control agent according to (1).

By analyzing the results, the performances of the closed-loop multi-agent system are improved when is used the adaptive control strategy proposed in this paper.

In future work the proposed control strategy will be evaluated on a real industrial process.

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