APPLICATION OF FUZZY LOGIC IN MOTION CONTROL

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Abstract: The presented paper shows the application of fuzzy control ideas in the process of motion control, concrete in control of the middle section of a continuous line mainly in terms of its comparison to controllers designed by analytical methods. Properties of the proposed fuzzy controller structure have been verified by numerical simulation in Matlab program package with parameters from the continuous line physical model built at the Department of electrotechnical, mechatronics and industrial engineering of TU Košice.

KEYWORDS: FUZZY LOGIC, FUZZY CONTROLLER, MOTION CONTROL, CONTINUOUS LINE

1. Introduction

In technical practice, the technologies which require processing of a continuous moving web driven by more electrical drives coupled with each other through this material, can occur very often. Typical representative of driven complex is the middle part of the continuous line, where the individual working machines are coupled with each other through the material. It can be lines for surface material finishing, paper fibre, tension processing of inner laminations and so on. The resulting production quality of this line is essentially dependent on the control of individual variables. From the point of control such complexes present non-linear multi-parameter systems. In literature there exists many methods which allow to reach the aims of continuous line control. Controlled structures with reference model based on II.Lyapunov method [1], is based, as it is the case with majority of the traditional control methods, on mathematical description of the system given in the form of block transfer functions or in the form of state description resulting from differential equations. The fuzzy control method requires none mathematical controlled system description as it is based on a linguistic description that emphasizes attainment of the controlled system qualitative properties [7, 8].

The requirement for the application of a fuzzy controller arises mainly in situations where:
- the description of the technological process is available only in word form, not in analytical form
- it is not possible to identify the parameters of the process with precision
- the description of the process is too complex and it is more reasonable to express its description in plain language words
- the controlled technological process has a „fuzzy“ character, i.e. its behaviour is not fully unequivocal under precisely defined conditions, or it is not possible to precisely define these conditions.

All of the mentioned features are often characteristic for systems involving continuous processing of material.

2. Description of the controlled system

The structure of the middle part of a continuous line (CL) is shown in Fig.1. The structure includes DC motors powered through transistor pulse converters TC. Working machines of the line are driven by motors via gearbox j; v₁, v₂ are speeds of the working machines, F is tension in the web of material between the two machines.

The main line disturbances are tensions in front of and behind the middle part of the considered line which are affecting the first and second drive (F₀₁ and F₁₃). Transient responses of the line to step-wise changes of input variables are shown in Fig.2. It can be seen that the line contains a „quick“ tension subsystem and a „slow“ speed subsystem and this two subsystems are influenced each other, i.e. the whole system is non-autonomous.
3. Fuzzy controller design strategy

As the operation of a fuzzy controller is based on qualitative knowledge about the system being controlled, it is first important to identify these properties. For the identification we shall therefore use time responses of output variables to step changes of input variables, shown in Fig.2.

On basis of the these properties it is possible to propose for example the following control strategy of the CL output variables:
- IF the variable is distant from its desired value THEN let it approach the desired value quickly
- IF the variable is near to its desired value THEN let it approach the desired value slowly

The proposed strategy can be validated on a „slow motion” model of the CL, in which an operator would effect the strategy determined inputs intuitively in discrete irregular moments of time. An example of the said validation is illustrated in Fig.3. It shows the case in which the operator tried to set the tension value of the CL to 0.1. As the plot shows, the proposed strategy makes it possible to achieve a nice smooth response of the CL tension value.

4. Fuzzy controller design

The basic structure of fuzzy control is shown in Fig.4. The tension subsystem is controlled by tension fuzzy controller FCF with two inputs \( w_F, F \) and one output \( u_1 \). The speed subsystem is controlled by speed fuzzy controller FCV with two inputs \( w_v, v \) and one output \( u_2 \).

The internal structure of both controllers is illustrated in Fig.5 and it is the same for both controllers. The broken line illustrates possible complementation of the controller by an integrating element, which in case of necessity enables achievement of zero control error.

5. Verification of fuzzy control for various operation states

Properties of the proposed structure of a fuzzy tension and speed of the CL controller have been verified by numerical simulations performed in Matlab program package, and parameters of CL model (listed in appendix) were taken from the continuous line physical model (Fig.7) built at the Department of electrotechnical, mechatronics and industrial engineering Technical University of Košice. More information about CL physical model you can find in [2].
The basic operation state is line acceleration to a certain speed while maintaining the defined web tension. Fig. 7 shows tension setting to value 0.25 at time 0s and subsequent acceleration of the line to speed value 0.1.

Additive disturbances that have substantial influence on the operational parameters of the line are changes in web tension in front of and behind the middle part of the considered line. Fig. 10 shows the influence of these disturbances of normalized value 0.1 in time of 10s and 15s. It can be observed that these disturbances influence the settled value of both tension and speed control error. In order to improve this behavior it is sufficient to simply add an integrating element with amplification $K_I = 10$ to each fuzzy controller (broken line in Fig. 5). The result of the adjustment is shown in Fig. 11.

The paper presents the application of fuzzy control logic in the area of motion control, concrete in control of the middle section of a continuous line. From the figures presented in chapter 5 it is clear that the proposed fuzzy controller has met basic goals of the continuous line control, namely required dynamics of setting individual controlled values, autonomy of decoupling of individual transfer channels, invariability under the influence of major disturbances occurring above and after the CL considered part and having the magnitude of the nominal moment, and also robustness against changes of the controlled system parameters that attained decuple change in the processed material elasticity constant.

Achieved results in comparison of the non-linear analytical control methods [3, 4, 5, 6] result in the following conclusion: In the case when the motion complex to be identified and controlled well known analytically traditional methods seem to be more advantageous though it’s applying may result in a more complicated structure [1]. At motion control where well known are only their inputs and outputs more convenient seems to be the fuzzy control method. Its application can leads to simpler structures and better properties that it is with the analytical method, but the proposal or design needs the extensive practice in identifying important qualitative properties of the system [9, 10, 11, 12].

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Appendix:
Parameters of the physical model:
- DC motors:
  \( U_N = 24 \text{ V} \)  \( n_N = 3650 \text{ rpm-s} \)
  \( R_a = 0.7 \Omega \)  \( I_N = 8.5 \text{ A} \)  \( P_N = 140 \text{ W} \)
  \( L_a = 90 \mu \text{H} \)
  \( M_N = 0.39 \text{ Nm} \)
  \( J_m = 0.17 \cdot 10^{-4} \text{ kgm}^2 \)
  \( c = 24 \)
  \( c\phi = 0.043 \text{ Vs} \)
- Converters:
  \( T_{TM} = 0.1 \text{ ms}, K_{TM} = 5.1 \text{ V/V} \)
- Processed material:
  \( b = 0.03 \text{ m}, h = 0.1 \cdot 10^{-3} \text{ m}, E = 1.8 \cdot 10^9 \text{ Nm}^2 \)
  \( SE = 5400 \text{ N} \)
- Working rollers:
  \( r = 0.04 \text{ m}, v_0 = 0.6 \text{ m/s}, l_{12} = 1.35 \text{ m} \)

References