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CONTROL OF MECHANICAL MANUFACTURING PROCESSES USING FUZZY LOGIC

Streszczenie. W pracy przedstawiono podstawowe idee sterowania złożonymi mechanicznymi procesami wytwarzania z użyciem regulatora rozmytego. Sterowanie tego typu, opierające się na doświadczeniu operatora - człowieka, jest stosowane w przypadkach gdy model procesu jest trudny do uzyskania.

Резюме. В работе представлены основные идеи управления сложными механическими производственными процессами с помощью размытого регулятора. Управление такого типа, основанное на опыте оператора-человека, применяется в случае, когда модель процесса очень трудно получить.

Summary. The basic ideas of the control complex mechanical manufacturing processes by means of fuzzy logic controller. Such a kind of control, based on the experience of human operator, is employed when the model of the process is difficult to define.

1. INTRODUCTION

Classical and modern control theories need a precise mathematical model of the controlled process and exact measurements of input & output parameters. For such processes as turning, milling, grinding or other machining processes [4,5,6,7] building mathematical models is a complicated task because of their nonlinearities, time varying, dead bands, randomness etc. Therefore the applications of conventional control methods are still very limited. In many industrial manufacturing processes the control relies heavily upon human experience. One of the tasks of artificial intelligence is to build machines to control processes based on human control strategy without human operator in the control loop. In this case the control concepts are different from conventional control systems [3].

In order to control a process without knowing its model, fuzzy set theory has proved to be very sucessful and it has led to the control algorithm called fuzzy logic controller (FLC) or fuzzy controller (FC).

This paper is organized as follows: Section 2 presents the general structure of fuzzy control system. Some simulation and experimental results are mentioned in Section 3. Section 4 contains some concluding remarks revealing advantages and disadvantages of such a kind of control.

2. FUZZY CONTROL SYSTEM

Analogically to conventional PID controller, which is built by means of a linear function of its arguments we can consider an example of FLC represented by [3]

$$K_4 u(k) = F[K_1 e(k), K_2 ie(k), K_3 de(k)] \tag{1}$$

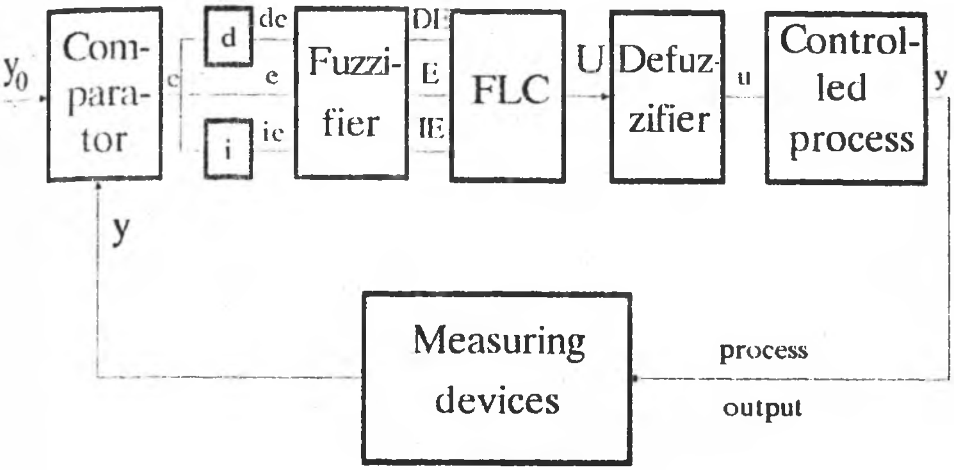
where:
- e - denotes error,
- ie - sum of errors,
- de - change in error,
- u - output of the controller,
- K_i, $i=2,\ldots,4$ - stands for an appropriate scaling mapping.

In Equation (1), F denotes the fuzzy relation defined by the rule base consisting of the rules which may have form

$$R_i: \text{ if } e \text{ is } A_i \text{ and } ie \text{ is } B_i \text{ and } de \text{ is } C_i \text{ then } u \text{ is } D_i \tag{2}$$

A set ($i=1, 2, \ldots, m$) of such linguistic description rules based on an expert's knowledge characterizes the dynamic behavior of a controlled system.

Fig. 1 shows the basic configuration of an FLC



Rys. 1. Podstawowa konfiguracja regulatora rozmytego (FLC)

Fig. 1. Basic configuration of fuzzy logic controller (FLC)

Fuzzy control rules may be combined by using the sentence connectives *and* and *also* (*or*, *else*). It means that the system can be characterized by a single fuzzy relation R which is the combination of the fuzzy relations R_i in the rule set [3].

To infer the output of the controller from the given process states E', IE', DE', and the fuzzy relation R, the so called sup-star compositional rule of inference can be applied

$$U' = DE' \circ (IE' \circ (E' \circ R)) \tag{3}$$

The compositional rule of inference (generalized modus ponens) does not yield a unique model. It contains several degrees of freedom. The main are: the choice of the composition and the choice of implication describing each control rule.

Special software designed for control purposes allows to switch from one possibility to another.

The output of the inference process so far is a fuzzy set specifying a membership function of control action. In the on-line control, a nonfuzzy action is required. There are many methods of defuzzification eg. [3]

a value where the maximum of membership function appears,

the mean of maxima when a fuzzy set has more than one peak value,

center of gravity of the membership function,

and others

In fuzzy control applications the observed data are usually crisp. Since the data manipulation in FLC is based on fuzzy set theory, a fuzzification is necessary during an earlier stage. In this case the fuzzification deals with a conversion of a crisp value into a fuzzy singleton within a certain universe of discourse.

3. SIMULATION AND EXPERIMENTAL RESULTS

Many simulation results have been obtained in the area of control of ill-defined complex processes. The authors of this paper have got also some interesting simulation results for the control of such processes [1,2].

The simulation experiments rely on the assumption of the existence of the process model described by a nonlinear function, eg. for the grinding process [7]:

$$R_a = 317.5\, f^{0.52}\, v_w^{0.65}\, v_s^{-0.80}\, K$$

where R_a - Center Line Average (CLA) value of surface finish (output of the grinding process),

f - feed rate (input of the process),

v_w - work speed,

v_s - wheel speed,

K - coefficient of dressing condition.

Using this model several simulation experiments were carried out [7].

The set of experiments can be divided into three main groups. The dynamical response curves of the system were investigated, with the set value R_a changing stepwise from R_{a_0} to R_{a_1}. The second group presents the dynamical response curves of the system when changing work speed v_w and wheel speed v_s. The third group shows the response curves for changing dressing condition implied by changing the coefficient K.

Simulation results may be obtained using a system of differential equations describing the model of the process. The simulation results published to date are mostly based on this kind of model description.

Apart from simulation results, several real applications of the fuzzy controller can be found in literature.

4. CONCLUDING REMARKS

FLCs, when used to controlling complex manufacturing processes, show several advantages over conventional methods [3]. These are:

1. FLC can be designed by means of human operator's experiences. Different operator's strategies are expressed by different linguistic rule sets, which means that FLC can simulate some features of human intelligence.
2. Using FLCs in automatic computer control can reduce computational overhead, when compared to conventional contollers.
3. FLC is particularly suitable for uncertain and complex processes, difficult to characterize by mathematical equations.
4. Software implementation of FLC assures flexibility of the control strategy, by changing the linguistic rules.

Despite of successful applications in particular processes [6], there is still much to be done in this field. Future investigations should concern theoretical, methodological and experimental research. In theoretical research the stability of fuzzy control systems, optimal control, influence of linguistic rules on control performance and other problems should be considered. Methodological research has to investigate such problems as design methods for FLCs, choice of optimal fuzzy linguistic rules, multi-input and multi-output systems, etc. Experimental research should result in developing software design methods, analysis of control performance, comparison of FLCs with conventional controllers. However, for some uncertain and complex processes, FLCs seem to be the only tool available for their control [6].

REFERENCES

[1] Czogala E., A generalized concept of a fuzzy probabilistic controller, Fuzzy Sets and Systems, 11 (1983), 287-297.

[2] Czogala E., Rawlik T., Modelling of a fuzzy controller with application to the control of biological processes, Fuzzy Sets and Systems 31, (1989), 13-22.

[3] Lee C.C., Fuzzy logic in control systems: Fuzzy Logic Controller - Part I, Part II, IEEE Transactions on Systems, Man and Cybernetics 20, 2, 1990, 404-418, 419-435.

[4] Ralston P.A.S., Simulation of Fuzzy Logic Control of a Lathe, Proc. of the 1988 Symposium on Advanced Manufacturing, Lexington, Kentucky, Sept. 26-28, 1988, 21-25.

[5] Sakai Y., Ohkusa K., On a control system for cutting process, Proc. of the 16th CIRP International Seminar on Manufacturing Systems, Tokyo, 1984, 188-195.

[6] Sakai Y., Ohkusa K., A fuzzy controller in turning process automation, in: M. Sugeno (ed.), Industrial Applications of Fuzzy Control, North Holland, 1985, 139-151.

[7] Zhu J.Y., Shumsheruddin A.A., Bollinger J.G., Control of Machine Tools Using the Fuzzy Control Technique, Cranfield Institute of Technology (UK), 347-352.

STEROWANIE MECHANICZNYCH PROCESÓW WYTWARZANIA Z ZASTOSOWANIEM LOGIKI ROZMYTEJ

W artykule przedstawiono podstawowe idee automatycznego sterowania złożonych mechanicznych procesów wytwarzania wykorzystując regulator oparty na logice rozmytej (Fuzzy Logic Controller, FLC). W punkcie 1 (wstęp) uzasadniono celowość stosowania tego typu sterowania w przypadku złożonych procesów, dla których uzyskanie matematycznego modelu jest trudne.

Podstawową strukturę systemu sterowania zilustrowano na rys. 1 i opisano w punkcie 2. Zwrócono uwagę na istotę sterowania rozmytego opartego na zbiorze reguł pochodzących z doświadczenia operatora sterującego procesem.

Punkt 3 porusza problemy symulacji cyfrowej i możliwości praktycznych zastosowań regulatorów rozmytych w sterowaniu złożonych procesów.

W punkcie 4 (uwagi końcowe) zawarto oprócz uwag końcowych dotyczących regulatora rozmytego wnioski uzyskujące konieczność prowadzenia dalszych badań nad tego typu regulatorami.