# Supervisory Fuzzy Controller for Linear Control System.

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***Abstract:*** *The paper presents a concept of control system with supervisory fuzzy controller. The fuzzy controller adjusts the sets ($K_p$, $K_i$, $K_d$) of PID controller to the current parameters values (amplitude A and frequency f) of disturbance signal. The rules for knowledge base are created using simulation tests. The performance of control system with supervisory fuzzy controller is compared to system with single feedback loop.*

# 1 Introduction

The new control systems require looking for new and better control algorithms. Neural networks and fuzzy systems are being used more often now due to development of microprocessors. Acting of numerous controllers is based on fuzzy algorithms, but it is still not popular enough to use them in any kind of control process. Designing of fuzzy logic or neural network is often too complicated and takes too much time to be used by average design engineer.

# 2 System structure

The control system with supervisory fuzzy controller consists of two parts (two feedback loops). First one is a standard control system with linear plant and PID controller. Second part is supervisory system (fig. 1.).

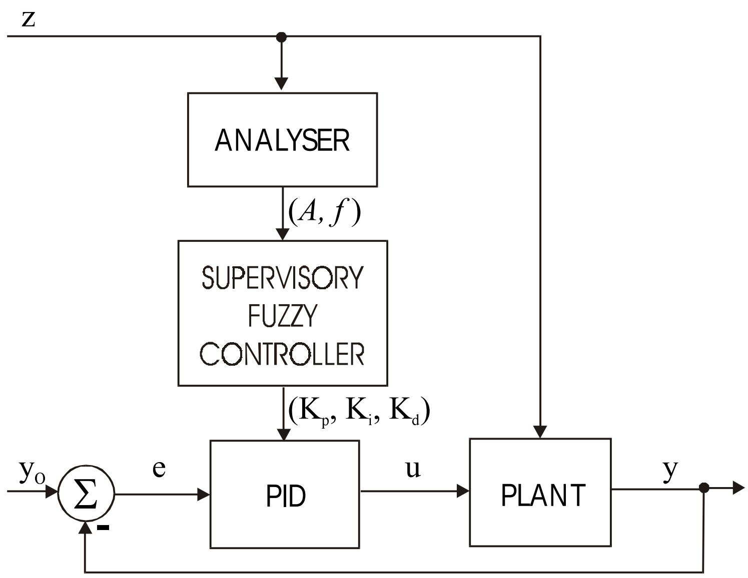


Fig. 1: Control system with supervisory fuzzy controller.

**Main feedback loop**

PID controller and linear plant (mass *m* supported by spring *k* and vibration damper *b*, fig. 2.) are in the main feedback loop. Formula (1) is a transfer function of the plant. Actuator *F* having transfer function (2) is mounted to the mass in parallel with spring and damper. Linear PID controller can be described by three parameters $K_p$, $K_i$ and $K_d$ which are respectively proportional, integral and differential gain. This part of control system can act without supervisory controller.

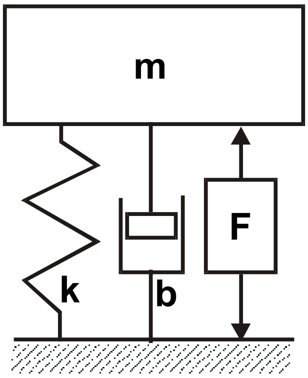

Fig. 2: Control plant with actuator *F*.

$$G_o = \frac{1}{10s^2 + 5s + 475} \tag{1}$$

$$G_a = \frac{198{,}2}{0{,}02s + 1} \tag{2}$$

**Supervisory feedback loop**
This part of control system consists of analyser and supervisory fuzzy (Mamdani) controller. Analyser calculates actual value of disturbance signal parameters. Fuzzy controller is build from three blocks (fig. 3.): *fuzzyfication, inference* and *defuzzyfication*. Membership functions of the input signals are in the first block. Thanks to them numerical values of inputs are changed into fuzzy values. Rules and output membership functions are in inference block. The decision about the optimal sets of PID controller is determined by rules and is taken upon the disturbance signal parameters (amplitude $A$ and frequency $f$). In the third part of fuzzy system numeric values of output is being count.

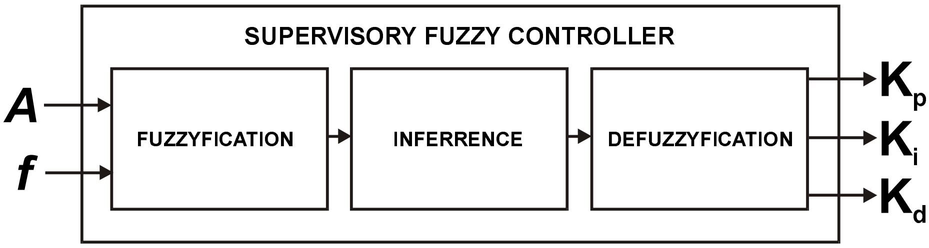

Fig. 3: Block diagram of supervisory fuzzy system.

# 3 Creation of fuzzy system

Following tasks had to be determined during fuzzy system creation:

- number, kind and variation range of inputs and outputs,
- input and output membership functions,
- rule base.

**Number, kind and variation range of inputs**
Two parameters of sinusoidal disturbance signal (amplitude $A$ and frequency $f$) are inputs to the fuzzy system. Amplitude changes from 0 [m] to 0,06 [m] and frequency changes form 0 [Hz] to 12 [Hz]. Variation ranges are chosen arbitrary.

**Number, kind and variation range of outputs**
Three sets of PID controller ($K_p$, $K_i$ and $K_d$) are outputs from fuzzy system. Variation range can be define after simulation tests.

**Input membership functions**
Triangular, not symmetrical input membership functions were assumed and were named with the numbers as it is shown in fig. 4.

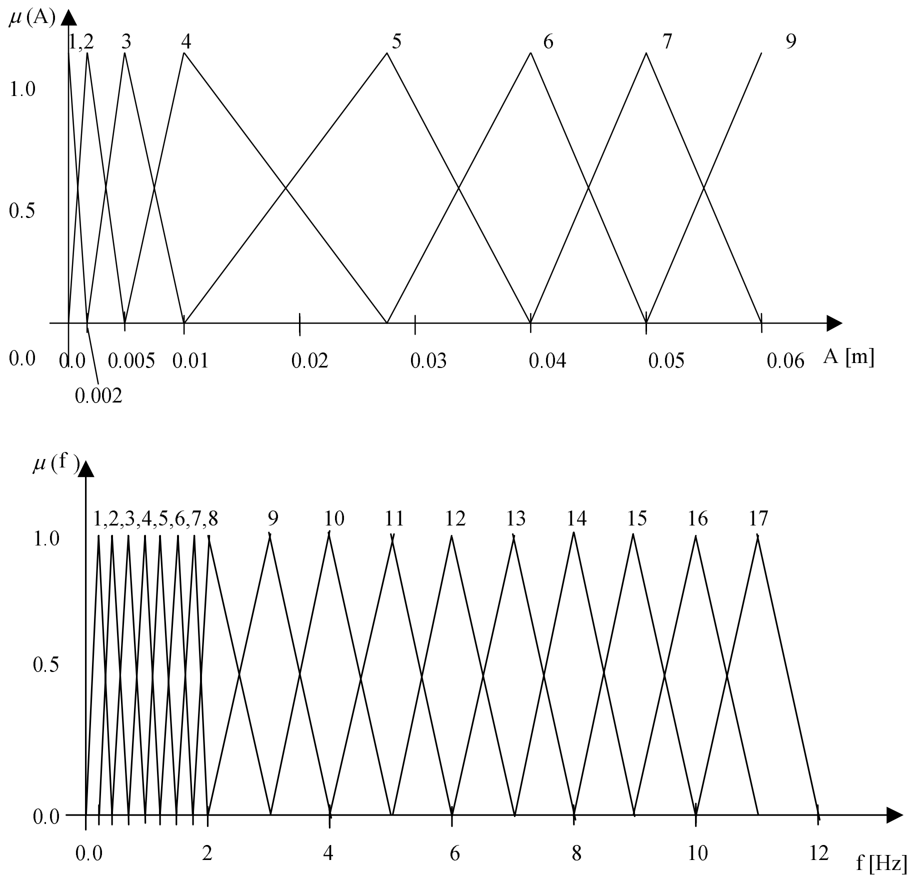


Fig. 4: Input membership functions of fuzzy system.

**Simulation tests**
Simulation tests were led to get knowledge about the optimal values of PID sets for different values of ($A, f$), fig. 5. Objective function that was minimised is the time integral squared error (quality coefficient $I_2$) (3).

$$I_2 = \int_0^\infty e^2(t)dt \tag{3}$$

where: $e$ - error, $t$ - time.
After every simulation test PID sets were changed in the way that leads the value of objective function to be minimised. This way of sets matching lasts very long. Computer routine was made to create the knowledge base automatically.

Based on simulation tests rules were created and variation range of output values could be determined. Coefficient $K_p$ varies from 0 to 200, $K_d$ varies from 0 to 20. Coefficient $K_i$ was almost constant, so decision not to include it into fuzzy system was taken.

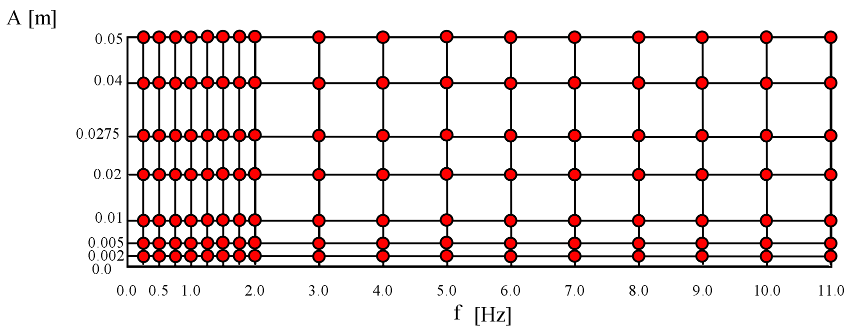


Fig. 5: Disturbance signal parameters for which PID sets were matched.

**Output membership functions**

Input membership functions can be chosen arbitrary, but output membership functions depend on not uniformly distributed simulation results. Maximum values of membership functions were determined in places where density of the simulation results was bigger. Fig. 6. shows output membership functions.

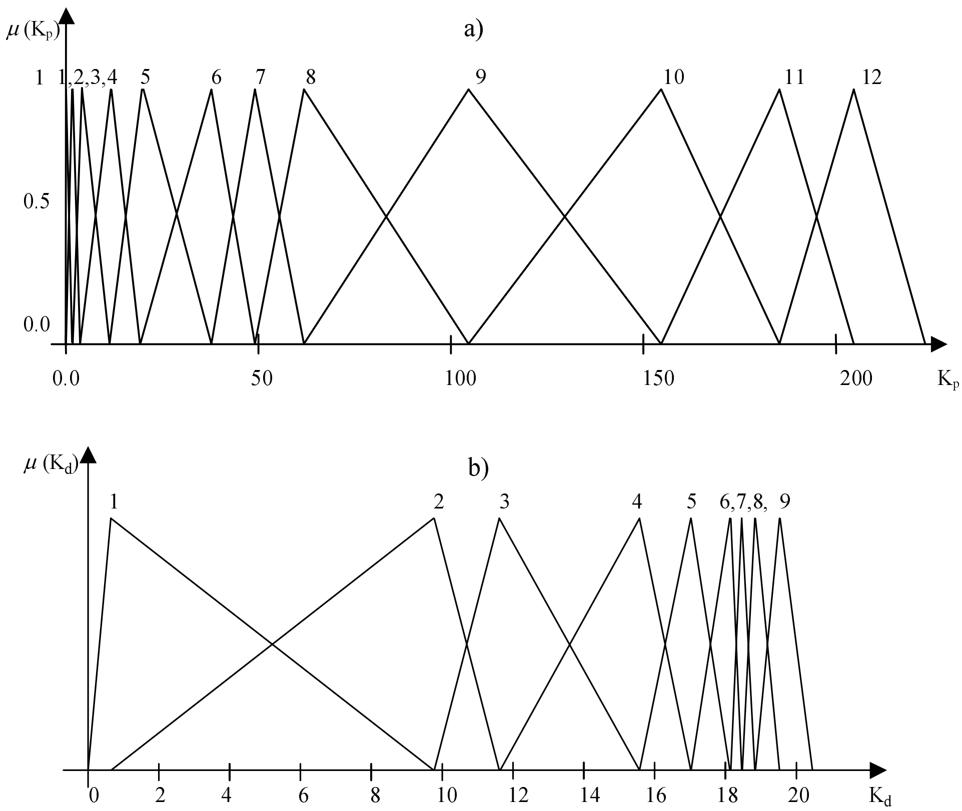


Fig. 6: Output membership functions for (a) $K_p$ and (b) $K_d$.

**Rule Base**

Rules in the fuzzy system join inputs with outputs. It is possible to show dependency between input and output with the help of surfaces (fig. 7. and 8.). The surfaces can be modified by

manipulating the elements of fuzzy system; rules, membership functions or mathematical methods.
Fuzzy system was modified in order to ease tuning and make system more clear. Supervisory controller represents dependency between input ($A, f$) and output ($K_p$, $K_d$):

$$[K_p, K_d] = f_r(A, f)$$

where: $f_r$ - vector function.
This vector function was separated into two scalar functions:

$$K_p = f_{r1}(A, f),$$
$$K_d = f_{r2}(A, f).$$

The separation was done by dividing rules:

$$\textbf{IF } A \text{ is } A^* \textbf{ AND } f \text{ is } f^* \textbf{ THEN } K_p \text{ is } K_p^* \textbf{ AND } K_d \text{ is } K_d^* (w), \quad (4)$$

where: $w$ - weight,
into two different rules with the same antecedent but not the same consequence:

$$\textbf{IF } A \text{ is } A^* \textbf{ AND } f \text{ is } f^* \textbf{ THEN } K_p \text{ is } K_p^*, (w_1), \quad (5)$$
$$\textbf{IF } A \text{ is } A^* \textbf{ AND } f \text{ is } f^* \textbf{ THEN } K_d \text{ is } K_d^*, (w_2).$$

Such kind of separation makes tuning of fuzzy system easier, because it is possible to change output value by changing the weight of every rule. Modifying weight $w$ in (4) changes both output values ($K_p$ and $K_d$) together. Modifying weights $w_1$ and $w_2$ separately in (5) only one output is being changed. Tuning of the system can be done automatically by computer routine, which changes weight in every rule and checks if the output of system is the same as results of simulation tests.

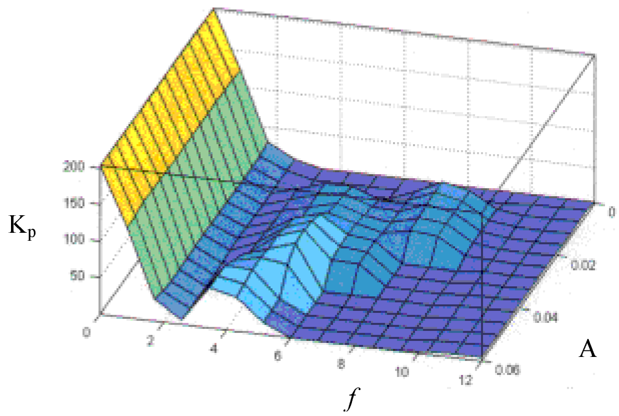


Fig. 7: Graphic representation of dependency between inputs ($A, f$) and output $K_p$.

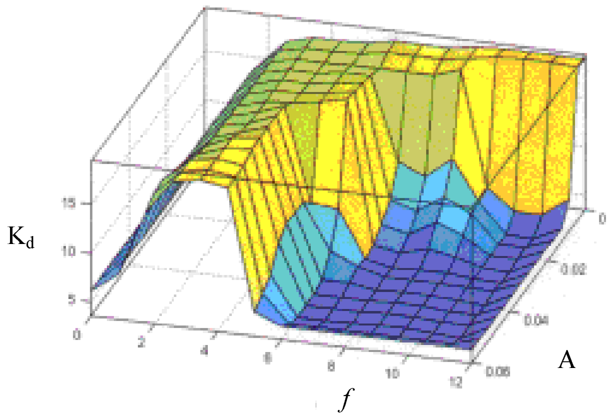


Fig. 8: Graphic representation of dependency between inputs (*A, f*) and output $K_d$.

# 4 Results of simulation tests

Exemplary simulation tests of control system with (fig. 11.) and without (fig. 10.) supervisory fuzzy controller were presented. Simulation tests were done with a help of Matlab-Simulink. In the case of control system with single feedback loop PID sets were matched with help of the same criterion, but for wide range of parameters (A, *f*) variation. Disturbance signal (fig. 9.), in both cases, has constant amplitude *A* = 0,05 [m] and its frequency *f* variation is presented in fig. 12. During simulation fuzzy system was changing PID sets in the way shown in fig. 14 and 15.

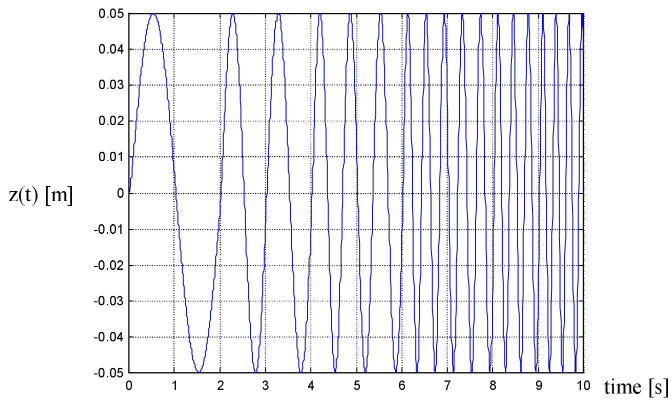


Fig. 9: Disturbance signal.

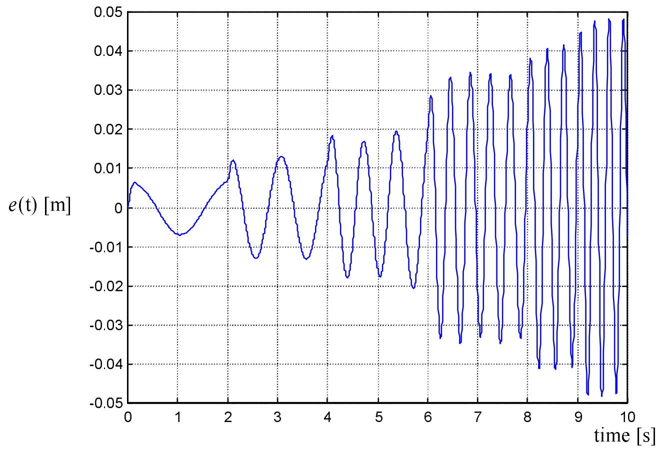


Fig. 10: Displacement error of control system without supervisory fuzzy controller.

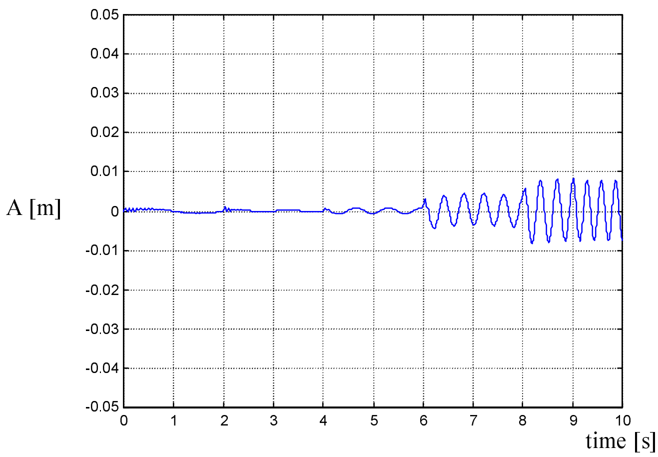


Fig. 11: Displacement error of control system with supervisory fuzzy controller.

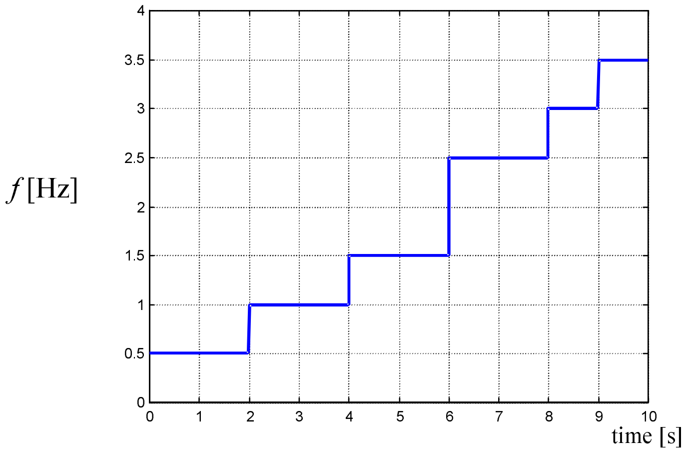


Fig. 12: Frequency *f* variation of disturbance signal.

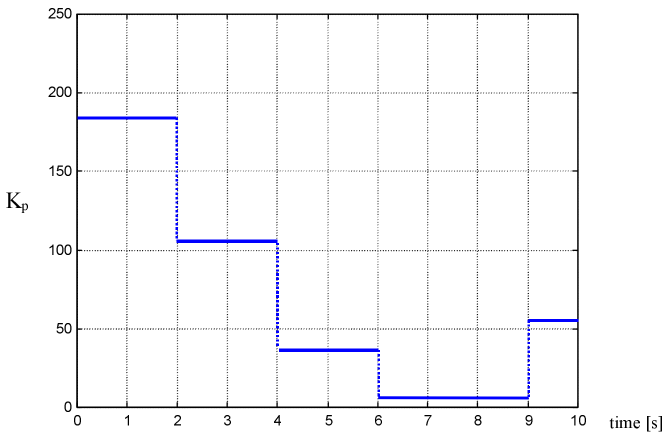


Fig. 13: $K_p$ PID set vs. time.

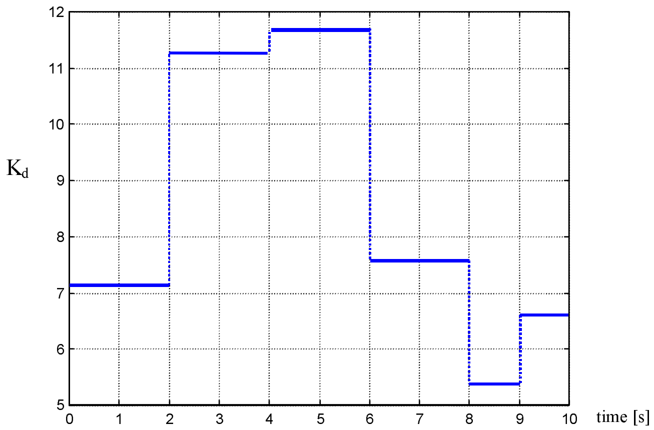


Fig. 14. $K_d$ PID set vs. time.

# 5 Conclusions

Presented simulation tests shows that considered control system with supervisory fuzzy controller has smaller displacement error than one without PID sets autotuning. Using fuzzy logic it is possible to adapt linear PID sets to different disturbance signal parameters. The way of knowledge base creation is universal enough to be used with different kind of control systems together with nonlinear plant [5] and different kind of disturbance signal.

# 6 References


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