Model of intelligent control system of road-building material compaction by pavers

A P Prokopev, Zh I Nabizhanov, V I Ivanchura and V L Sabinin
Siberian Federal University, prospect Svobodny, 79, Krasnoyarsk, Russia, 660041

E-mail: prok1@yandex.ru

Abstract. The article considers the task of designing intelligent controllers of automatic control systems by working modes of pavers during compaction of road-building materials. Intelligent controller is submitted in a form of fuzzy PID-controller. Mathematical model which takes account of metallic structures of compacting working body and road-building materials is provided. Simulation model of working process under the study in terms of MATLAB/Simulink programme is obtained. Numerical example of comparison between system’s transient characteristic and continuous, digital and fuzzy controllers is provided.

1. Introduction
Low-quality asphalt road pavements are the topical issue nowadays. The quality of road pavements strongly depends on road materials, framework of asphalt pavers and road rollers, mode parameters of road building machines. A significant improvement in the quality of asphalt road pavements can be obtained by automatically controlling the mode parameters of road materials’ compaction by asphalt pavers. Taking into account the multifactorial nature of the technological process of compacting road materials by pavers, the use of intelligent (fuzzy logic, artificial neural networks, expert system) regulators is the effective tool.

Modern pavers with efficient working bodies can ensure the compaction of asphalt concrete mixture to the standard (set) values of the compacting factor. The regulating effect is provided by changing the frequency of impacts of the ramming bar in the range of 15-30 Hz and the frequency of vibration of the plate in the range of 20-60 Hz. Controlled value is a compaction coefficient, which varies in the range of 0.92-0.99, at a constant speed of the paver - 0.033-0.083 m/s.

High-order models are obtained in the mathematical formulation of objects of automatic control systems (ACS) [1]. The problem of designing continuous controllers for high-order systems is characterized as relevant. In the general theory of automatic control, the controller’s structure is selected based on the model of the control object. At the same time, more complex control objects correspond to controllers that are more complex [2].

The idea of controlling the working process of compaction by asphalt pavers using fuzzy controllers is proposed. The efficiency of using fuzzy controllers in automatic control systems by technological processes is the subject of scientific research and discussion [3-7].

The aim of this paper is to investigate the effectiveness of using a fuzzy PID controller in the control system of the working process of road materials’ compaction by asphalt pavers in real time.

The following tasks were solved to achieve this goal:
• mathematical and simulation models of the interaction process between the compacting working body of the asphalt paver and road materials are obtained;
• a method for designing PID controllers for high-order systems is proposed; a parametric synthesis of the controller for a specific example is performed;
• the design of a fuzzy PID controller for a system of a fourth-order control object is performed;
• a comparison between the quality of regulation by the transient characteristics of control system models and continuous, digital and fuzzy controllers is carried out.

2. Methods
As a result of the implementation of the method in the state space the transfer function (TF) of the fourth-order control object is obtained

\[ W(s) = \frac{0.001115 \cdot s^2 + 0.02509 \cdot s + 153.3}{s^4 + 29.41 \cdot s^3 + 1.553 \cdot 10^5 \cdot s^2 + 7,963 \cdot 10^3 \cdot s + 7,436 \cdot 10^8}. \]

The design of a continuous controller for a fourth-order system is carried out according to the method proposed by the authors [8]. The simulation model in the MATLAB/Simulink program is shown in figure 1.

![Figure 1. Simulation model of the control system in MATLAB / Simulink.](image1)

According to the simulation results, the process is aperiodic, the transition time is 1 s, there is no overshoot.

A simulation model of a control system with a digital controller in terms of the MATLAB/Simulink program is obtained, figure 3.

![Figure 3. Simulation model of a control system with a digital controller.](image3)
The study of the model with a digital PID controller was carried out with a sampling period of $T = 0.01 \text{ s}$. According to the simulation results, the process is aperiodic, the transition time is 1.2 s, there is no overshoot. This result satisfies the task for designing an automatic control system.

The development of a simulation model of a fuzzy ACS in the MATLAB/Simulink program has been completed. Based on the selected structure the PID controller equation is written as the following expression [5]:

$$u(t) = \left( \frac{1}{2} K_p e(t) + K_d \frac{de}{dt} \right) + \left( \frac{1}{2} K_p e(t) + K_i \int e(t) \cdot dt \right).$$

Here, the first bracket describes the PD controller, the second bracket describes the PI controller (figure 4).

![Simulation model of a control system with a digital controller.](image)

The fuzzy logical inference is based on the Mamdani algorithm. In order to minimize the number of rules, we will use 7 terms for the input variables (which gives 49 monitor rules). In this case, each variable corresponds to its own range of the base scale, presented in table 1 (figure 5, figure 6).

**Table 1.** Law of control of FLC_PD and PI.

|     | NB   | NM   | NS   | Z    | PS   | PM   | PB   |
|-----|------|------|------|------|------|------|------|
| e   | -1   | -0.66x2 | -0.33x1 | 0    | 0.33x1 | 0.66x2 | 1    |
| u   | -1   | -0.66 | -0.33 | 0    | 0.33 | 0.66 | 1    |

![Linguistic description of input variables of the PD type.](image)
Figure 6. Linguistic description of input variables of the PI type.

7 terms are used to describe the control signal (figure 7). The linguistic control law takes the form shown in table 2.

Table 2. Rules of the FLR_PD-and PI regulator

| $e^*$ | NB | NM | NS | Z | PS | PM | PB |
|-------|----|----|----|---|----|----|----|
| $\Delta e^*$ | NB | NB | NB | NB | NM | Z | PB |
| NB | NB | NB | NM | NS | PS | PB |
| NM | NB | NM | NS | Z | PM | PB |
| NS | NB | NM | Z | PS | PM | PB |
| PS | NB | NM | Z | PS | PM | PB |
| PM | NB | Z | PM | PB | PB | PB |
| PB |

The general rule table takes the following form: it contains 49 rules, and each rule has 7 meanings (figure 8).

Figure 7. Linguistic description of the output variable of the PD and PI type.
3. Research results

The transient characteristics of the systems with synthesized regulators are compared. Modeling is necessary to analyze the quality of ACS by dynamic characteristics and the nature of the dynamic process.

The transient response of the fuzzy controller shows better dynamic properties than the classical and digital PID controllers: the transition time is 0.1 s, so the practical effect of replacing the controller is quite obvious (figure 9).

It can be noted that overshoot is not observed in any of the control systems according to the simulation results. The control system with a fuzzy controller shows the shortest transition time.
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