ANLYSIS OF TRANSPORT SPEED CONTROL BASED ON FUZZY LOGICS ELEMENTS

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Abstract. Translation motion control along given trajectory for a car is investigated. System control uses only one input sensor – object velocity that allows calculating velocity error, and additionally determining error variation depending on velocity differences in a small time interval. Results show that systems with fuzzy logic elements are very stable and allow us to maintain levels of velocity in horizontal directions as well as other movement control in normal road situations like slopes, and additionally taking into account system vibration parameters.

Keywords: speed control, adaptive control, fuzzy logics control, robotics.

Introduction

The theory of fuzzy sets has advanced in a variety of ways and in many disciplines. Applications of fuzzy technology can be found in artificial intelligence, computer science, control engineering, decision theory, expert systems, logic, management science, operations research, robotics, and others. Theoretical advances have been made in many fields [1-4].

This paper is related to the synthesis of new adaptive control mechatronic systems. Main forces acting on the object (car) moving along given path are (Fig. 1): constant "dry" friction resistance, nonlinear (square) air resistance, additional wind resistance, variation of gravity force component in slopes, vertical vibrations interactions with rough road surface, controlled torque from engine. In this report three output actions are investigated: optimal control (in minimal time period to return back to steady-state motion), linear surface control, fuzzy logic flat control. In the main task maximal steady-state velocity is given as a parameter. Additionally, cases with small or large velocity limits (as switches) are investigated. For all cases computer modeling was made.

Fig. 1. **Car motion along given trajectory**

Equation of motion

Transport vehicle (car) simplified differential equation along given 3-D space trajectory may be formulated as (Fig. 2.):

$$m \cdot \ddot{s} = -F[s, \dot{s}, sign(\dot{s}), V, \varphi(s,t)] - m \cdot g \cdot \sin(\alpha(s)) - R(t, s, \dot{s}) + u(t, s, \dot{s}), \quad (1)$$

where m – mass;

$s, \dot{s}, \ddot{s}$ – curvilinear co-ordinate, velocity and tangential acceleration;

$F[s,\dot{s},sign(\dot{s}),V,\varphi(s,t)]$ – all resistance forces, including wind velocity V with action angle φ;
g – free fall acceleration;
t – time; α – slope angle;
$R(t,s,\dot{s})$ – rough road interaction force;
$u(t,s,\dot{s})$ – control action. Therefore for object control action $u(t,s,\dot{s})$ can be synthesizing.

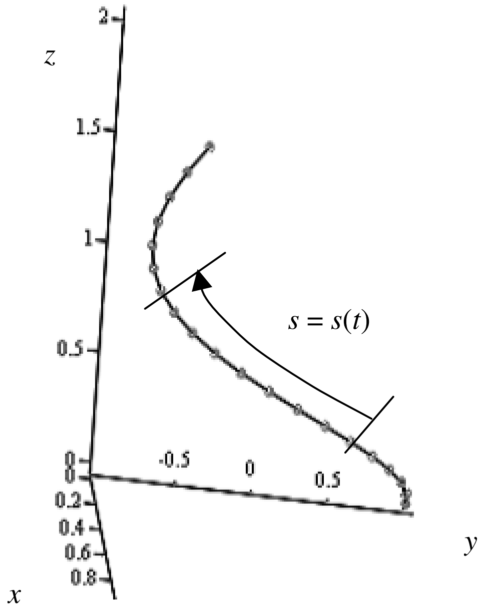

Fig. 2. **Model for motion equation**

Optimal control

Idea of optimal control shows that any time interval control can move object back to steady state position with formulated velocity. If control $u(t,s,\dot{s})$ has limits (2) with boundaries u_1, u_2:

$$u_1 \le u(t,s,\dot{s}) \le u_2, \tag{2}$$

The control action has one value for both boundaries (2). Examples of modeling are shown in Fig. 3-6. Here and next MathCAD program was used.

It is shown that with "bang-bang" control actuators can work in switch regime with very high frequency (Fig. 4).

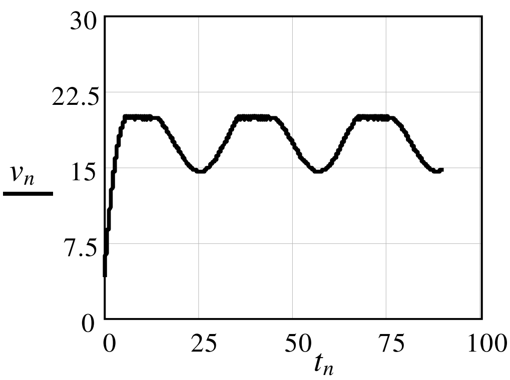

Fig. 3. **Velocity as time function**

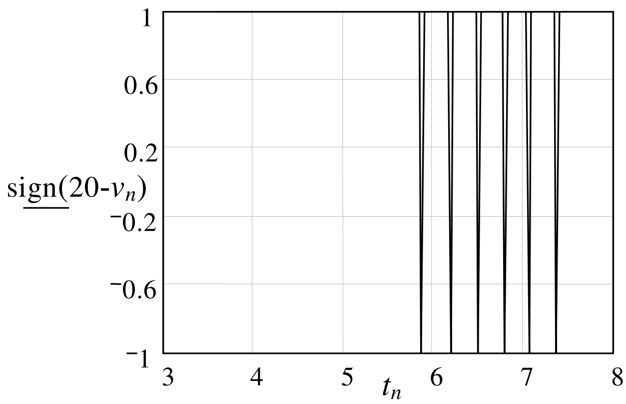

Fig. 4. " **Bang-bang" control action in time region 3-8**

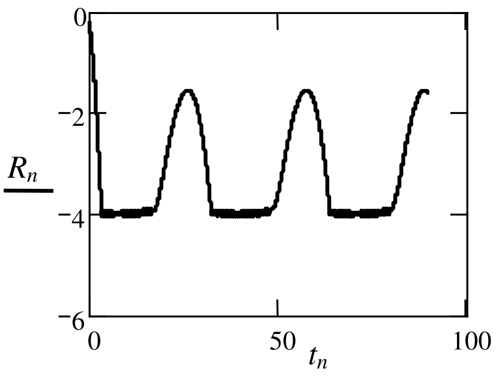

Fig. 5. **Resistance force as time function**

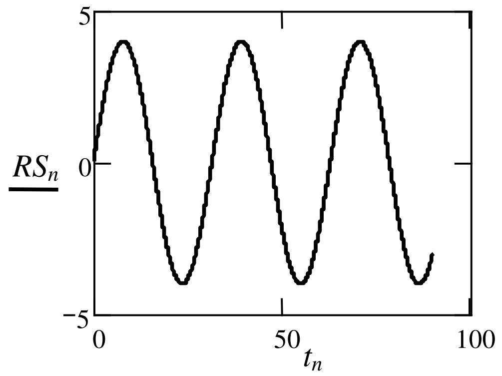

Fig. 6. **Harmonica component of gravity**

Linear surface fuzzy logic control

Results of modeling are shown in Fig. 5-8.

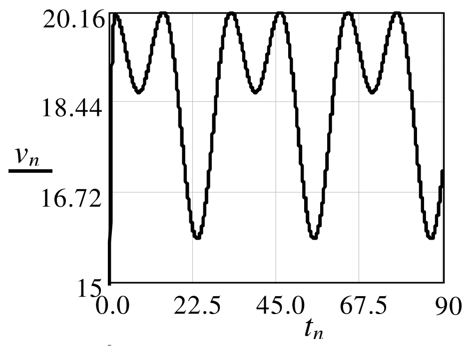

Fig. 7. **Car velocity as time function**

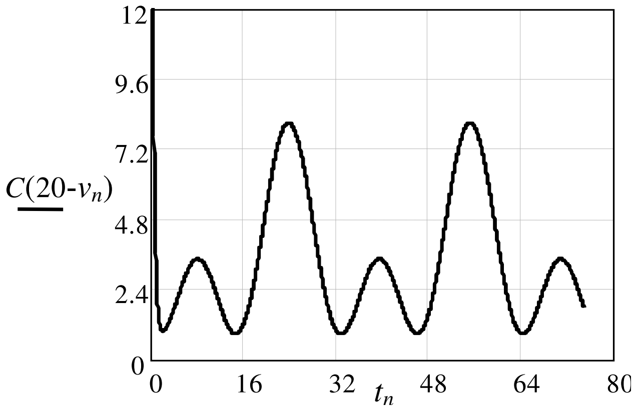

Fig. 8. **Linear component of control**

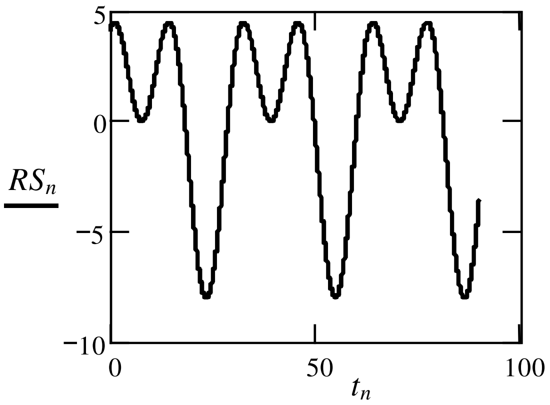

Fig. 9. **Bi-harmonica component of gravity**

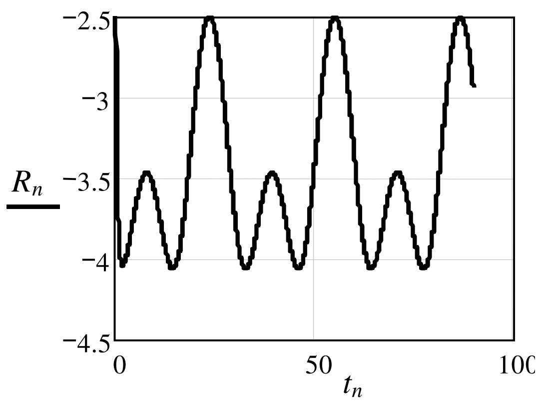

Fig. 10. **Resistance force**

Fuzzy logic flat control

Fuzzy logic flat control was investigated with three levels of impact of the control actions: - minimal, - middle; - maximal (Fig.11).

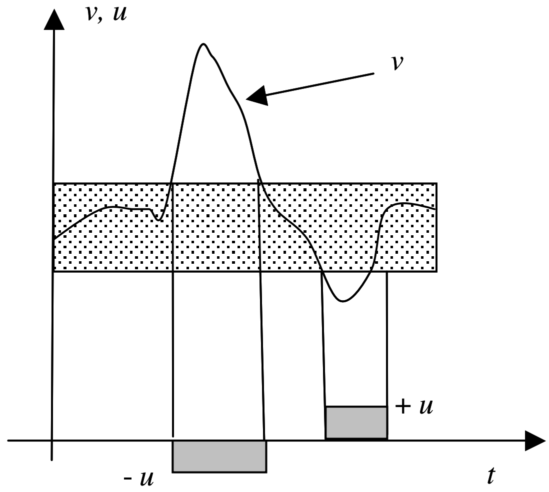

Fig. 11. **Scheme of velocity exchange *v* = *v*(*t*) and flat control *u* = *u*(*t*) action in time t domain**

Flat control was investigated with three levels of impact of the control actions: - minimal, - middle; - maximal. In the middle region of allowable speed range control action was switched off at all (Fig. 11). Some results of modeling are shown in Fig. 12 and 13.

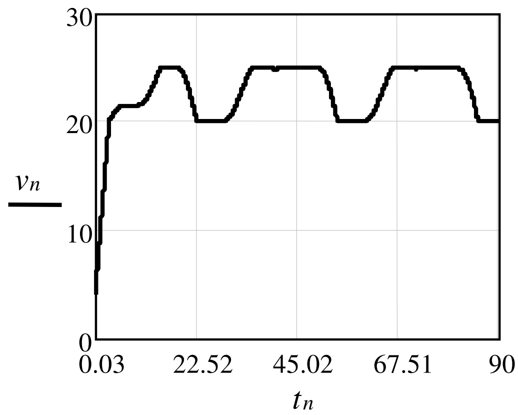

Fig. 12. **Velocity in time domain**

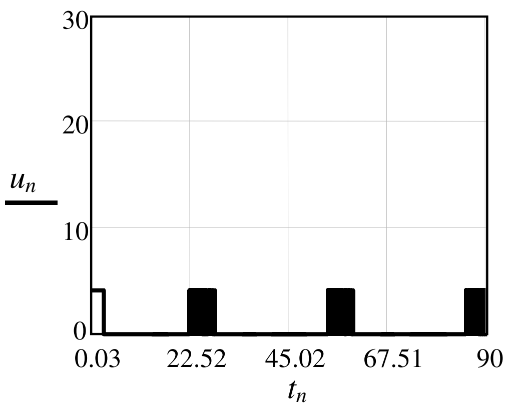

Fig. 13. **Flat control action in time domain**

Control with velocity limits

Control with velocity limits means that transport road through the inhabited regions or towns have velocity limits. This situation can be taken into account of control action to observe these limits.

By control with velocity limits we assume that robotic driver has determined velocity limits. This situation can be taken into account of control action to observe those limits. Example of modeling in this case by mixed control (proportional and “bang-bang”) is shown in Fig. 14-16.

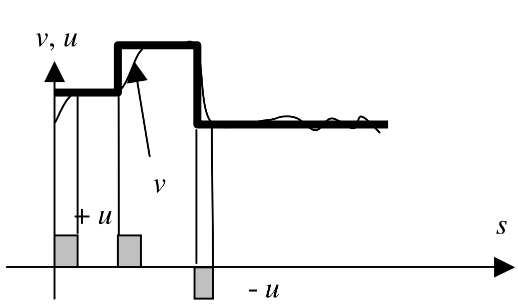

Fig. 14. **Scheme of velocity limits as function of coordinate *s***

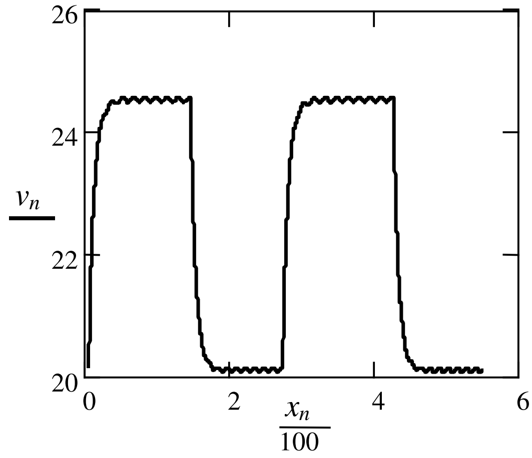

Fig. 15. **Velocity in road domain in kilometers**

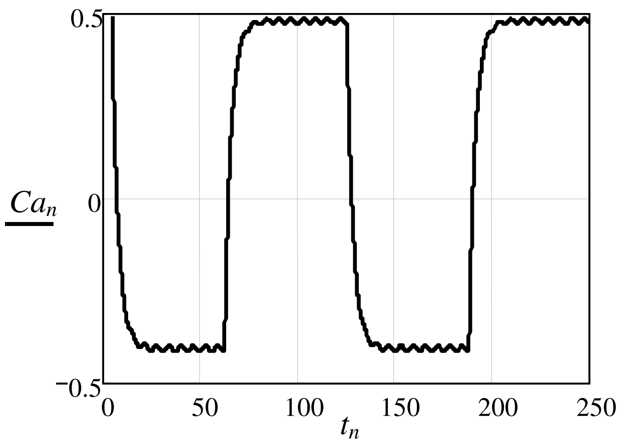

Fig. 16.**Control action in time domain**

Results and discussion

Traditional control systems are based on mathematical models in which the control system is described using one or more differential equations that define the system response to its inputs. Such systems are often implemented as "proportional-integral-derivative (PID)" controllers. They are the products of decades of development and theoretical analysis, and are highly effective [5]. The PID controller is the most common form of feedback. It was an essential element of early governors and it became the standards tool when process control emerged in the 1940s. In process control today, more than 95 % of the control loops are PID type, most loops are actually PI control. PID controllers are today found in all areas where control is used [5].

If PID and other traditional control systems are so well-developed, why bother with fuzzy control? It has some advantages. In many cases, the mathematical model of the control process may not exist, or may be too "expensive" in terms of computer processing power and memory, and a system based on empirical rules may be more effective [6-8].

Furthermore, fuzzy logic is well suited to low-cost implementations based on cheap sensors, low-resolution analog to digital converters. Such systems can be easily upgraded by adding new rules to improve performance or add new features. In many cases, fuzzy control can be used to improve existing traditional controller systems by adding an extra layer of intelligence to the current control method.

Fuzzy logic was first proposed by Lotfi A. Zadeh of the University of California at Berkeley in a 1965 paper [6]. He elaborated on his ideas in a 1973 paper that introduced the concept of "linguistic variables", which in this article equates to a variable defined as a fuzzy set. Other research followed, with the first industrial application, a cement kiln built in Denmark, coming on line in 1975.

Fuzzy systems were largely ignored in the US because they were associated with artificial intelligence, a field that periodically oversells itself and which did so in a big way in the mid-1980s, resulting in a lack of credibility in the commercial domain.

The Japanese did not have this prejudice. Interest in fuzzy systems was sparked by Seiji Yasunobu and Soji Miyamoto of Hitachi, who in 1985 provided simulations that demonstrated the superiority of fuzzy control systems for the Sendai railway. Their ideas were adopted, and fuzzy systems were used to control accelerating, braking, and stopping when the line opened in 1987. Another event in 1987 helped promote interest in fuzzy systems. During a international meeting of fuzzy researchers in Tokyo that year, Takeshi Yamakawa demonstrated the use of fuzzy control, through a set of simple dedicated fuzzy logic chips, in an "inverted pendulum" experiment. This is a classic control problem, in which a vehicle tries to keep a pole mounted on its top by a hinge upright by moving back and forth.

Observers were impressed with this demonstration, as well as later experiments by Yamakawa in which he mounted a wine glass containing water or even a live mouse to the top of the pendulum. The system maintained stability in both cases. Yamakawa eventually went on to organize his own fuzzy-systems research lab to help exploit his patents in the field.

Following such demonstrations, the Japanese became infatuated with fuzzy systems, developing them for both industrial and consumer applications. In 1988 they established the Laboratory for International Fuzzy Engineering (LIFE), a cooperative arrangement between 48 companies to pursue fuzzy research. Japanese companies developed a wide range of products using fuzzy logic, ranging from washing machines to autofocus cameras and industrial air conditioners [6].

Conclusions

Use of fuzzy logic elements allows different kinds of transport systems control in real road situations. Modelling shows that "bang-bang" control gives good results for non-stationary motion control because controllers and actuators can work in switch regime with very high frequencies. Results of the report may be used as well for floating and diving devices control in robotics.

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