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MICROCONTROLLER BASED CONTROL SYSTEM FOR AN MR DAMPER IN A DRIVER'S SEAT

SYSTÉM ŘÍZENÍ MR TLUMIČE POMOCÍ JEDNOTKY MIKROKONTROLERŮ

Abstract

This aim of the paper is to present the development of a control system for an MR damper in a driver's seat which is based on a microcontroller with a fuzzy set processing unit. The paper presents: model of a driver's seat, control objective, applied control algorithm, development of the control system and experiments.

Abstrakt

Tento příspěvek se zabývá vývojem řídicího systému MR tlumiče sedadla řidiče, který je založen na výpočetní fuzzy jednotce mikrokontroléru. Příspěvek prezentuje model sedadla řidiče, aplikovaný řídící algoritmus, vývoj řídicího systému a jeho ověření.

1 MODEL OF A DRIVER'S SEAT

We investigate the driver's seat considered as a system with one or with two degrees of freedom whose models are shown in Figure 1.

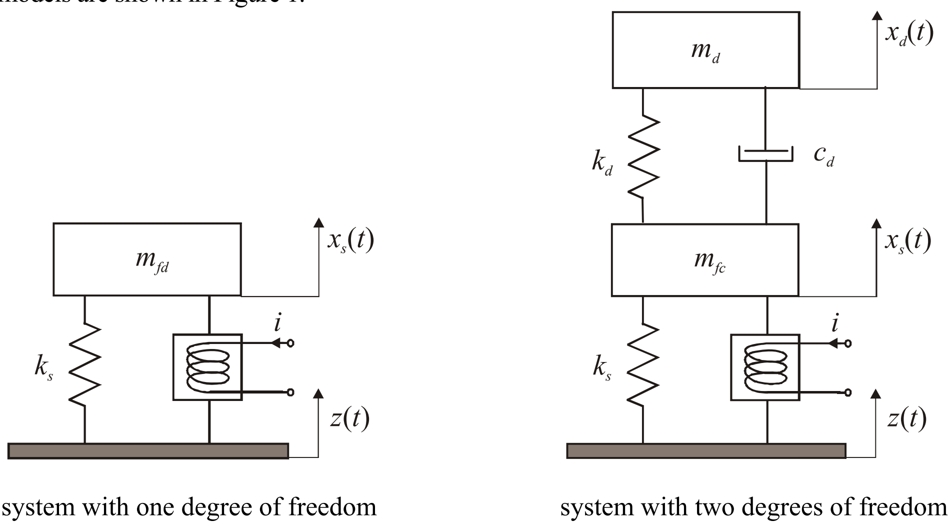

Fig. 1 Model of a driver's seat

In the system with one degree of freedom (the seat cushion is removed) the designations are as follows: k_s is spring stiffness, i is current in the MR damper, m_{fd} is mass of the driver and seat frame, x_s is displacement of the driver and z is disturbance. The equation of system motion can be written as:

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$$m_{fd}\ddot{x}_s(t) + k_s x_s(t) = F_d(t) + k_s z(t) \quad (1)$$

where $F_d(t)$ is the MR damper force.

In the system with two degrees of freedom (the seat with cushion) the designations are as follows: k_d is cushion stiffness, c_d is damping coefficient of the cushion, m_d is mass of the driver, $x_d(t)$ is displacement of the driver, m_{fc} is mass of the seat (frame and cushion) and $x_s(t)$ is displacement of the seat frame. Other designations are that in the system with one degree of freedom. Then equations of system motion can be written as:

$$\begin{aligned} & m_d\ddot{x}_d(t) + c_d\dot{x}_d(t) + k_d x_d(t) - c_d\dot{x}_s(t) - k_d x_s(t) = 0 \\ & m_{fc}\ddot{x}_s(t) - c_d\dot{x}_d(t) + (k_s + k_d)x_s(t) - k_d x_d(t) = F_d(t) + k_s z(t) \end{aligned} \quad (2)$$

2 CONTROL OBJECTIVE

The control objective is to reduce vibration transmitted to the driver. The performance index for the system with one degree of freedom is assumed to be displacement transmissibility defined as:

$$T_{zs} = \frac{|X_s(j\omega)|}{|Z(j\omega)|} \quad (3)$$

where $X_s(j\omega)$ and $Z(j\omega)$ are Fourier transforms of displacements $x_s(t)$ and $z(t)$.

The performance indices for the system with two degrees of freedom are assumed to be displacement transmissibility T_{zd} and T_{xd} defined as:

$$T_{zd} = \frac{|X_d(j\omega)|}{|Z(j\omega)|} \quad (4)$$

$$T_{zs} = \frac{|X_s(j\omega)|}{|Z(j\omega)|} \quad (5)$$

where $X_d(j\omega)$, $X_s(j\omega)$ and $Z(j\omega)$ are Fourier transforms of displacements $x_d(t)$, $x_s(t)$ and $z(t)$.

3 CONTROL ALGORITHM

The applied control algorithm is a fuzzy algorithm with the Mamdami inference system (Fig. 2). The algorithm is developed for seat considered as a system with one and two degrees of freedom. The input signals for the algorithm are the velocities $\dot{x}_s$ and $\dot{x}_s - \dot{z}$ and the output signal is current i in the damper. The rules for the algorithm are listed in Table 1. The number of five rules was taken, as it was appreciable. It was demonstrated in (Sapiński 2006) that when the number of rules in the fuzzy algorithm went up there was no significant improvement in system performance.

Table 1. Rules for the algorithm

No.	Rule
1	if $(\dot{x}_s - \dot{z})$ is MED and $\dot{x}_s$ is MED then i is MIN
2	if $(\dot{x}_s - \dot{z})$ is MIN and $\dot{x}_s$ is MIN then i is MAX
3	if $(\dot{x}_s - \dot{z})$ is MAX and $\dot{x}_s$ is MAX then i is MAX
4	if $(\dot{x}_s - \dot{z})$ is MIN and $\dot{x}_s$ is MAX then i is MIN
5	if $(\dot{x}_s - \dot{z})$ is MAX and $\dot{x}_s$ is MIN then i is MIN

The algorithm uses three linguistic variables: MIN, MED and MAX for the velocities $\dot{x}_s$ and $\dot{x}_s - \dot{z}$ and two linguistic variables for the current *i*: MIN and MAX. The variables MIN and MAX for current *i* are associated with the values 0.00 A and 0.15 A. The input membership functions for the velocities $\dot{x}_s$ and $\dot{x}_s - \dot{z}$ are of triangular shape, and the output membership functions for current *i* are of singleton type. The fuzzy graph of the algorithm is shown in Figure 3.

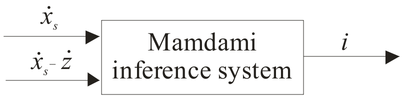


Fig. 2 Structure of the algorithm

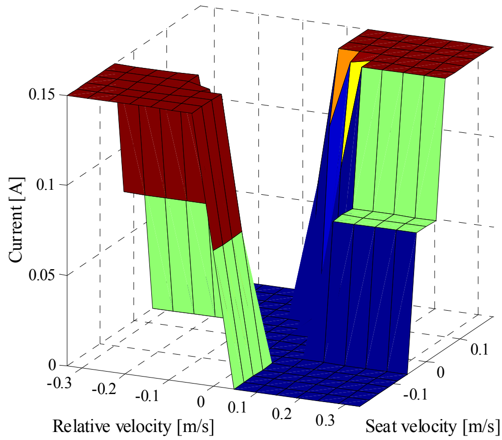


Fig. 3 Fuzzy graph for the algorithm

4 CONTROL SYSTEM DEVELOPMENT AND TESTING

4.1. Description of the microcontroller and integrated development environment

The developed control system was based on the ST52E420 microcontroller which is supported by the Visual Five-IDE integrated development environment.

The ST52E420 microcontroller provides a high computational flexibility to perform arithmetical, logic and fuzzy operations (STMicroelectronics 2002a). The microcontroller contains Decision Processor which allows for the implementation of a Mamdami type fuzzy inference with crisp consequents. Inputs for fuzzy inference are stored in 8 dedicated fuzzy input registers. The result of a fuzzy inference is stored directly in a location of the register file. The limits on the number of fuzzy rules and fuzzy blocks are only related to the program memory size.

The Visual Five-IDE is the integrated development environment that allows the programming of the ST52 family of fuzzy microcontrollers (STMicroelectronics 2000, STMicroelectronics 2002b). The Visual Five-IDE provides a visual programming approach to graphically define the program's logic flow by means of interconnected blocks. This can be achieved by designing the block-diagram of the project by inserting the appropriate blocks. Each block that is inserted is already designed for a definite type of functionality that can be programmed either in a graphic way or with high-level instructions. The links among the blocks determine the logic flow of the program. The Visual Five-IDE is equipped with tools that allow the machine code generation and program debugging.

The whole project is organized in the Project Window as a tree-view, which allows the user to access the entire project. The editors may be opened to configure the device or define the variables from the tree-nodes. The block editors may also be opened from the tree-nodes allowing the user to establish the program parts, procedures and interrupt routines. Each single block can also be reached from the Project Window.

4.2. Implementation of the algorithm on the microcontroller

The control algorithm implemented in the ST52E420 microcontroller is shown in Figure 4. In the fuzzyfication phase the intersection between the input values (seat velocity $\dot{x}_s$ and relative velocity and $\dot{x}_s - \dot{z}$) and the related membership functions is performed. The inference phase manages the weights obtained during the fuzzyfication phase to compute the truth value for each rule. This is a calculation of the maximum (for the OR operator) and/or minimum (for the AND operator) performed on weights values according to the logical connectives of fuzzy rules. Several conditions may be linked together by linguistic connectives AND/OR, NOT operators and brackets. The truth value and the related singleton membership function (Current_Mbf) are used by the defuzzyfication phase, in order to complete the inference calculation.

The algorithm implemented in the ST52E420 microcontroller is shown in Figure 4. The designation Mbf in blocks refers to membership functions. The peripherals configuration window of the Visual Five is presented in Figure 5. The measured analog signals are fed to microcontroller's analog input pins: Ain0, Ain1 and Ain2.

The output signal is fed to PWM type output pins T0OUT. The other signals of ST52E420 are set by default. Three membership functions of the triangular type for each input and three membership functions of the singleton type for the output are selected accordingly. An example of membership functions for inputs is shown in Figure 6 and of membership function for the output in Figure 7.

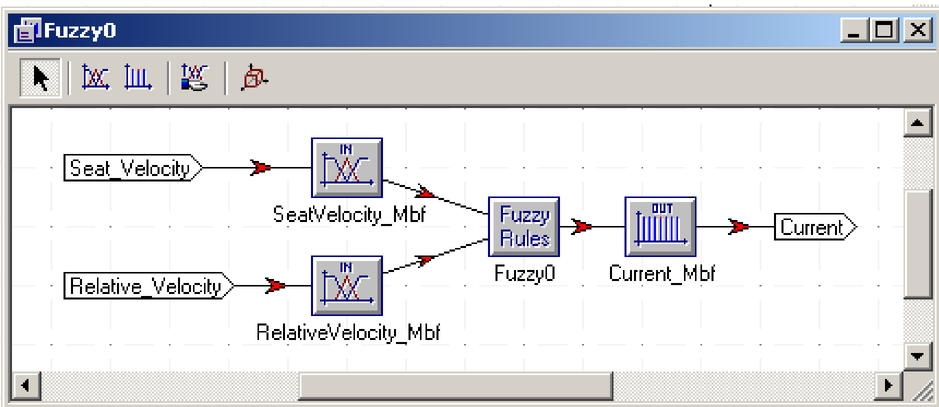


Fig. 4 The algorithm implemented in the ST52E420 microcontroller

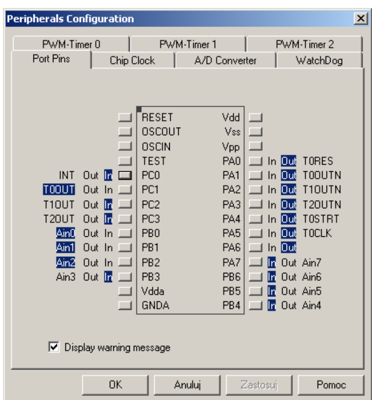


Fig. 5 Configuration of inputs and outputs

The axis of abscissa is scaled in binary format of 8-bit length signed number. This number corresponds to 8-bit resolution of A/D converter. The converted voltage is in the range of (0, 5) V. The voltage 2.5 V corresponds to zero value of the signal obtained from displacement sensor. The axis of abscissa is scaled in binary format of 8-bit length unsigned number. This number corresponds to duty cycle of 8-bit resolution PWM output channel.

The base of rules of the algorithm for the system with one degree of freedom is shown in Table 2. The current is expressed in relative values, with respect to its maximal value varied throughout the test over the range (0.00, 0.20) A. The diagram of the developed control system is shown in Figure 8.

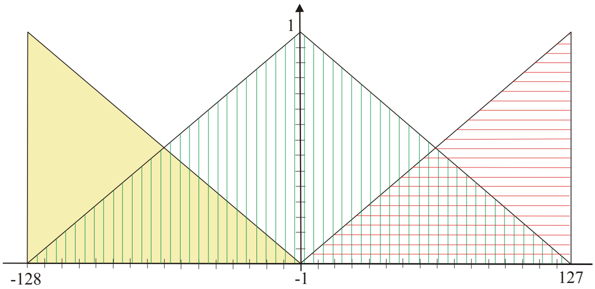


Fig. 6 Input membership functions

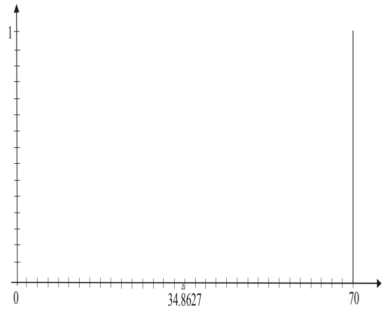


Fig. 7 Output membership function

Tab. 2 Rules for the algorithm implemented on the ST52E420 microcontroller

Fuzzy0 - Rules

№ Rule	Fuzzy Rule
1	if RelativeVelocity_Mbf is Medium and SeatVelocity_Mbf is Medium then Current_Mbf is Min
2	if RelativeVelocity_Mbf is Min and SeatVelocity_Mbf is Min then Current_Mbf is Max
3	if RelativeVelocity_Mbf is Max and SeatVelocity_Mbf is Max then Current_Mbf is Max
4	if RelativeVelocity_Mbf is Min and SeatVelocity_Mbf is Max then Current_Mbf is Min
5	if RelativeVelocity_Mbf is Max and SeatVelocity_Mbf is Min then Current_Mbf is Min

4.3. Experiments and results

The the driver's seat ready for tests (system with one and two degrees of freedom) is shown in Figure 9. The experimental setup is equipped with measurement system (a PC with an I/O board installed and supported by MATLAB/Simulink and RTWT running on Windows). The seat is supported by the RD-1005-3 damper. The disturbance is generated by the base displacement. The damper force is adjusted according to the output signal of the power controller. The displacements are measured with displacement sensors.

In the system with one degree of freedom the values of the parameters are assumed to be: k_s = 36860 N/m and m_{fd} = 80 kg, while in the system with two degrees of freedom they are: k_d = 45000 N/m, c_d = 450 N·s/m, m_{fc} = 33 kg and m_d = 50 kg.

– In the first stage we tested the system with one degree of freedom by the damper in passive mode. We measured system responses under sine displacement of the shaker base (disturbance) with amplitude of 3×10^{-3} m and frequency range (1, 8) Hz when the current was varied in the range (0.00, 0.20) A. This range of input current enabled us to effectively control resonant frequency of the seat (Sapiński 2006). The frequency was kept constant at 5 second intervals. The frequency was increased by 0.25 Hz in a discrete manner in every consecutive interval.

– The obtained transmissibility plots are shown in Figure 10. The plots show that the resonance frequency of the system with the MR damper and no current is 3.25 Hz and it takes higher values as current increases.

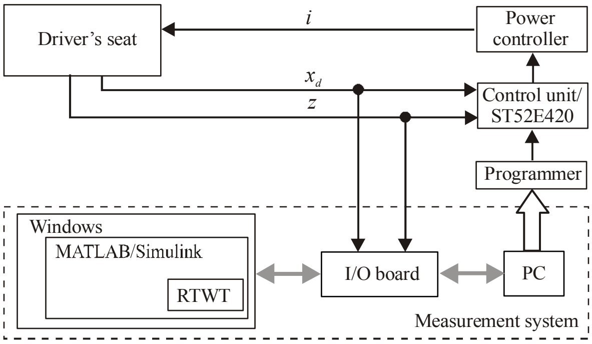


Fig. 8 Diagram of the developed control system

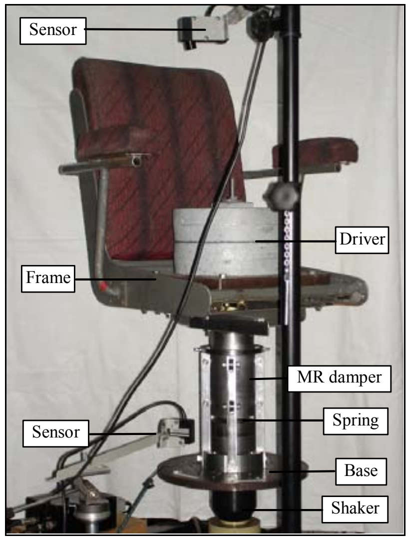


Fig. 9 Driver's seat ready for tests - system with one or two degrees of freedom

In the second stage we tested the system with one and two degrees of freedom by the damper in controlled mode (applying the algorithm with Mamdami inference system). Experiments were run for sine displacement of the shaker base with amplitude 3.0×10^{-3} m over the frequency range (1, 12) Hz and current in the range (0.00, 0.20) A.

– The obtained results are shown in Figures 11, 12 and 13. In Figure 11 we compare time patterns of displacements in the system with one degree of freedom, at frequency 3.25 Hz. Similarly in Figures 12 and 13 we compare time patterns of displacements in the system with two degrees of freedom.

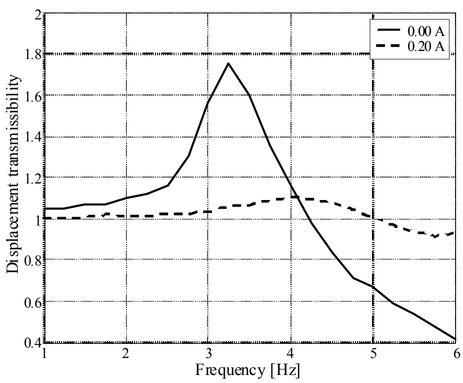


Fig. 10 Transmissibility of the system with one degree of freedom, passive mode

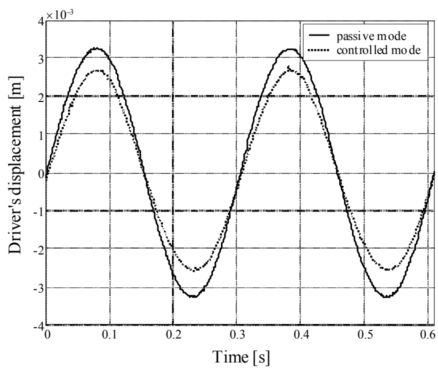
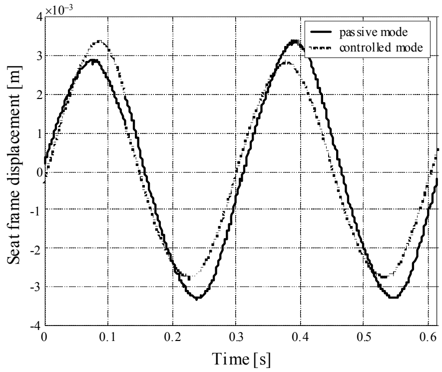


Fig. 11 Time patterns of drivers' displacement in the system with one degree of freedom



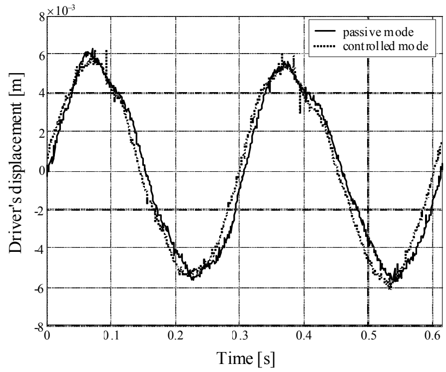


Fig. 12 Time patterns of seat frame displacement in the system with two degree of freedom

Fig. 13 Time patterns of driver's displacement in the system with two degree of freedom

It is apparent that the amplitudes of vibration displacements are reduced. The plots demonstrate system performance improvement by the damper in controlled mode. This confirms the adequacy of the developed control system based on the ST52E420 microcontroller.

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