FUZZY CONTROL OF INVERTED PENDULUM USING REAL-TIME TOOLBOX

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Abstract

The paper describes a process of design of a fuzzy control system for the Amira PS600 Inverted pendulum system. The control system is realized in the MATLAB/Simulink environment and uses the Fuzzy Logic Toolbox. A connection of the Simulink scheme to the PS600 system is realized through the Real Time Toolbox.

1 Inverted pendulum

Inverted pendulum is a typical example of an unstable nonlinear system and is often used to test the performance and efficiency of control methods. The goal of the control process is to move the pendulum from the lower (stable) equilibrium position to the upright (unstable) equilibrium position and keep it in this position. Movement of the carriage acts as an actuator of the control system. Moreover, the control system should be able to move the carriage to the desired position while keeping the pendulum in the upright position.

2 PS 600 Inverted Pendulum System

The Amira PS600 Inverted Pendulum System consists of the carriage which can perform rectilinear motion along a guiding bar, the pendulum which can freely rotate around the spindle connected to the cart and a DC motor connected to the belt which is used to move the cart. The scheme of the system is shown in Fig 1.
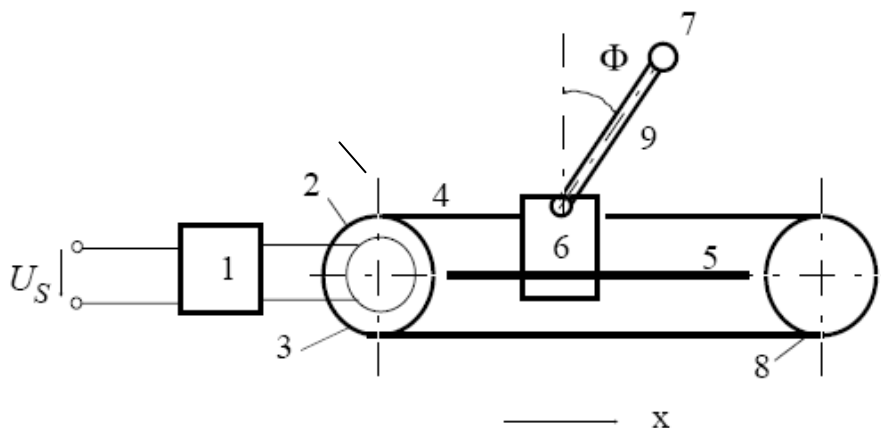

Figure 1: Functional scheme of PS 600 pendulum (1-Servo amplifier, 2-Motor, 3-Drive wheel, 4-Transmission belt, 5-Guiding bar, 6-Carrige, 7-Pendulum weight, 8-Guide roll, 9-Pendulum rod)

The following quantities of the PS 600 Inverted Pendulum System can be measured and used in the control system:

- Carriage position using incremental encoder

- Angle of the pendulum rod (Φ) using incremental encoder

The system can be controlled by control voltage (U_S) of the servo amplifier which is connected to the DC motor.

The photo of the system is presented in Fig 2.

Figure 2: PS 600 system

A mathematical model of the pendulum can be found in the [1].

3   Design of a fuzzy control scheme

Classical approaches to the control of such a nonlinear unstable system are based on either adaptive control techniques [2] or model predictive control [3]. Such techniques require model of the controlled system. This model can be obtained by mathematical-physical analysis of the system or computed from measured data by either off-line or on-line identification techniques.

One of the main advantages of the fuzzy control approach consists in fact that the design of the controller does not require model of the controlled system. The controller is based on fuzzy rules which are set using knowledge about the controlled system. This knowledge base is obtained from experiences of similar group of the system or from experiments performed on the particular control system.

As well as most control schemes used to control inverted pendulum systems, the proposed fuzzy control scheme acts in two relatively independent phases:

- Swing-up of the pendulum from the stable equilibrium to the position close to upright position
- Control of the pendulum in the upright position

The second phase can be promoted to the task of the control of the cart position while keeping the pendulum in the upright position.

3.1   Swing-up

The fuzzy control scheme used to perform the swing-up of the pendulum is presented in the Figure 3.
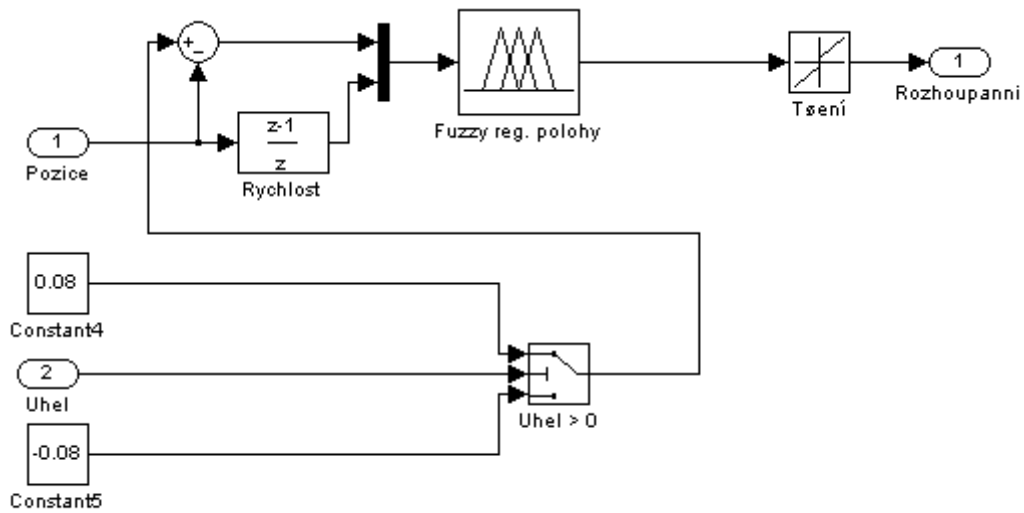
Figure 3: Simulink scheme of the swing-up of the pendulum

The control scheme is based on fuzzy control of the cart position. The set-point of the position is being changed according to the pendulum angle. The scheme adds energy to the pendulum and thus swings with increasing amplitude occur.

The scheme uses carriage position and pendulum angle as inputs and produces control voltage of the DC motor as its output.

3.2   Control in the upright position

The fuzzy control scheme used to control the cart position while keeping pendulum in the upright position is presented in the Figure 4.
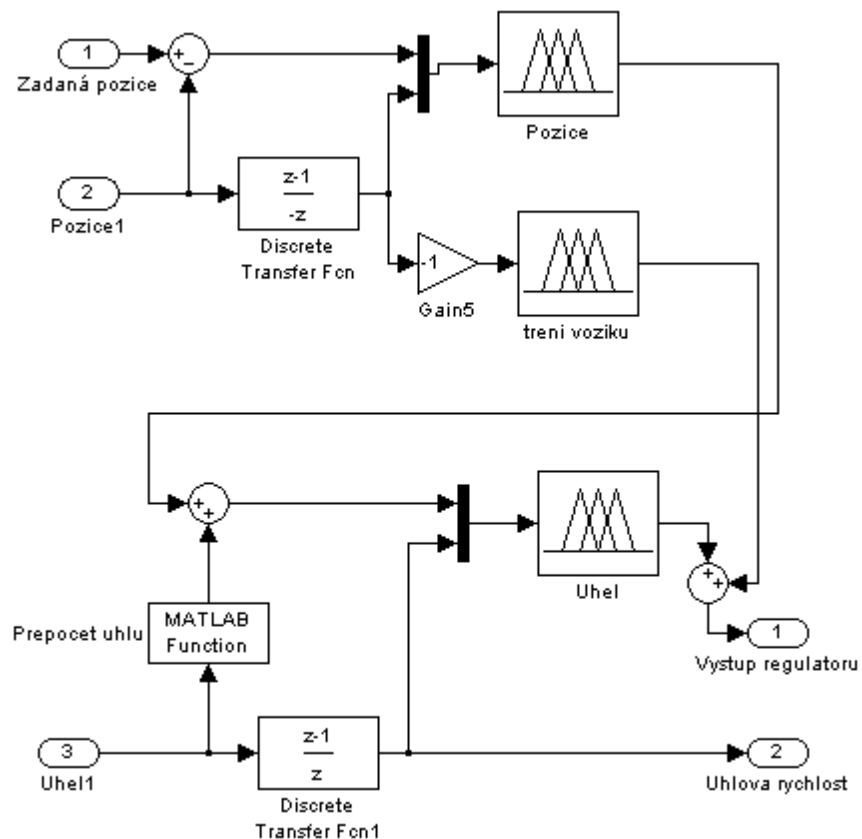

Figure 4: Scheme of control of carriage position

The control scheme consists of three fuzzy control blocks. The first one generates of the angle on base of carriage velocity and current control error - i.e. difference between desired and actual carriage position.

The next fuzzy control block is used to compensate friction between carriage and guiding bar. The output of this block is added to control signal produced by the third fuzzy control block.

The third and last fuzzy control block produces control voltage of the DC motor on the basis of angle velocity of the pendulum and difference between current pendulum angle and angle produced by the first fuzzy block.

3.3 Supervisory logic

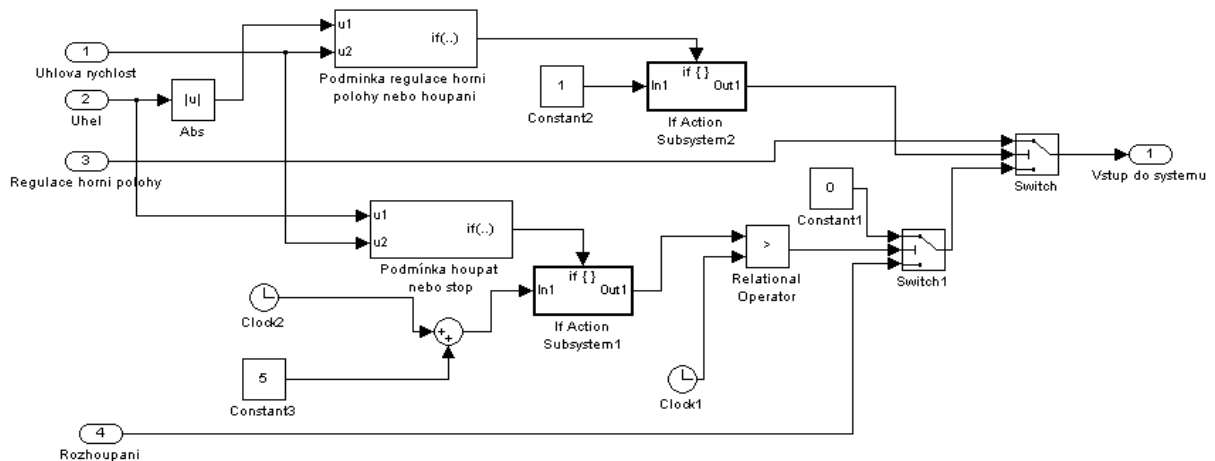The scheme of the supervisory logic is presented in Figure 5.

Figure 5: Supervisory logic

The supervisory logic is responsible for switching among three regimes of the whole control scheme:

- Swing-up

- Control of the cart position while keeping pendulum in upright position

- Idle

The Idle regime occurs when an external disturbance causes too fast rotations of the pendulum and thus the second regime is not able to catch the pendulum in the upright position. The carriage is not moved in the idle regime and the supervisory logic switches to swing-up regime after several seconds in the idle regime.

3.4 Complete control scheme

The whole control scheme is composed by interconnection of the control schemes described in the previous subchapters. The scheme is presented in the Figure 6.
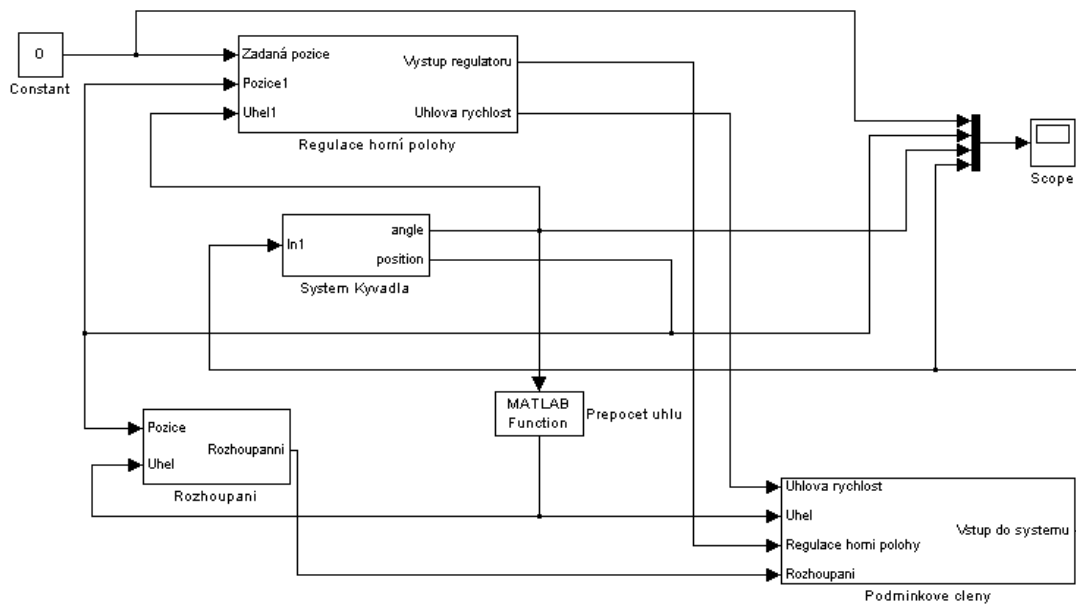
Figure 6: Complete control scheme

4   Real-time control

The connection between Simulink control schemes presented in the previous chapter and the Amira PS 600 system was realized by Real Time Toolbox and MF614 data acquisition board.

The tuning of individual fuzzy control blocks was quite complicated tasks because almost 40 fuzzy sets was defined and about 170 parameters had to be defined and set.

One of typical control courses is presented in the Figure 7.
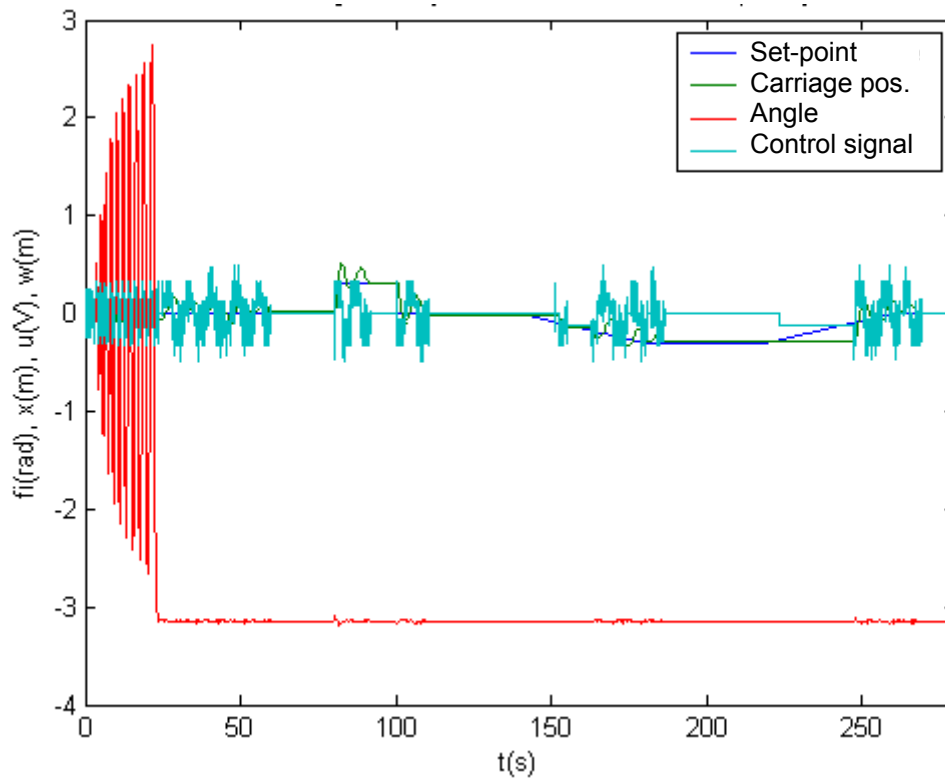

Figure 7: Control course

It can be seen that in the first approximately 25 seconds the swing-up is performed and then step and ramp is applied to the set-point. The controllers were able to reach zero control signal in the steady states. On the other hand a small steady state control error occurred as can be observed in Figure 8 which was obtained from the same control process.
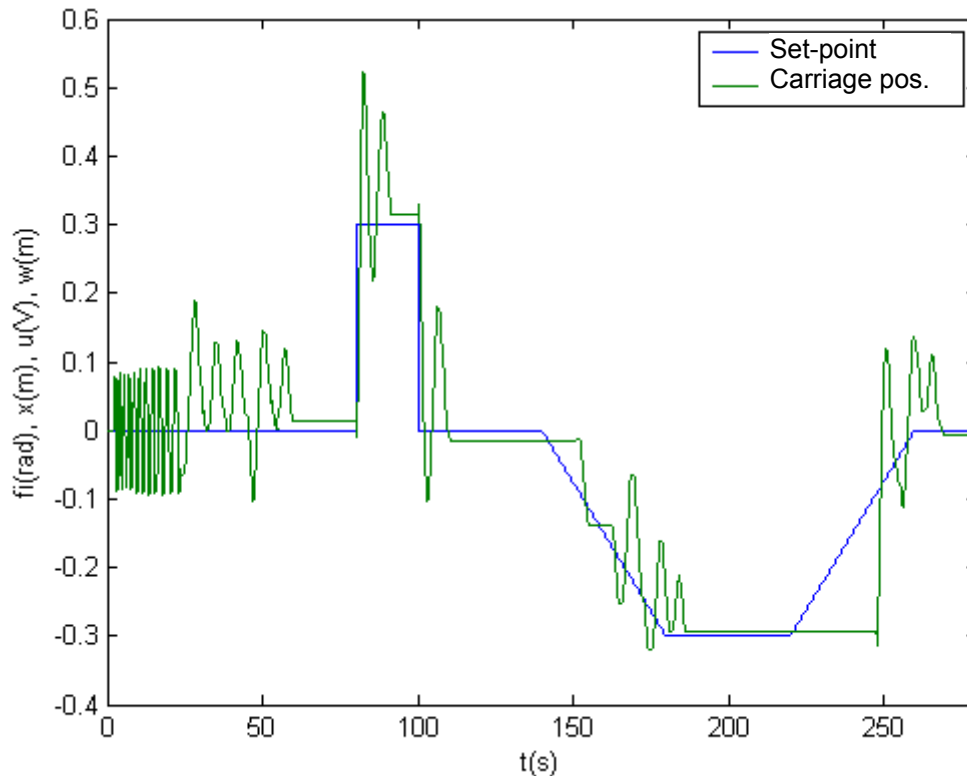

Figure 8: Courses of set-point and carriage position

These small control errors in steady states are caused by setting the fuzzy set for the zero control error. This set is has a triangular shape and contains not only zero but also values close to zero.

5   Conclusion

A fuzzy control scheme for control of the inverted pendulum system was proposed and verified in this paper. The aim of the control system is to track set-point of the carriage position while keeping pendulum in the upright position.

The control scheme consists of three relatively independent parts: swing-up controller, position controller with the pendulum angle constraint and the supervisory logic. The proposed control scheme is able to perform swing-up of the pendulum and is also able to cope with external disturbances.

The main shortcoming of the control scheme consists in small steady state control error.

6   Acknowledgements

References

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