STEPPER MOTOR DRIVEN INVERTED PENDULUM CONTROLLED BY MATLAB/SIMULINK

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Abstract

Mathematical modeling of scientific and technical problems is very suitable tool for analysis and design of real plants or devices. But there can appear many additional problems in construction of a real device which we are not able to consider in advance when we use only mathematical model. This paper shows shortly the design of Matlab/Simulink mathematical model of an inverted pendulum and construction of low-cost real device, controlled by Matlab/Simulink. Authors compare differences between theory and real plant and describe basic control system designed for real inverted pendulum.

1 Principles and ideas of an inverted pendulum plant

An inverted pendulum is well known problem usefull for example for education of classical automatic control theory. This example is theoretically described in [1].

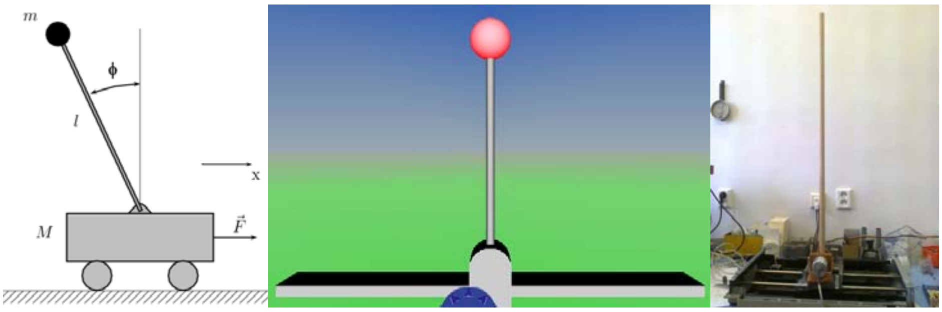

Figure 1: Drawing of principle of an inverted pendulum (left), Matlab/Simulink virutal reality model (middle) and photo of real plant (right)

2 Matlab/Simulink model of an inverted pendulum and its control

The basic model of inverted pendulum can be developed using the Newton laws of mechanics, for example as in [1]. When we simplify the situation by considering only small angular values, we can obtain mathematical model of the form

$$
\begin{aligned}
\dot{x}_1 &= x_2 \\
\dot{x}_2 &= x_1 g \frac{m+M}{Ml} - \frac{1}{Ml} u \\
\dot{x}_3 &= x_4 \\
\dot{x}_4 &= -x_1 \frac{mg}{M} + \frac{1}{M} u
\end{aligned}
\qquad (1)
$$

Where $x_1 = \varphi$ (pendulum angle), $x_2 = \dot{\varphi}$ (pendulum angular velocity), $x_3 = x$ (drive position), $x_4 = \dot{x}$ (drive speed). Physical parameters are defined as follows - m – mass of ball, M – mass of the drive, l – length of pendulum, g - standard gravity, u – actuating force. Mathematical model (1) can be easily reworked in Matlab/Simulink. Its easily possible to show, that system (1) is not stable (for example by computing of the eigenvalues of system). Classical following approach is the design of state feedback in order to stabilize the system (further in [1]). When we provide this stabilization of system using proportional state feedback, we can then control the system by simple PID controller. The result of such approach shows Figure 2.

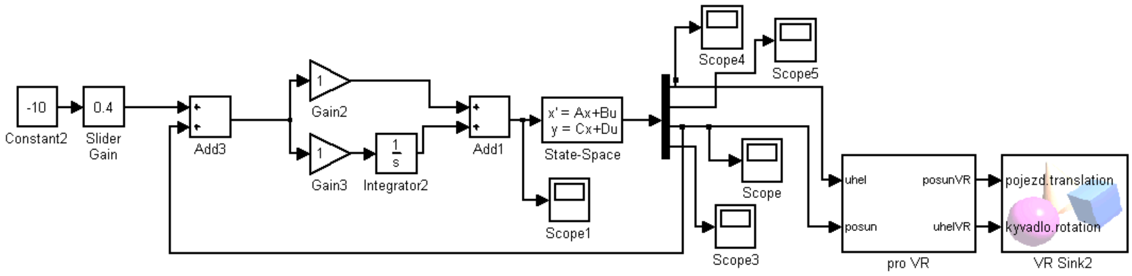

Figure 2: Matlab/Simulink model of inverted pendulum system with state feedback controlled by PI controller with virtual reality output.

3 Real design of a low-cost inverted pendulum plant

The very basic idea was to design a low-cost platform for real inverted pendulum plant. There was necessary to resolve several problems:

- construction of a drive
- construction of an accurate angular meter
- construction of a control system
- connection all above mentioned devices in one functional complex

In order to meet the targets (easy, low cost system) authors used old discarded HP scanner equipped with 2 coil stepper motor with cogged belt driven cart. There was only necessary to remove original control electronics and replace it with suitable stepper motor driver. This approach brought several problems – weak and slow engine and several clearances in the drive. In order to control the stepper motor there was developed a driver based on microcontroller Atmega32 and 2 H-bridges with possibility of continuous speed and direction change – see Chapter 5, Figure 3.

Accurate angular meter is based on industrial rotation magnetic quadrature encoder TRME-2. The measurement is based on a well known principle of detection of falling/rising signal edges in two rectangular, phase shifted signals. For details of the angle encoding/decoding see [2], for simplified detector circuit diagram see Chapter 5, Figure 4.

In the very first phase was control system designed as classical closed-loop circuit with parallel PD controller with a FIR filter. The control structure was implemented as a Matlab/Simulink circuit, wich allows us easily to modify it, use standard blocks, log data etc.

There was necessary to design a communication lines between the control computer, angular meter and stepper motor driver. In order to get experiences with various possibilities of data acquisitoin and control using Matlab/Simulink software is used for output signals (direction, speed) data acquisition card AD622. For transfer of data form angle decoder is used standard serial port of computer (RS232) – for simplified circuit diagram see Chapter 5, Figure 5.

4 Technical problems

There appeared two main problems. The first one was above mentioned control of small (thus weak and slow) available stepper motor. On the chosen platform it was not possible to improve its properties.

More difficult problem was quick and proper measurement of inverted pendulum angle. Authors provided several experiments with accurate potentiometers, but there were still several problems with signal processing – there was addiotional noise and also variable (time varying) offset, moreover the measurement of small angles using the potentiometers is complicted (thnik over the clearances in the mechanism and wear of the resistance track). Finally there was found ****

5 Real plant and its control

The real plant is driven by a 2 coil stepper motor. Thus we can consider simplification of equations (1), based on stepper motor behavior. When any stepper motor moves by that way, that it should (when the motor is not overloaded), position of the shaft is determined by numer of steps or number of impulses sent to the motor. In this case the dynamics of the drive can be neglected and the set of equations (1) can be simplified as follows:

$$J\ddot{\varphi} = mglx \tag{2}$$

where φ means angle of pendulum, J moment of inertia, m mass of pendulum, g standard gravity, l distance beween pendulum axis and center of mass of pendulum and x actuating quantity, here position. Its easily possible to show that this system can be succesfully controlled by PD controller. This approach was chosen as very first control principle for initial experiments, For final solution of individual parts of system see Figures 3-5.

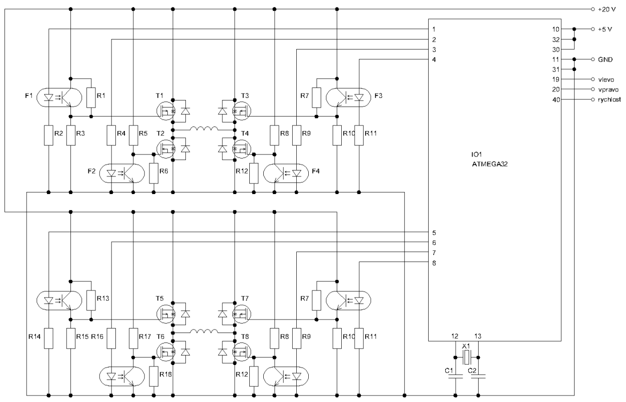

Figure 3: Circuit diagram of the stepper motor driver

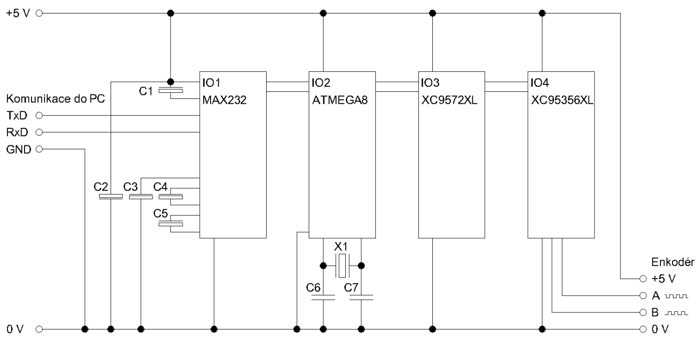

Figure 4: Angle meter circuit diagram

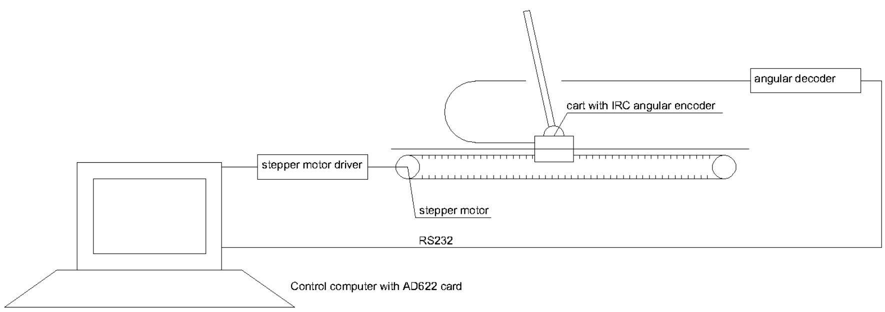

Figure 5: Block diagram of whole plant with control system

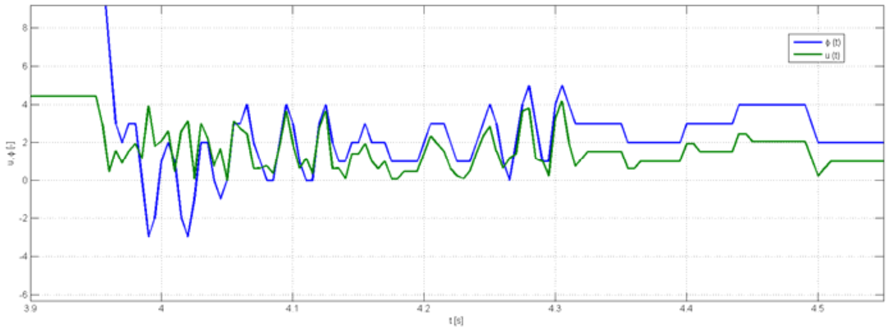

Figure 6: Succesfull PD controller angle control

6 Conclusions

Authors showed the idea of design of a real plant based on mathematical model, they showed also problems, that appeared just in the real construction. Authors showed succesfull control of an inverted pendulum using linear PD controller. The device will be used for education and experiments with advanced control principles, for example Kalman filter based control system with accelerometers.

7 Acknowledgement

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References

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[2] *IRCDEK2 - hradlové pole s implementovaným kvadraturním dekodérem.* EG Medical s r. o., Brno 2007.

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