DSP SYSTEM FOR ROTARY INVERTED PENDULUM CONTROL

Gabriel Vasile Iana[1], Georgeta Raluca IONESCU[2]
[1,2]University of Pitesti, ROMANIA
[1]gabriel.iana@upit.ro, [2]ionescu_raluca@yahoo.com

Keywords: stabilization, rotary inverted pendulum, PID

Abstract: *This paper describes the design and implementation of an inverted pendulum swinging in a circular trajectory. The system was designed for use in research and education engineering where many variations can be studied as control algorithms and digital signal processing. The evaluation is based on-board microcontroller family DsPIC33 specialized to implement DSP algorithms and motor control. Transmission position of pendulum to microsystem is realized by a magnetic rotary encoders. Controlling the position of the pendulum is achieved with a DC motor which is controlled by known PID algorithm trough a PWM signal.*

1. INTRODUCTION

Inverted pendulum control is one of the most interesting issues in the field of classical engineering. Uniqueness and widespread application of the technology derived from this system has attracted the interest of several researchers and worldwide robotics enthusiasts. In recent years, the idea of mobile inverted pendulum has been applied to various problems such as the design of humanoid robots and personal transportation systems [1], [2], [3].

Inverted Pendulum is, mechanically, like a pendulum of a clock, the difference between pendulum of a clock is the position where we want the pendulum to be stable. Inverted pendulum scope of the problem is that, by a force (energy) applied external to the pendulum, to make the pendulum to stand upright above, instead of falling down in the vertical position, that is its natural tendency. The force applied to the pendulum will be dependent on the two specific elements of the pendulum motion to the equilibrium position (down up) required: the angular position and the angular velocity of the pendulum. For the control of the inverted pendulum there are a variety of methods. These methods can be classified into three categories. The first category is presented by classical methods such as PID or PI controllers [4], [5] The second category consists of modern methods based on the optimum adaptation and the third category consists of methods that are based on artificial intelligence as fuzzy algorithms, genetic algorithm, neural network [6], [7].

From a practical point it is more complicated to be keeping vertical pendulum taking into consideration the forces of friction, pendulum bearings and linearity of the sensors.

In terms of hardware, the pendulum is controlled by a system that is based on a microcontroller specializes in motor control and it has a DSP processing core. The position of the arm and the pendulum is given by magnetic rotary encoders.

2. SYSTEM SETUP

Currently, the computing power of microcontrollers has grown considerably and was many more integrated peripheral circuits such as incremental coder, half bridge controller, PWM controller, synchronous and asynchronous serial ports communication which gives us the possibility to implement a cheaper solution for control systems without the needed complex systems with enhanced DSP processing capacity. They can be integrated into a system that can be programmed using different programming environments, from the programming at low level in assembly language to high level of programming using the C language, C # or visual environments such as MATLAB Simulink, hardware in loop (HIL). When it is desired a high power of calculation at high speed, can be used reconfigurable hardware structure as FPGA circuits. For selecting hardware and software structure it is necessary to care about cost, speed of processing and complexity of control algorithms.

The proposed system of rotary inverted pendulum is shown in Figure 1.

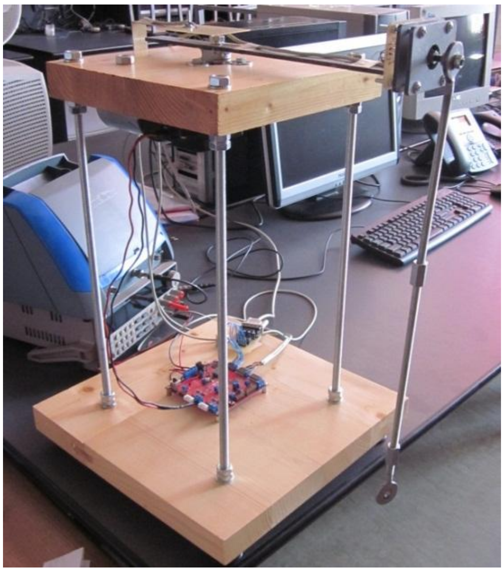

Fig. 1 Proposed of rotary inverted pendulum system

It is desirable that the system should be easy to handle by the students, but at the same time to provide a high diversity as in the application of algorithms in terms of software.

From the mechanical point of view, it consists of a pendulum attached to the end of a rotating arm and the opposite end of the arm is attached to the shaft of a DC motor. The arm is rotated in the horizontal plane and the pendulum is moving vertical plane and it always is perpendicular to the rotation of arm.

In terms of hardware the system has the configuration shown in Figure 2. Its configuration is based on a development board named CEREBOT MC7, two rotary magnetic encoder (sensor1 and sensor2) and a communication module (RS-232).

The development system is based on a DSP controller which ensures sufficient computing power to implement the control algorithms and additional has peripherals for communication with rotary magnetic encoders, respectively for command of c.c. engine that is moving the rotary pendulum arm.

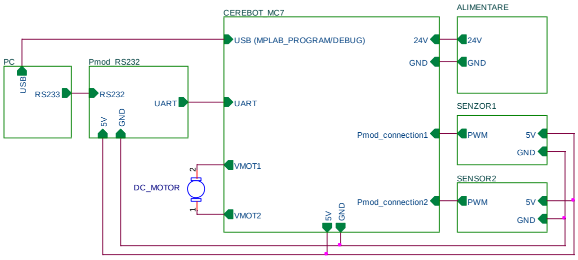

Fig. 2 Schematic bloc of rotary inverted pendulum system

From the functional point of view, the determination of arm and the pendulum angle α and β, figure 3, there are used two programmable rotary magnetic encoders that measure the angle that the magnetic flux generated by the neodymium magnets mounted on the arm and the pendulum. They can measure with a degree representing resolutions of 0.08 degree, which means 4096 positions per revolution. Mention that the sensors deliver a PWM signal with duty cycle proportional to the angle. The control algorithm is implemented on the controller signal. The controller reads the angles α and β from rotary magnetic sensor using two capture time modules. Depending on the read angles, the control algorithm provides a numerical value and the controller sends a PWM signal acting the DC motor. At the same time, the controller sends information angle on a serial port; data can be retrieved by a personal computer.

3. THE DYNAMIC MODEL

In this chapter are summarized ideal dynamic equations of the inverted pendulum. The pendulum can be rotated without a limit to horizontally arm, Figure 3. Horizontal arm can be overcome in horizontally plane from the left to the right a maximum of ±90 degrees to avoid wristed wires of the pendulum that connect an rotary magnetic encoder. This constraint is enforced by conditional instructions in the software without affecting the mathematical apparatus. Length L of the pendulum can be modified to be tested the control algorithm performance.

The equations that governing the simplified vertical pendulum from figure 3 are the following [5][7]:

$$\begin{cases} a\ddot{\theta} - b\ddot{\alpha}cos\alpha = cV_m - d\dot{\theta} - b\dot{\alpha}^2 \sin\alpha \\ -b\ddot{\theta}cos\alpha + e\ddot{\alpha} = fsin\alpha \end{cases} \quad (1)$$

where:

$$\begin{cases} a = J_{eq} + mr^2 + \eta_g K_g^2 J_m \\ b = mrL \\ c = \frac{\eta_m \eta_g K_t K_g}{R_a} \\ d = \frac{\eta_m \eta_g K_t K_g K_g^2}{R_a} + B_{eq} \\ e = J_B + mL^2 \\ f = mgL \end{cases} \quad (2)$$

And $\alpha, \dot{\alpha}, \ddot{\alpha}$ is the position, speed and acceleration of the pendulum and $\Theta, \dot{\Theta}, \ddot{\Theta}$ is the position, speed and acceleration of rotating arm in horizontal plane.

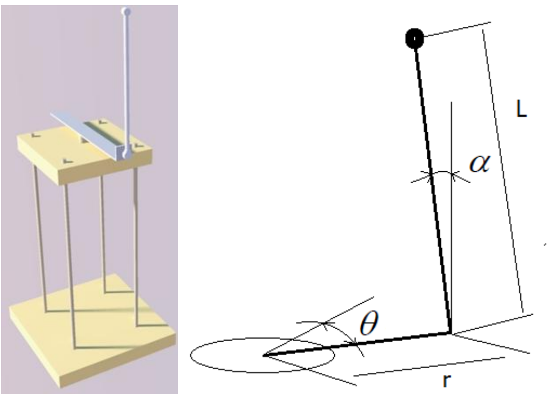

Fig. 3 Simplified model of rotary inverted pendulum system

Note that the equations of the inverted pendulum are strongly nonlinear. If all parameters are known, the equations can be linearized but in this system it supposed isn't know any parameter (viscosity frictions of rotating arm, friction between pendulum and rotating arm, etc.) excepting the angle of pendulum α and the angle of rotating arm Θ. Additionally there are more elements witch aren't specified in the equations. Practically, the implementation of control algorithm must replace all unknown elements but event linear and nonlinear elements arise from mechanical part of the system.

4. THE APPLICATION MODEL

To achieve the software control program of the pendulum is respected the following constrains:

- The values regarding at angle of pendulum, respectively the angle of rotating arm are obtained from a PWM signal generated by magnetic encoders.
- To maintain the inverted pendulum in balance, the angle of vertical arm of the pendulum should vary in ±15 degree interval.
- Before beginning the balance, the inverted pendulum is calibrated to determine the equilibrium angle of the magnetic flux from the magnet by vertical arm.

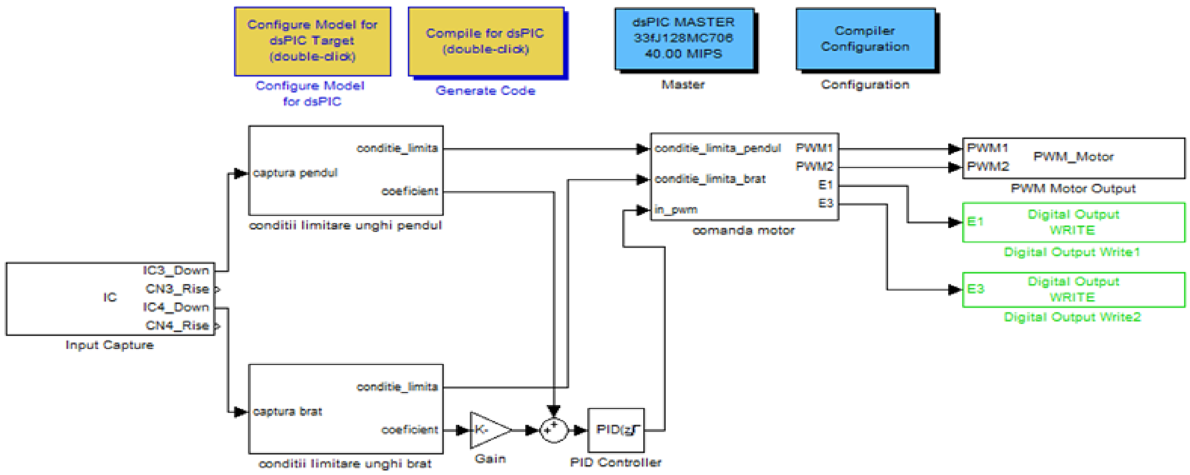

Fig.4. Simplified model of rotary inverted pendulum system

In this example, the control is performed by well-known PID algorithm. Vertical pendulum control scheme is given in Figure 4. Information regarding the angles is converted into numerical values by *capture time* block. This block takes the information from the two capture time modules for computing the angle of vertical arm, respectively from horizontal arm. The information about angles of pendulum is processed by the *pendulum limiting conditions* block where are set the maximum / minimum deviation angle of the pendulum from the equilibrium point. At out of these limits, practically, the system stops and isn't able to get him into balance position the pendulum. The block *limiting conditions arm* constrains the angle of horizontal arm to move in the range of ±90 degrees. If the horizontal arm deviate from the starting position deviates by an angle β, it adds to the angle of pendulum alpha proportional value of β so that the horizontal arm to oscillate around the initial position. *PID control* module is practical the control algorithm of vertical pendulum whose pendulum angle sum of input values α and a fraction of the horizontal arm angle β.

5. EXPERIMENTAL RESULTS

The performances of the control system have been validated experimentally. Coefficients of PID control algorithm for the optimal behavior of the pendulum were: kp = 20, kd=0.3, ki= 0.002.

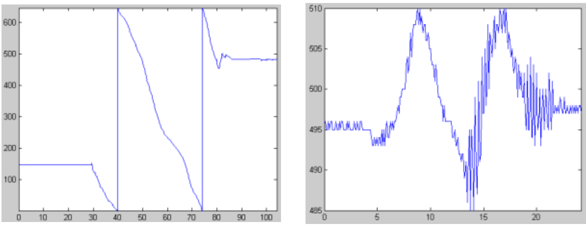

Fig.5.a) α angle at 360 degree rotation in time b) evolution of α angle while the pendulum is in equilibrium

In Figure 5.a. is made a rotation of 360 degree of pendulum to determine the magnetic sensor nonlinearity. In Figure 5.b. is plotted the evolution in time of α angle when the pendulum is kept in balance. The angles acquired from the magnetic sensor have an error of 0.1 degree.

6. CONCLUSIONS

In this paper was presented the achieving of a rotary pendulum system which is controlled by a DSP microcontroller. The control algorithm was developed on the well-known PID method taking into account the hardware constraints and nonlinearities introduced by the mobile arm bearings. In terms of software, the system is modular allowing a flexibility to modify them or the use of anther control algorithms.

The main contribution of this work is to design a control system of a rotating pendulum in terms of hardware that not only keeps the pendulum in the equilibrium position but may vary swearing a horizontal arm angle. The system described in this paper can be used in the preparation of academic science education to raise awareness, inspire and motivate students in this area.

7. REFERENCES

[1]. Mark, W. S., Daniel, J. B., "The Pendubot: A Mechatronic System for Control Research and Education", Proceedings of the 34th IEEE Conference on Decision and Control 1995, Vol. 1, pp. 555-556, Conference publications, 1995

[2] Shimada, A., "Movement control of two-wheeled inverted pendulum robots considering robustness", SICE Annual Conference 2008, pp. 3361-3366, Conference publication, 2008.

[3] Takey, T., "Baggage Transportation and Navigation by a Wheeled Inverted Pendulum Mobile Robot", IEEE Transactions on Industrial Electronics, vol. 56, pp. 3985-3994, IEEE Transations, 2009

[4] Sukontanakarn, V., and Parnichkun, M., "Real-time optimal control for rotary inverted pendulum", American Journal of Applied Sciences 6, 1106–1115, 2009

[5] Muskinja, N., Tovornik, B., "Swinging up and stabilization of a real inverted pendulum". IEEE Transaction Ind. Electron, pp. 631–6392006.

[6] Lee, Michael A., Takagi, Hideyuki, "Integrating Design Stages of Fuzzy Systems using Genetic Algorithms", Proc. of the 2nd Int'l Conf. on Fuzzy Systems (FUZZIEEE'93), Vol.1, pp. 612-617, 1993

[7] A. V. Duka, "Adaptation of a Fuzzy controller's scaling gains using genetic algorithms for balancing an inverted pendulum", Scientific bulletin of "Petru Maior", University of Targu Mures, Vol. 8 (XXV) no. 2, ISSN 1841-9267, , 2011