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APPLICATIONS OF ITERATIVE LEARNING CONTROL TEHNIQUES ON AN INVERTED PENDULUM SYSTEM

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Abstract: *The paper aims to apply the development and the implementation techniques of Iterative Learning Control structures on adjustment problems related to the "inverted-pendulum" system. The application has not been addressed so far in literature for experiments conducted on the "inverted pendulum" system laboratory equipment. Iterative Learning Control (ILC) differs from most control methods because it exploits every opportunity to incorporate information from the past: error or in some cases the input signal, to build the control action in the present.*
Key words: *algorithm, adjustment, controller, pendulum, signals*

1. INTRODUCTION

The use of Iterative Learning Control algorithm aims to improve performance of automatic control systems that perform a repeated operation. This can be found in many industrial production processes, robotics or chemistry, in which repetition is caused by mass production or assembly lines. The basic ideas of ILC have been formulated for the first time in a U.S. patent (Garden, 1971) and in a Japanese publication in 1978 (Uchiyama, 1978). Various tests were performed with ILC and concluded that ILC is truly a new method of control. In the first book dedicated to ILC due to Arimoto (Arimoto et al., 1984), has been used a derivative learning function (D) with continuous time. Proportional, derivative and proportional-derivative functions are the most used types of learning functions especially for nonlinear systems. Most known learning algorithms use linear functions ranging in time (Lee et al., 2000), (Moore et al., 2005), (Lee et al., 1997), and functions ranging according to the iteration j (Moore, 1993), (Owens & Rogers, 2004).

2. THE "INVERTED-PENDULUM" SYSTEM

The inverted-pendulum system consists of a pendulum mounted on a cart so that the pendulum can swing by itself vertically (fig. 2). The cart is driven by a DC motor. To oscillate or swing the pendulum, the cart is pushed back and forth on a track of limited length. Pendulum stationary positions (vertical or down) are equilibrium positions in which no force is applied. Generally, the problem is to bring the pendulum in one of the equilibrium positions. It is preferable to do this as soon as possible, with little vibration and without leaving the angle or the speed grow too much.

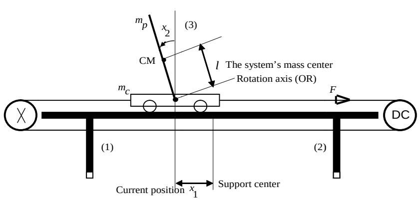

Fig. 1. Functional block diagram of the pendulum – cart system laboratory model

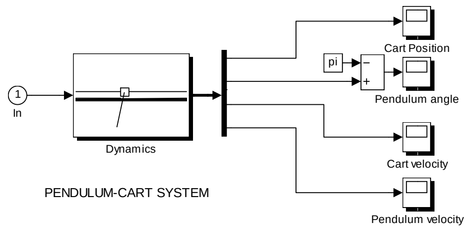

Fig. 2. Pendulum-cart's simulation model

The pendulum can rotate verticaly around the axis fixed on the cart. The cart is moving on a horizontal support (pair of rails) located in the plane of rotation. In fig.1, F, is the traction force (control force) applied on the cart. Cart's mass is m_c , and pendulum's mass is, m_p. The distance between the rotation axis (OR) and system's mass center (CM) is noted with l and system's inertia moment is denoted by J. The system's state is the column vector x=col (x_1, x_2, x_3, x_4) where: x_1 is the cart's position (distance from the support's center); x_2 is the angle between the upper position and the line that connects the mass center with the momentary position of the pendulum, measured counterclockwise reverse (x_2=0 for its upper position); x_3 is the cart's speed and x_4 is the angular velocity of the pendulum. The simulation model of the pendulum-cart system is shown through a Simulink function and is shown in fig.2.

3. REAL TIME CONTROL PENDULUM-CART SYSTEM DESIGNED USING PID REGULATORS WITH ILC

A proportional–integral–derivative controller (PID controller) is a generic control loop feedback mechanism (controller) widely used in industrial control systems; a PID is the most commonly used feedback controller. A PID controller calculates an "error" value as the difference between a measured process variable and a desired setpoint. The controller attempts to minimize the error by adjusting the process control inputs. It will therefore be considered the pendulum-cart system with two PID controllers (fig. 3), the first one to adjust the angle and the second one to adjust the position. Regulator's outputs are summed to achieve the final input (input U) for the digital-analog converter, acting on the cart's movement.

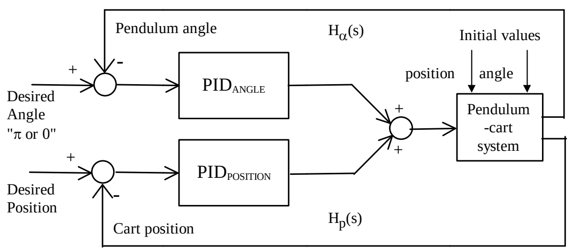

Fig. 3. The block diagram of the system with two PID control loops

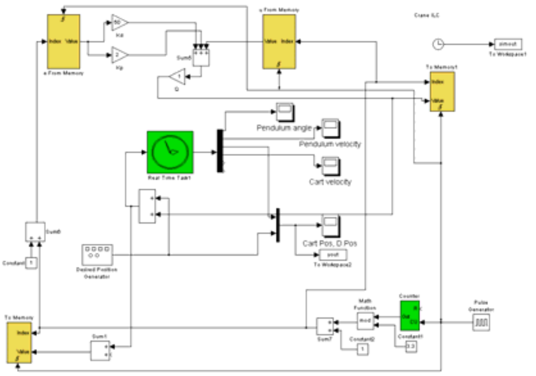

Fig. 4. External interface for real-mode system in Crane mode, with series ILC algorithm

Therefore we implemented the PID controller in the Crane method, optimized by using the ILC algorithm. "Crane control problem", described below, is the simplest control problem, in terms of number of input variables because its only one input. In this case the only objective pursued is to establish a reference for the cart's position, without the influence of other variables such as angular velocity or pendulum's angle. ILC can be combined with a conventional control structure in several ways: serial, parallel and with current iteration. In the Crane mode, was applied, the learning algorithm ILC in the serial version because in this situation the ILC contribution acts directly on the reference. The Simulink diagram of the controller is shown in fig. 4.

The output signal in fig. 4 is a vector containing the following elements: pendulum's angle, cart's position, angular velocity, cart's speed, cart's reference position, engine's control input.

The override is defined by the relationship (1):

$$\sigma = (Z_{max} - Z_{inf})/\Delta Z_{inf} \qquad (1)$$

It can be seen in fig.5 that time to reach maximum value, t_m, is 11.5 seconds and the adjustment time, t_r, is 12 seconds. So, the override in this case is 5.5%.

The values for the quality indicators calculated above, are characterizing the effect of introducing the ILC learning algorithm to adjust the inverted pendulum system.

To observe the contribution brought by the ILC algorithm, in fig. 6, is presented the variation of the two signals: the reference (the input) and cart's position (the output), without applying ILC algorithm.

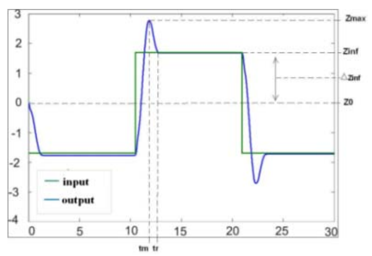

Fig. 5. Temporal variation of the reference and of cart's position after using the ILC algorithm

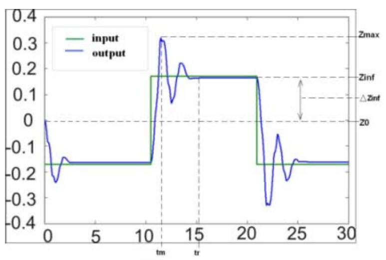

Fig. 6. Temporal variation of the reference and of cart's position without using the ILC algorithm

As it can be seen in fig. 6, the override does not increase very much from the case when we included the ILC algorithm, but the adjustment time t_r, is clearly bigger, going over 15 seconds.

4. CONCLUSION

The use of the ILC algorithm brings a clear improvement over the situation presented in fig.6. ILC learning algorithm leads to improved empirical quality indicators and the override decreases during iterations, but the disadvantage is that must be completed several iterations to achieve this performance. A notable advantage of the ILC algorithm is that it does not require a mathematical modelation of the process on which is implemented. This has significance both for the specific process but also in general, because there are many processes whose mathematical models are very difficult if not impossible to determin. The use of the ILC method on the presented system allows the author to outline the simplicity in which the method can be applied on a process. The contents of this paper aimed to provide the reader an insight into important ideas, potential and limits of the ILC algorithm.

In conclusion, the results of the experiment conducted in this paper, respond to the question "Why using ILC?". Answers should be: ILC seeks exit using facilities without any knowledge about the system's state, it has a simple structure (integration along the iteration axis), it is a learning process based on memorizing (requires to remember the error signals or input signals across the whole period of time), requires little information about the process, actually is almost a model independent method and this is a special feature in implementation and finally the reference must be the same for all iterations.

Indeed, the early results of the ILC include many results and learning algorithms which exceed this exposure. Although is the beginning of the third decade of active research and the ILC field does not show any sign of a slowdown. The results are encouraging, especially since the chosen process is a complex one because of the oscillating character and of the shown nonlinearities.

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