DESIGN AND SIMULATION AN OBSERVER-BASED CONTROLLER FOR NONLINEAR SYSTEM BASED FEEDBACK LINEARIZATION

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Abstarct: In nonlinear systems, using a conventional controller cannot improve the system behaviors with an acceptable accuracy. Therefore, to meet a specified specifications modification in system structure and in controllers must be done. In this paper an adaptive approach (e.g. Linear Quadratic Optimal State Estimator Integral Control [LQOSEIC]) is used in such a way to make a linearized system model that operate as a model reference for the nonlinear system and provides the best performance for the nonlinear system.

Key word: Nonlinear system, Linearized system, PID controller, LQR, Integral control, Observer.

I. INTRODUCTION

Control of nonlinear system is an important task. nonlinear systems are usually difficult to be treated mathematically, and there are no general methods available for predicting their behaviors, nor there are systematic procedures for designing nonlinear control system. Most of the real physical systems inherent nonlinear behavior, but some of those behaviors are close to an equilibrium point that can be approximated by a linearized model, if the operating range is small, and involves smooth nonlinearities [1,2]. To design nonlinear control systems, it is practical first to design the controller based on the linear system model. The designed controller is then applied to the nonlinear system for evaluation or redesigning by computer simulation [3,4].

II. DESCRIPTION OF THE PHYSICAL SYSTEM

The process used in this paper is the Cart-Pole System (CPS) . The cart-pole control problem is the same as trying to balance a broom handle on your fingertip. The plant includes five parts. They are pole, cart, track, motor and sensors[4,5]. The system is shown as Figure1.

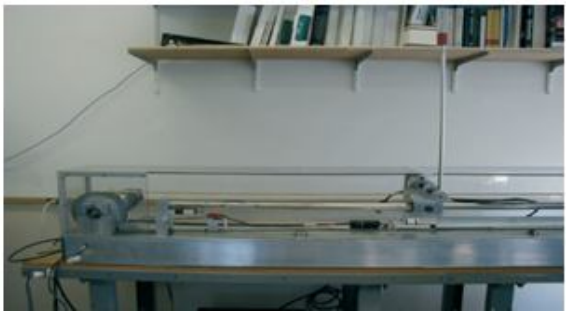


Figure 1: The real cart-pole system (cps)

2-1 Dynamic Equations Of The Nonlinear Plant

The CPS is an inherently nonlinear, single input multi output (SIMO) and unstable open-loop system. It is a suitable process to test prototype controllers due to its high nonlinearity and lack of stability. This means that standard linear techniques cannot model and control of the nonlinear system (CPS). The system dynamical equations will be derived using Lagrange Equations. Using this method, it is possible to derive dynamical system equations for a complicated mechanical system such as the CPS [5].

Nonlinear dynamic model of this system is given by the following equations: -

$$(M+m)\ddot{x} - ml\dot{\theta}^2 \sin\theta + ml\ddot{\theta}\cos\theta = f \ ,$$

$$m\ddot{x}\cos\theta + ml\ddot{\theta} - mg\sin\theta = 0$$

M: Mass of the cart
m: mass of the pole
l: length of the pole
g: acceleration of gravity

θ: rod angle
$\dot{\theta}$: rod angle velocity

f: control force
x: cart position
$\dot{x}$: cart velocity

2-2 Simulink Case Study

In the previous stage, a set of equations describing the plant has been developed. In this stage a Simulink model of the nonlinear plant is constructed. Figure 2 shows the Simulink model block of CPS.

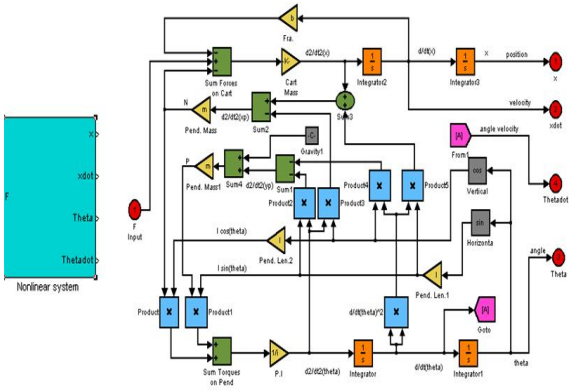
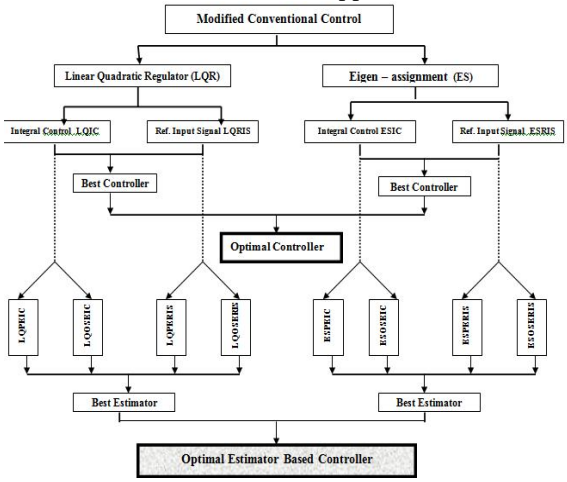


Figure 2 : Simulink model of the nonlinear system (CPS)

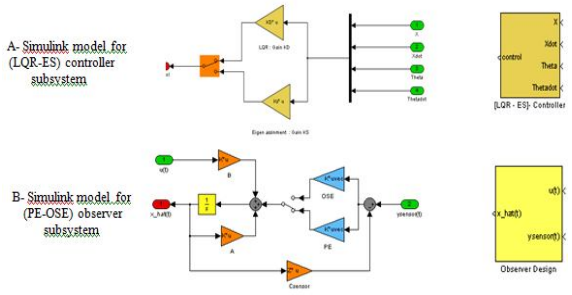
III. DESIGN OF A MODIFIED CONVENTIONAL CONTROLLER

Since the conventional controllers such a PID can not improve the nonlinear system behavior and will not be able to lead the system to an acceptable accuracy. Therefore the following modifications can applied to design a modified controllers. Figure 3, shows the required steps for designing the modified controllers. Starting from conventional controllers the modification considering Linear Quadric Regulator (LQR) is applied as well as the Eigen Assignment (ES) control method. Then using the Integral Control (IC) and Reference Input Signal (RIS) for both mentioned methods , that results the (LQRIC, LQRIS, ESIC and ESRIS).These controllers are valid if all the system states are available. If not, as in our case study, the observer-based controller must be designed using Optimal State Estimation(OSE) and Place Estimation(PE) methods to produce (LQOSEIC, LQPERIS,ESOSEIC, ESPERIS……). From above modifications applied on the system, the best control based estimator are found and applied[6,7].



IV. SIMULINK MODEL OF OBSERVER-BASED CONTROLLER

Figure 4, shows Simulink model for the observer-based controller subsystem. In this paper another technique will be used as shown in Figure 5. This figure show the mechanism of how to use the linearized system operates as a model reference to the nonlinear system. It is connected in parallel across linearized system and original nonlinear system to provide that they behave in the same way [8].



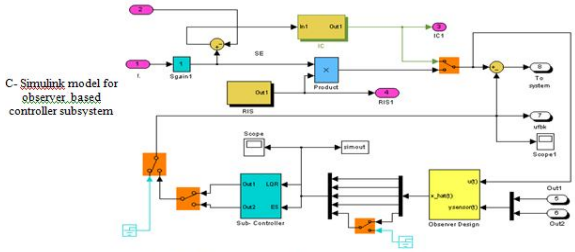


Figure 4: Design steps of the observer based-controller

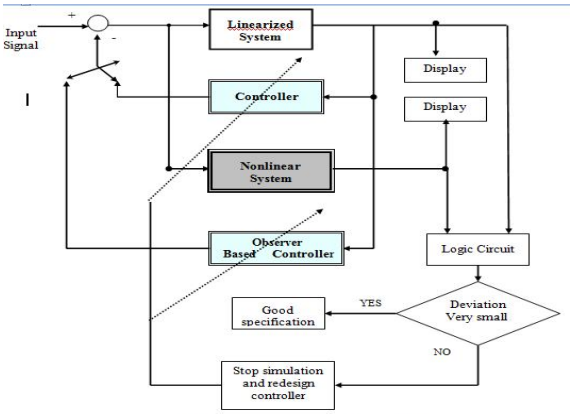


Figure 5 : Block diagram of linearized and nonlinear control systems

V. SYSTEM SIMULATION

In this section, a simulation of nonlinear system is demonstrated using Simulink and Matlab code programs to show the effects of using different controllers and choose the optimal controller among them. A step function is used as an exciting signal. Figures(6,7,8,9) implementing the Simulink model of ESOSERIS,ESOSEIC,LQOSERIS and LQOSEIC with nonlinear system.

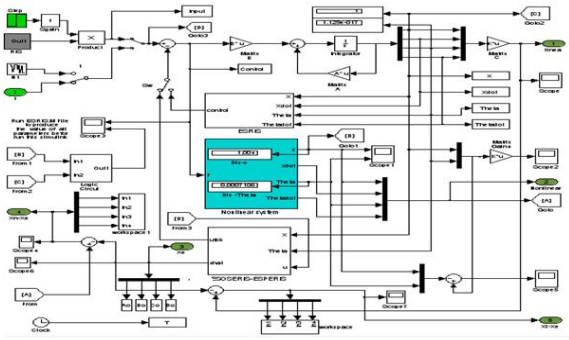


Figure 6 : Simulink model implementing ESOSERIS controller

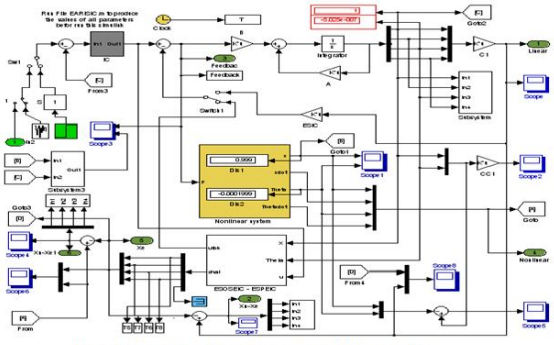


Figure 7 : Simulink model implementing ESOSEIC controller

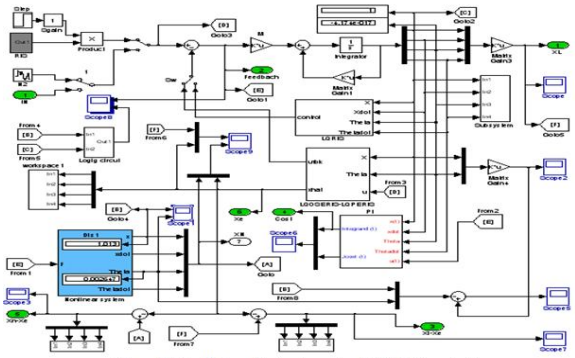


Figure 8 : Simulink model implementing LQOSERIS controller

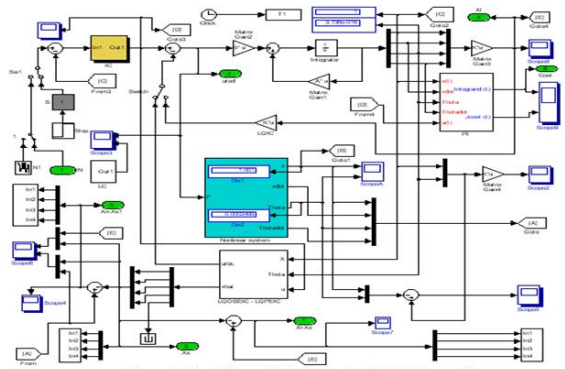


Figure 9 : Simulink model implementing LQOSEIC controller

VI. SIMULATION RESULTS

I- Step Response of States System

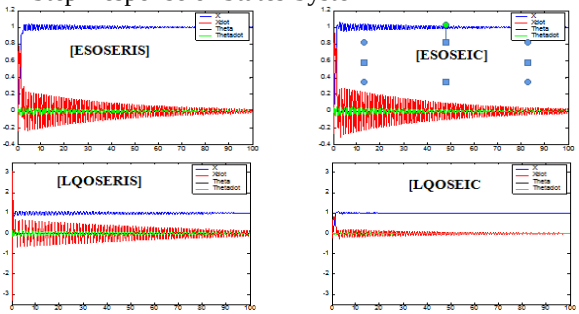


Figure 10: Simulation results using observers- based controllers

II- Estimated Error States

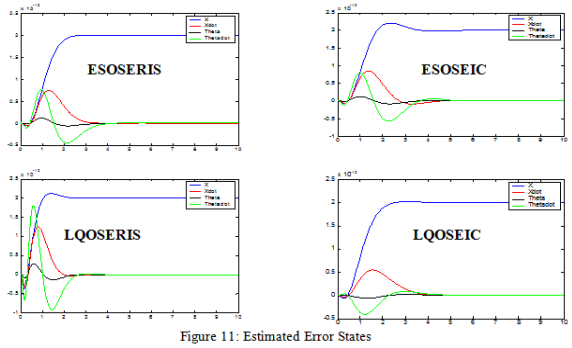


Figure 11: Estimated Error States

III- Minimum Time Problem and Tracking Problem

Minimum Time Problems (MTP): How to transfer a system from an arbitrary initial state $x(t_o) = x_o$ to a specified target set S in minimum time .The performance measure to be minimized is $J = t_f - t_o$, with t_f the first instant of time when x (t) and S intersect.

2- Tracking Problems(TP): How to maintain the system state x(t) as close as possible to desired state r(t) in the interval $[\, t_o , t_f \,]$.

Figures(10,11) show the effects of change of types controllers on the behavior of the plant output .Table 1 display the performance (MTP,TP) for linearized and nonlinear system. This resulted converted into area plot in Figure(12).

Table 1: MTP and TP for linearized and nonlinear system based estimator based-controller

State	MTP				TP			
	ESOSERIS	ESOSEIC	LQOSERIS	LQOSEIC	ESOSERIS	ESOSEIC	LQOSERIS	LQOSEIC
Linearized System								
X m	3	3.5	1.25	1.25	0.045	0.18	0.07	0.009
Theta rad	2	3	1.25	1.3	0.08	0.3	0.06	0.012
Nonlinear System								
X m	3.5	4	1.5	1.25	0.26	0.5	0.13	0.03
Theta rad	1.75	2	0.75	0.71	0.11	0.17	0.05	0.006

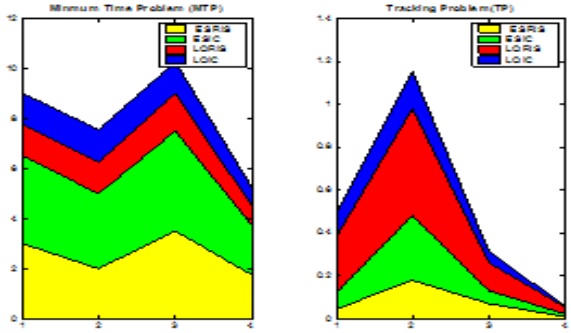


Figure 12: Performance area plot

IV- Regulator Problem (RP) and Mean Square Error (MSE)

A regulator problem is the special case of a tracking problem which results when the desired state values are zero [r(t) = 0] for all $t \in [t_o , t_f]$. But the MSE is the average square error between the desired point and actual output. Table 2 display the performance (RP,MSEP) for linearized and nonlinear system. This resulted converted into area plot in Figure(13) .

Table 2 : RP and MSE for linearized and nonlinear system based estimator based-controller

State	Regulator Problem (RP)				Mean Square Error (MSE)			
	ESOSERIS	ESOSEIC	LQOSERIS	LQOSEIC	ESOSERIS	ESOSEIC	LQOSERIS	LQOSEIC
X	1.0E-4	7.5E-3	1.0E-5	7.5E-6	2.84E-4	6.1E-4	7.6E-4	2.0E-4
Theta	1.2E-5	1.11E-5	5.3E-6	1.3E-6	9.6E-6	1.85E-5	3.3E-5	6.6E-6

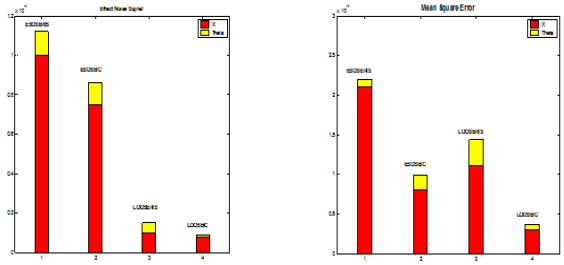


Figure 13: PR and MSE area plot

CONCLUSION

In this paper, nonlinear system behaviors are investigated and improved, A nonlinear controller for the nonlinear system based on the approximate linearization technique is designed. Applying modified conventional controllers such as LQOSERIS, LQOSEIC, ESOSERIS and ESOSEIC to relative the linearized system as a reference model for the nonlinear system showed acceptable performance. Simulated results showed the effects of changing the controller types on the behavior of the nonlinear system outputs. From which it is clear that the optimal Estimator-Based Controller for nonlinear system is [LQOSEIC] provides best performance of the nonlinear system.

REFERENCES

[1] W. K. Pang , Nonlinear Dynamical Control Systems, Dep. of Electrical Engineering, University of Queensland, (2003).

[2] UC Berkeley, A. Packard, Jacobian Linearizations, Equilibrium Points, Lecture Notes,2004.

[3] Abougarir A., Design And Simulation of Adaptive Controller for Nonlinear System Using Artificial Neural Network, M.Sc Thesis, Alfateh University, (2006).

[4] Jean-Jacques E., Applied nonlinear Control, Slotine (1991)

[5] R. Q. Escalante, Identification of a Nonlinear Forced Pendulum, M.Sc In Control Systems, Virginia University, USA, (2003).

[6] Linear Quadratic Regulator (LQR) State Feedback Design EE 4343/5329 - Control System Design Project, Lecture 11, (2000).

[7] Prof. Donald E. Kirk: Optimal Control Theory, Naval Postgraduate School, Monterey, California, USA. Prentice Hall Inc.(1980)

[8] El-Bakush M., Lectures Slides on Nonlinear Systems and Adaptive Control,(Fall - 2005).

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