CONTROL AND STABILIZATION OF AN INVERTED PENDULUM USING GA BASED CONTROLLER

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ABSTRACT

One of an important aspect in the field of control system is stability. It becomes challenging for a nonlinear system like inverted pendulum. The inverted pendulum stabilizing is a problem inside control system. The most commonly used control method is the PID controller. For stabilizing the inverted pendulum, many researchers use various design techniques. In this article, the genetic algorithm technique is used to control the inverted pendulum and the output is compared with the conventional proportional integral derivative controller. The performance of controllers is determined by simulation.

Keywords: Inverted Pendulum, Modeling, PID Controller, Genetic Algorithm


1. INTRODUCTION

Control theory is an area that leads to an automatic decision process. In these fields of control theory, it is a great platform for all the researchers [1] and also it is a good criterion for testing system control problems [2].

An inverted pendulum is a pendulum whose center of the mass above its pivot point. The system is unstable, uncertainty. The system is under-actuated. This makes the system cost effective. Most uncertainties are because of model uncertainty, transmission error. In real
control, these uncertainties are reduced by controlling the errors. The transfer function of inverted pendulum will affect the stability margins. It has two equilibrium states. In the stable state, the pendulum is vertically downwards. In unstable state, the pendulum is in upwards [3]. So even the slightest disturbance cause the pendulum to fall. Therefore some sort of control is needed.

The dynamic equations of the inverted pendulum consist of non-linear terms. So the inverted pendulums are nonlinear systems. It constitutes a pole pivoted on a cart. The objective of the inverted pendulum is fluctuate the pendulum from the down to the up state [4, 5]. It is a SIMO (single input multiple outputs) system. The input is the force applies to the cart and the two output are the position of the cart and angle of the pendulum [8].

![Figure 1 Inverted Pendulum System](image1)

2. MATHEMATICAL ANALYSIS
The inverted pendulum system model is shown in figure 2. In this model, first, imagine the rod is massless. The cart mass is denoted as M and the point mass is denoted as m. The angle is defined as $\theta$. The force applied to the system is $u$ and $l$ are the rod length.

![Figure 2 Inverted Pendulum System Analysis](image2)
According to Newton's law, force is equal to the product of mass and acceleration. Summing the forces in the horizontal direction gives

$$M \frac{d^2x}{dt^2} + m \frac{d^2x_G}{dt^2} = u$$  

(1)

For the point mass

$$x_G = x + lsin\Theta$$ and $$y_G = lcos\Theta$$  

(2)

Substitute equation (2) in (1) gives

$$(M+m)\ddot{x} - mlsin\Theta \dot{\Theta}^2 + mlcos\Theta \dot{\Theta} = u$$  

(3)

In the same manner, perform a torque balance.

The torque can be

$$(F_x\cos\Theta) - (F_y\sin\Theta) = (mgsin\Theta)l$$  

(4)

Where  $$F_x = m \frac{d^2x}{dt^2}$$ and $$F_y = m \frac{d^2y}{dt^2}$$

$$F_x = m \frac{d^2x}{dt^2} = m[l\dot{x}sin\Theta - 2 + 4cos\Theta -]$$  

$$F_y = m \frac{d^2y}{dt^2} = -m[4cos\Theta - + lsin\Theta -]$$

After calculating equation (4) by putting $$F_x$$ and $$F_y$$ gives

$$mx\cos\Theta + ml\dot{\Theta} = mg\sin\Theta$$  

(5)

The cart position and pendulum angle dynamics will be obtained by manipulating above two equations. The equations are

$$\ddot{x} = \frac{u + ml(sin\Theta)^2 - mg\cos\sin}{M + m - mc^2}$$  

(6)

$$\dot{\Theta} = \frac{uco - (M + m)gsin\Theta + ml(cos\sin\Theta)}{mlcos\Theta - (M + m)^2}$$  

(7)

These two equations represent the mathematical form of nonlinear inverted pendulum system.

3. EXISTING SYSTEM

In existing method, the inverted pendulum control was achieved by control techniques like PID controller, fuzzy logic, and ANFIS. The proportional integral derivative control is an efficient controller. It can control steady state and transient response. ANFIS integrates both fuzzy logic control and neural networks [9]. The fuzzy logic controller is a very good option for inverted pendulum. The methods are then compared in terms of three factors. They are settling time, overshoot and error. In the proposed work, instead of intelligent controllers, the optimization techniques are used to control the inverted pendulum.

3.1. Proposed system

In proposed method, controller is tuned using the genetic algorithm and is used for controlling the inverted pendulum. The controller is then designed for the stabilization and errors.

3.2. Genetic Algorithm

A genetic algorithm is an algorithm applied to different fields like business, science, and technology. It is based on natural selection and natural genetic. It has the capability to locate high-performance areas. Genetic algorithm is more computationally efficient as compared to other optimization techniques [10] because

- It use probabilistic transition rules
- It does not require derivative information.
- It works on encoding parameter sets.
- Good parallel capabilities
- Provides a list of good solutions
• Optimizes both continuous and discrete functions.

The simplest structure of genetic algorithm comprises three types of operators. They are
• Selection operators
• Crossover operators
• Mutation operators

A selection operator selects chromosomes reproduction. Selection procedures can be mainly divided into two. They are
  1. Fitness Proportionate Selection
  2. Ordinal Selection

After selection, individuals are combined to create a new offspring. Crossover operator chooses a locus. It is a powerful tool to introduce new genetic material and for maintaining genetic diversity. The crossover operator mimics the biological recombination between two haploid organisms. The most commonly used crossover operators are
  a) Cycle Crossover
  b) Davis’ Order Crossover
  c) Partially Matched Crossover

Mutation operator flips some bits in a chromosome. The most common mutation is the bit-flip mutation. Swap mutation is common in permutation based encodings. The algorithm will converge to a local minimum, if the selection and crossover operators are used without mutation operator. Therefore by using all the three operators together can the genetic algorithm become a noise-tolerant algorithm. The flowchart of the genetic algorithm is shown below.

![Flowchart of Genetic Algorithm](image)

**Figure 3 Flow Process in Genetic Algorithm**

The process begins with a set of solutions. This process is initialization and then followed by selection which means choosing random solutions. There are two methods for initialize the population and they are random initialization and heuristic initialization. The diversity of the population should be maintained. The population size should not be very large. Therefore, an optimal population size needs to be decided. Parent solutions are selected to form new offspring. This process will stop when a stopping criterion is reached [11]. The terminating conditions are;
• A solution is found which satisfies minimum criteria
• Fixed number of generations reached
• Allocated budget reached
• Manual inspection
The genetic algorithm differs from the classical algorithm in mainly two factors. They are
• Classical algorithm develops a single point at every repetition.
• The classical algorithm chooses the next point in the sequence.

4. PID CONTROL
The PID controller is the most common controller in control system. Most of the feedback loops are based on PID control. The output of the PID controller is the sum of Proportional, integral and derivative terms [12].

A PID controller calculates an error value. An important problem arising from the ideal PID implementations is the integral windup. Integral windup is also called integrator windup or reset windup. The integral terms accumulate the error during the windup. The figure below shows the schematic diagram of a feedback control system.

![Feedback Control System](image)

Figure 4 Feedback Control System

To control the cart, a PID controller is needed. The final equation for the PID control is given by [13]

\[ u = K_p e + K_i \int e(t) dt + K_d \frac{de}{dt} \]

Where \( K_p, K_i, \) and \( K_d \) are the parameters
\( e(t) \) is error
\( u \) is the control signal

The pendulum angle and cart position will get affect, if there is any change in controller parameters. The tuning of control parameters is done by observing the Simulink model [4].

5. RESULTS
The behavior of the system is simulated in MATLAB, using the transfer function. To visualize the response of the system, the PID controller is simulated in MATLAB. It is a high-performance language for computing and is used for matrix manipulations and interfacing the programs written in other languages. It consists of a development environment and the mathematical function library. Simulink can work directly with nonlinear equations. So there is no need to linearize the equations. Simulink is a block diagram environment for simulation and design. It is mainly used for simulation, automatic code generation and verification of embedded systems. It is integrated with MATLAB to incorporate algorithms into models and for analysis export results to MATLAB. The inverted pendulum model is shown below.
The system response for $K_p = 100$, $K_i = 0$ & $K_d = 0$ is shown in figure 8 that represents a oscillatory system with faster response. Further increase of $K_p$ value makes the response more oscillatory. So, the $K_p$ value is tuned at 100.
After tuning the value of $K_p$, derivative gain $K_d$ is tuned to one to reduce overshoot as well as settling time.

Then increase the $K_d$ value to 20. The complete PID tuning is $K_p = 100$, $K_i = 1$ & $K_d = 20$. Figure below illustrates the response.

Figure 10 System Response with $K_p = 100$, $K_i = 1$ & $K_d = 0$
The system response, for $K_p = 100$, $K_i = 1$ & $K_d = 20$ represents a stable system. The figure below shows the genetic algorithm- proportional integral derivative controller.

![System with Genetic algorithm-PID Controller](image1.png)

**Figure 11** System with Genetic algorithm-PID Controller

Genetic algorithm-proportional integral derivative controller is developed using m-file in MATLAB by writing a program. This will reduce an objective function.

![Step Response](image2.png)

**Figure 12** Genetic Algorithm - PID Controller of Angle

6. CONCLUSION
The objective of this work is to control an inverted pendulum using the genetic algorithm. The use of Genetic Algorithms offers several advantages like in the case of decrease in overshoot percentage, increase in the settling times. The result is compared with the conventional PID controller. The Genetic Algorithms has proved better when compared to conventional tuning parameters.
REFERENCES


