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# Hybrid Flower Pollination and Particle Swarm Controller for Stabilization of Double Inverted Pendulum with Time Delays

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Abstract: A novel hybrid controller designed with the combination of a particle swarm and flower pollination is proposed in this paper. This paper envisages the impact of time delay and investigates method to mitigate the effect of time delay for the stabilization of the pendulum. The pendulums are stabilized under the influence of time delay taking into consideration a fitness function which is the resultant function of constraints and seeing the performance differences with and without time delays. The obtained results are compared with a standard linear quadratic controller performance and it is observed in all the cases the control effort taken for stabilizing the system is lesser with the hybrid algorithm when compared to the standard LQR which is definitely a novel solution to the class of pendulum systems wherein it indicates that it is better to use the hybrid algorithm when compared to solving the algebraic ricatti equation when the system is under the influence of time delays.

***Keywords:*** Time delay, Flower pollination, Double inverted pendulum, particle swarm optimization, stabilization

## 1. INTRODUCTION

The classical pendulum problems dates back to the broomstick balancing on the palm and its origin probably being the Indianmagician's rope trick where a rope is made to stand in thin air without any support. Double Inverted Pendulum (DIP) is a basic control plant model with typical applications in the field of robotic manipulator design and in systems like segway transport which use various levels of dynamic systems. The under actuated model by itself is a model for analyzing complex dynamic systems of higher order. It could be used as a test bed for humanoid robots where the leg movement and walking can be interpreted using this plant model.

Srikanth et al [1] have investigated the classical and neural network techniques for the system identification and the control of the pendulum system about the upright equilibrium position. Sivanandam [2] has highlighted the control of the inverted pendulum using fuzzy logic and also have developed methods for studies on time delays. Amit[3] has elaborated on the algorithms that are existing such as the particle swarm optimization for the systems which are classified under computational intelligence techniques. Srikanth et al [4] have developed meta-heuristic methods like the BAT algorithm for the control of the pendulum systems. Makappati et al [5] have developed methods for the inclusion of time delay as an integrated state space variable in their work.

Flower pollination is a nature inspired algorithm which has emphasis on a single objective unconstrained optimization[6]. The story of evolution of various flowering plants is an example by itself on indicating the efficiency of the evolutionary process. Yang[7] has clearly developed and outlined the advantages based on how pollen gets transferred which becomes the approach for the development of the algorithm. Authors [8][9] have studied the impact of time delays for the pendulum type systems.

However, this work presents a novel hybrid algorithm applied to the double inverted pendulum model with integrated time delays into the system matrix based on the studies of [1] to [9]. The proposed

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algorithm uses a combination of flower pollination and particle swarm utilized for the stabilization of the two pendulums about the upright unstable equilibrium position.

## 2. PLANT DYNAMICS AND IMPLICATIONS DUE TO TIME DELAY

The plant that needs to be controlled can be represented as depicted in figure 1, and with the dynamics of inverted pendulum taken from the authors work as in [1]. The plant model is derived from the Newtonian Physics yielding the Euler Lagrangian equations. The torque acts as the only control input. Based on the linearized system model , the two pendulums are to be stabilized over the unstable upright equilibrium position. The case study here would involve the particular condition that the pendulum is in the vicinity of the upright equilibrium and is then tried to be stabilized. So, the initial condition is around five degrees of variation about the upright equilibrium position for the pendulum.

The plant model of the integrated time delay double inverted pendulum dynamics is adopted from srikanth et al[4] derived from the basic governing euler-lagrangian equation taken from [1] and developed by considering the time delay parameter as an additional state is shown below as

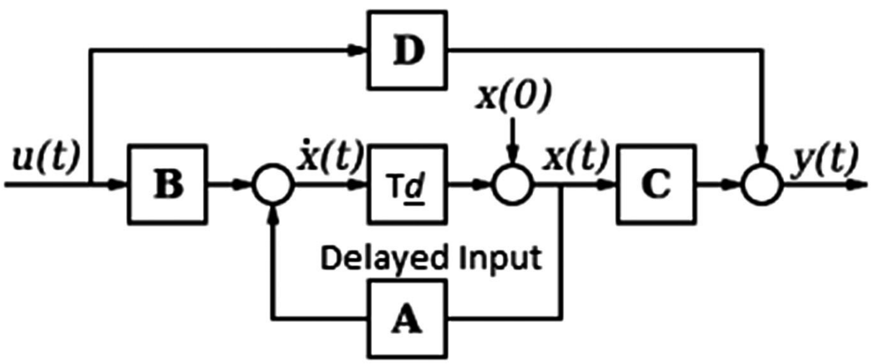


**Figure 1: Block diagram of system state space model with delay**

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \\ \dot{x}_4 \\ \dot{x}_5 \\ \dot{x}_6 \\ \dot{x}_7 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & A_{42} & A_{43} & A_{44} & 0 & 0 & 0 \\ 0 & A_{52} & A_{53} & A_{54} & 0 & 0 & 0 \\ 0 & A_{62} & A_{63} & A_{64} & 0 & 0 & 0 \\ \frac{-4}{\Gamma} & 0 & 0 & 0 & 0 & 0 & \frac{2}{\Gamma} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \\ x_6 \\ x_7 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \\ B_{41} \\ B_{51} \\ B_{61} \\ 0 \end{bmatrix} u \tag{1}$$

$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \\ y_5 \\ y_6 \\ y_7 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \\ x_6 \\ x_7 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} u \tag{2}$$

Where $A_{ij}$ represents generic dynamic system constants defined as in [1] and Γ refers to the time delay embedded into the system matrix defined as in [4,10]. The values for system constants are given based on the following assumptions made as per the nomenclature given, where

$$p_1 = (m_1+2*m_2)*L_1;$$

$$p_2 = m_2*L_2$$

$$p_3=2*m_2*L_1*L_2$$

$$p_4 = (m_1 + 4*m_2)*L_1*L_2$$

$$p_5 = m_2*L_1*L_1$$

$$\text{Den} = M*p_4*p_5+2*p_1*p_2*p_3 - p_2*p_2*p_4 - M*p_3*p_3 - p_1*p_1*p_5$$

Where the matrix parameters are parameters are

$$A_{42} = \frac{((p_2*p_3 - p_1*p_5)*p_1*g);}{\text{Den}}$$

$$A_{43} = \frac{((p_1 * p_3 + p_2 * p_4) * p_2 * g);}{\text{Den}}$$

$$A_{44} = \frac{-((p_4 * p_5 - p_3 * p_3) * f);}{\text{Den}}$$

$$A_{52} = \frac{((M * p_5 - p_2 * p_2) * p_1 * g)}{\text{Den}}$$

$$A_{53} = \frac{-((M * p_3 - p_1 * p_2) * p_2 * g);}{\text{Den}}$$

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$$A_{54} = \frac{-((p_1 * p_5 - p_2 * p_3) * f}{\text{Den}}$$

$$A_{62} = \frac{((M * p_3 - p_1 * p_2) * p_1 * g)}{\text{Den}}$$

$$A_{63} = \frac{((M * p_4 - p_1 * p_1) * p_2 * g)}{\text{Den}}$$

$$A_{64} = \frac{-((-p_1 * p_3 + p_2 * p_4) * f);}{\text{Den}}$$

$$B_{41} = \frac{(p_4 * p_5 - p_3 * p_3)}{\text{Den}}$$

$$B_{51} = \frac{(p_1 * p_5 - p_2 * p_3)}{\text{Den}}$$

$$B_{61} = \frac{(p_1 * p_3 + p_2 * p_4)}{\text{Den}}$$

### 2.1 Hybrid Particle Swarm With Flower Pollination For Dominant Pole Controller Design

Particle swarm optimization is an algorithm in which a random set of particles would get displaced by a set of update equations for position and velocity. The application of the flower pollination and particle swarm has been done for stabilization of inverted pendulum. The update equations yield the local best position and global best position and fitness function is evaluated. The evaluation of fitness is then continued for all the particles and the particles displacement happens as per the update equations. Flower pollination is an algorithm in which the pollination of the flower is used as a guiding factor. In this hybrid algorithm the logic of using the particles which are normally swarms are used for pollination of the flowers and the flower pollination update is happening, taking the best particles. The advantage of using a combination of a hybrid particle swarm and flower pollination is that the particles which are swarms are moving at their best rate and the best particles carry the pollen. This way we are using a double impact for energy efficiency because the particles when optimizing the fitness use minimum energy and similarly the flower pollination update happens based on the rate at which the pollen gets carried from the neighborhood of each flower. The generic algorithm for flower pollination would be

The algorithm for flower pollination is given below:

***Algorithm:***

1. Initialize population
2. Find the best solution for the designated fitness function (Energy Function taking into consideration the cumulative effect of constraints on the plant and fitness)

$$Z = (1 - E(1)\ ^{2} + 100 * (E(2) - E(1)^{2})^{2} + 100 * (E(3) - E(2)^{2})^{2}$$

3. Provide switch probability
4. While N<Generations
   (a) For all flowers
      (i) Evaluate levy distribution
      (ii) Evaluate global solution
5. If new solution is better update previous solution
6. Find current best solution

Now, this algorithm is extended with the best solutions as the input to the particle swarm and the particles would then expand as follows as shown in the flow chart shown in figure 2. The flow chart clearly highlights the case where the inputs to the particle comes from the flower pollination algorithm best solutions. It can be considered that the best pollen is taken by the swarms using the particle swarms. Thus with the input of the flower pollination the particles would evaluate the fitness and generate the best set of poles that would suit to the control of the plant and hence this control design would yield a set of dominant poles which minimize the control effort and also minimize the energy used for the control and stabilization of the plant.

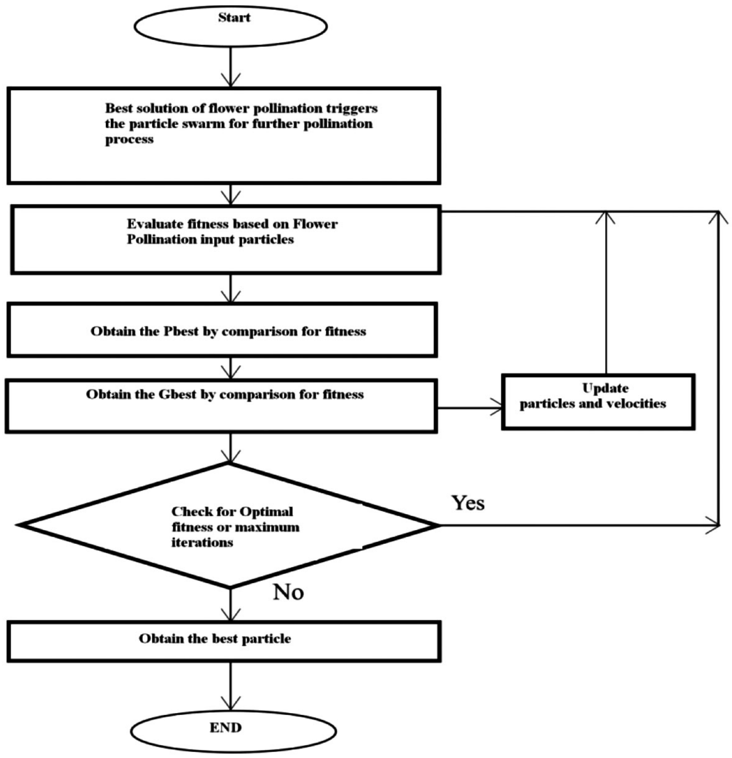


**Figure 2: Flow chart for variation of particles from flower pollination**

## 3. RESULTS

The configured values that yielded the performance comparison are tabulated in table 1 where the hybrid parameters are given. Fitness value obtained for the flower pollination and the consecutive values of particles used for the particle swarm are given. The relative variation of the poles placed is given where the variation is less than 10% from the initial configured values by the algorithm. Figures 4 to 6 indicate the output responses of the system compared to a standard LQR controller which clearly indicates that the control effort involves a smoother transition for the stability rather than an abrupt change as in the LQR which can be considered to be a better utilization of energy without surges which indicate high voltages and current in the motors that are driving the system.

**Table 1**

| *Parameter* | *Value* |
|---|---|
| Fitness (Flower Pollination) | 3.2057 |
| Best Particles(PS0) | [-1.7625 -1.412] |

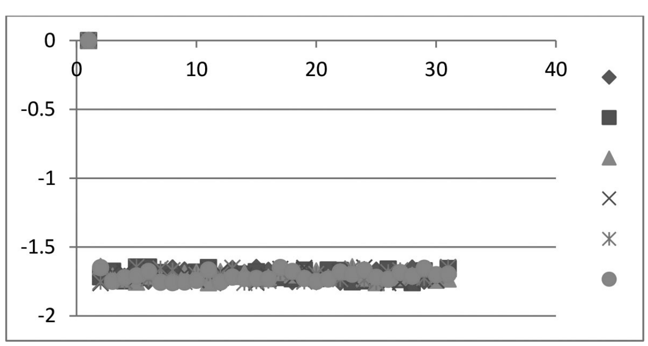


**Figure 3: Population of pole positions obtained with hybrid algorithm**

## 4. CONCLUSIONS

Some of the prominent observations that have been made are as follows

- The usage of an algorithm with combination of particle swarm and flower pollination yields a system which mimics nature where particle swarms can be considered to the birds and the flower pollen is carried with the pollen.
- The performance in terms of computations involved is lesser when compared to solving the algebraic ricatti equation by using classical control techniques.
- This method clearly becomes one such combinational optimization which evolves into a method with good feasibility to be extended to higher order complex dynamic systems.
- The output responses clearly indicate that when compared to classical LQR, the undershoots and overshoots are less which indicate that the system is energy efficient and the hybrid algorithm gives a better control of the system.

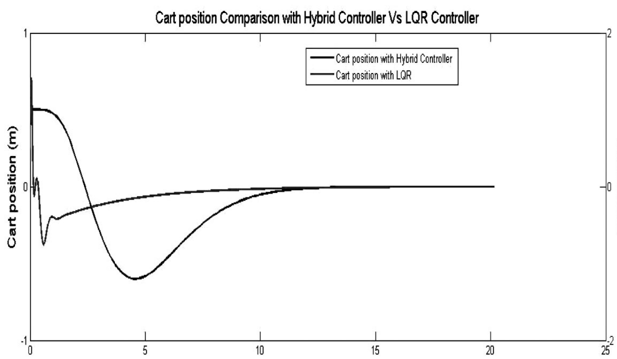


**Figure 4: Cart Variation with hybrid algorithm compared to LQR**

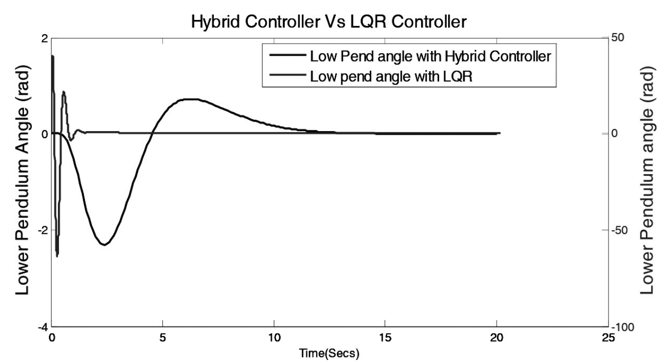


**Figure 5: Lower Pendulum position with hybrid algorithm compared to LQR**

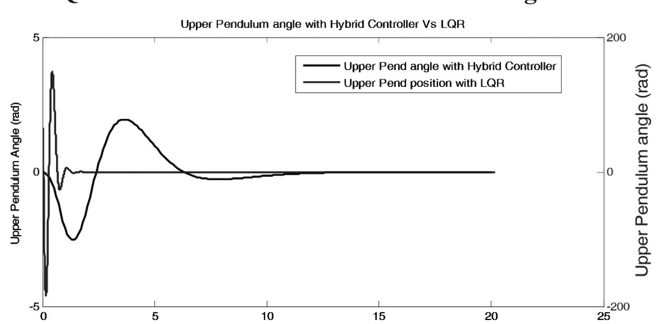


**Figure 6: Upper Pendulum position with hybrid algorithm compared to LQR**

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