Serial Manipulator Control Optimization Using Ant Colony Algorithm

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Abstract. Serial manipulator is one of robot type that commonly used on industry. The high Degree of Freedom (DoF) of serial manipulator lead to more flexibility on manipulation but at the same time it also lead to more complex mathematical model of serial manipulator. Because of this complexity, we cannot use the common Proportional-Integral-Derivative (PID) tuning method such as Ziegler-Nichols and Cohen-Coon while the parameter on controller is need to be optimal in order to reduce the error during position control and avoid instability which may cause hazard to the operator. Ant colony algorithm proposed to optimize the controller of serial manipulator and result of optimization evaluated through experiment.

1. Introduction

Serial manipulator type robot massively used on industry. The main reason are their ability to do complex object manipulation task because its configuration of joint. Movement of serial manipulator divided into two, which is joint control and task control. Joint control is control scheme of individual joint toward desired angle. While task control is control scheme of end-effector of serial manipulator to reach desired position and orientation.

To perform task control, resolved motion rate control used. This control method use jacobian matrix to map speed of each joint and end-effector and use Proportional-Derivative (PD) controller to reduce the error. But because of its system transfer function cannot transformed into s-domain, PID tuning such as Ziegler-Nichols and Cohen-Coon cannot be applied to this system to obtain the optimal value of PD variable.

At present, there are several method to tune PID parameter. One method is ant colony algorithm, a bio-inspired algorithm proposed by Dorigo in 1997 [1]. This algorithm mimicking how ant find the best path between nest and food source. Using probabilistic for each ant movement and cost function to evaluate each path, this algorithm can be used to solve problem such as path planning [2][3] and parameter tuning [4][5]. Thus, in this paper ant colony algorithm proposed to tune PD for serial manipulator control to obtain the optimal movement.

The main objective of this paper is implementation of ant colony algorithm in order to minimize the position error of serial manipulator movement. The rest of the paper structured as follows. Section II present the mathematical model of serial manipulator. Section III explain about resolved motion rate control a control method utilized to control serial manipulator. Section IV discussing about ant colony algorithm and its implementation on optimization of serial manipulator control. Section V examining
the effect of each ant colony algorithm variable and discussing the ability of ant colony algorithm to optimize system. Finally, section VI concludes the paper.

2. Modelling of serial manipulator

![Figure 1. 6-DOF Serial Manipulator](image)

Serial manipulator used on this research as shown on figure 1 have six revolute joint. In order to be controlled, serial manipulator need to be modelled. The modelling use modified denavit-hartenberg (MDH) method. Parameters of serial manipulator model are presented on table 1.

| Link | Alpha | A  | D  | Offset |
|------|-------|----|----|--------|
| 1    | 0     | 0  | 0.05 | 0      |
| 2    | 90    | 0.06 | 0  | 0      |
| 3    | 0     | 0.13 | 0  | 0      |
| 4    | 90    | 0.025 | 0.16 | 0      |
| 5    | -90   | 0  | 0  | 0      |
| 6    | 90    | 0  | 0.25 | 0      |

In movement control of serial manipulator there are two control space which is joint-space and task-space. In joint-space control, the goal of controller is to move specific robot joint from initial angle to desired angle. In task-space control, the goal of controller is to move end effector position on three dimensional space from initial position to desired position. Movement component of task-space control divided into translational and rotational. For rotational part, ZYZ euler angle are used to represent the orientation of end-effector.

3. Control system of serial manipulator

Control of serial manipulator started with acquiring position of object respect to serial manipulator base and then move its joint to grab the object. Resolved motion rate control method utilized to control the movement. PD controller of end-effector position control presented below.

\[
e = X_{ref} - X_{real} \quad (1)
\]

\[
\dot{X} = K_p * e + K_v * (e - e_{old}) \quad (2)
\]

Resolved motion rate control method use inverse of jacobian matrix to map cartesian speed of end-effector to angular speed for each serial manipulator joint.
\[ \dot{\theta} = J^{-1}(\theta) \cdot \dot{X} \]  

(3)

The complete system control block diagram are presented by figure 2.

**Figure 2. Block diagram of serial manipulator controller**

4. **Ant colony algorithm**

Ant colony algorithm is a bio-inspired swarm algorithm introduced by Marco Dorigo in 1999 in his Ph.D. Initially named Ant System, this algorithm used to solve problem such as finding the optimal path in graph and travelling sales man problem.

This algorithm inspired by how colony of ant find the optimal path between its nest and food source. First ant will wander randomly from their nest, upon reaching their food it will return to its nest. While doing so, ant also lay pheromone along the path they travel. The less time needed to travel using a path, the more pheromone laid on that path. This pheromone create an indirect interaction between ant. Ant more likely to go to the path with more pheromone than the other path. This will lead to ant go through the optimal path between nest and food source.

Implementation of ant colony system are presented below

4.1 **Initialization**

At this stage a number of ant, possible nodes, and cost function are set. Pheromone generated on each possible path. Ant will wander randomly at first stage.

4.2 **Choosing path**

\[ p_{ij}^k(t) = \frac{[\tau_{ij}(t)]^\alpha [n_{ij}]^\beta}{\sum_{j \in N_i^k} [\tau_{ij}(t)]^\alpha [n_{ij}]^\beta} \]  

(4)

Every path each ant choose based on probability given by equation (4). With \( N_i^k \) is a number of node that has been visited by \( k \) th ant from \( i \) to \( j \) where \( j \in N_i^k \). \( \tau_{ij}(t) \) is a value of pheromone on the path between point \( i \) and \( j \). \( n_{ij} \) is a visibility, a value that represent inverse of distance between \( i \) and \( j \). \( \alpha \) and \( \beta \) is a relative weight of variable pheromone trail and heuristic information.

4.3 **Pheromone Operation**

Given \( \Delta \tau_{ij}^k(t) \) were value of pheromone on the segment traversed by ant \( k \)-th on each iteration, value of pheromone on that segment are presented by equation (6).
\[ \Delta \tau^k_{ij}(t) = \begin{cases} \frac{1}{L_k} & \forall (i,j) \in L \\ 0 & \text{otherwise} \end{cases} \] (5)

\[ \tau_{ij}(t + 1) = \tau_{ij}(t) + \sum_{k=1}^{m} \Delta \tau^k_{ij}(t) \forall (i,j) \in L \] (6)

Pheromone on that segment exposed to the evaporation given by equation (7)

\[ \tau_{ij} = (1 - \rho) \tau_{ij} \forall (i,j) \in L \] (7)

5. Testing and analysis
To verify the reliability of ant colony algorithm to optimize the serial manipulator control, we simulate the optimization process and then put the value into serial manipulator control system. On optimization process, the cost function used were integral absolute error (IAE) from each axis movement and parameter used on algorithm are presented on table 2.

| Table 2. Ant colony algorithm parameter |
|-----------------------------------------|
| Parameter      | Value  |
| \( \alpha \)   | 0.8    |
| \( \beta \)    | 0.2    |
| \( \rho \)     | 0.7    |
| Iteration      | 10     |
| Ant            | 100    |
| Error measurement | IAE    |

After tuning process done, control variable obtained from the tuning are presented on table 3.

| Table 3. Control variable value comparison |
|-------------------------------------------|
| Tuning Method   | Kp    | Kv |
|-----------------|-------|----|
| Trial and error | 1     | 0.5|
| Ant colony algorithm | 1 | 0.9|

For testing, we gonna measure IAE of two movement on each axis and simultaneous movement on all axes for both control parameter. The simulation of serial manipulator control using controller parameter from ant colony algorithm are presented on table 4.

| Table 4. IAE comparison for each movement |
|------------------------------------------|
| Movement (cm) | IAE value |
|               | Trial and error | Ant colony algorithm |
|----------------|-----------------|----------------------|
| X + 10        | 0.0036          | 0.0023               |
| X + 20        | 0.0102          | 0.0081               |
| Y + 15        | 0.0046          | 0.0025               |
| Y - 10        | 0.0029          | 0.0015               |
| Z + 15        | 0.0046          | 0.0025               |
| Z - 10        | 0.0031          | 0.0017               |
| X + 7; Y +8; Z -5 | 0.0065      | 0.0037               |
Simulation show that ant colony algorithm able to find optimal parameter for serial manipulator, that shown by very small ripple on serial manipulator movement and end-effector error very low along the determined path. Simulation of the system are shown on figure 3.

Figure 3. Movement of serial manipulator end-effector on all three axes using Ant Colony algorithm.

6. Conclusion
In this paper, we propose and implement ant colony algorithm in order to optimize the control of serial manipulator. Ant colony algorithm used to find the optimal control parameter for serial manipulator. Simulation has been done and the result presented and discussed. Simulation prove the reliability of ant colony algorithm to reduce the position of end-effector error during movement.

7. Reference
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