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Analysis Multi-Agent with Precense of The Leader

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Abstract. The phenomenon of *swarm* is a natural phenomenon that is often done by a collection of living things in the form of motion from one place to another. By clustering, a group of animals can increase their effectiveness in food search and avoid predators. A group of geese also performs a swarm phenomenon when flying and forms an inverted V-formation with one of the geese acting as a leader. Each flying track of members of the geese group always follows the leader's path at a certain distance.

This article discusses the mathematical modeling of the swarm phenomenon, which is the optimal tracking control for multi-agent model with the influence of the leader in the 2-dimensional space. The leader in this model is intended to track the specified path. Firstly, the leader's motion control is to follow the predetermined path using the *Tracking Error Dynamic* method. Then, the path from the leader is used to design the motion control of each agent to track the leader's path at a certain distance. The result of numerical simulation shows that the leader trajectory can track the specified path. Similarly, the motion of each agent can trace and follow the leader's path.

Keywords: Multi Agent, tracking, tracking error dynamic, numerical simulation

INTRODUCTION

The phenomenon of swarm is a natural phenomenon of a collection of animals in the form of motion clustered from a place of origin to the final destination. Clustered motion can provide several advantages over moving individually. A group of swans performs a swarm phenomenon in the form of flying in a reversed V-formation. By doing this phenomenon the group of swans can increase the flight range by about 70 percent and the flying power 24 percent faster than if flying alone [8]. In this formation, one member of the goose group will act as a leader, and is followed by the members of his group. This situation illustrates the group of geese that track the leader's path.

Research on tracking problem has been done by some previous researchers. For example, Hirscom [7] discusses the issue of tracking with the singularity method. Furthermore, Cuevas, et al [2] discussing tracking problems with the Kalman filter method. Later in the same year, Manfredi et al discussed about network prediction and tracking problems using the smallest squares method and Kalman filter switching. Yao, et al. [15] and Gazi and Ordonez [6] discussed the tracking problems of particular trajectories of the swarm model with artificial potential and sliding mode control methods. Artificial potential method is used for kinematic system control design, while sliding mode control is used for dynamic system design. The sliding mode control algorithm is also used by Defoort, et al. [3] to learn the tracking and stability issues of the Heisenberg system extension by adding integrator factors to the input path. Tang, et al [14] discussed optimal tracking for bilinear system problems with functional quadratic charges. The method used is a successive approximation approach (SAA) by transforming non-linear optimization problems into non-homogeneous linear sequence problems with two boundary value points. Furthermore Miswanto, et al. [12] discusses swarm behavior for tracking problems by inserting a pull factor to a specified path so that all members can

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follow a specified path at a certain distance. Miswanto, et al. [13] also discusses the optimal control tracking of swarm problems with geometric approaches applied to multiple dubin's car systems.

This article is organized as follows. Section 2 the problem statement is described of multi-agent with precence of the leader. In section 3, we design the control of the leader using tracking error dynamics methods. Finally, the numerical simulation output is shown by error tracking of the multi-agent system movement towards desired path followed by the leader of multi-agent and agents.

MULTI-AGENT WITH PRECENCE OF THE LEADER

Consider the multi agent system [1] described as:

$$\dot{x}_i = -\sum_{j=1}^{M} w_{ij}\left(x_i - x_j\right)\left(a - \frac{r}{b + c x_i - x_j^{2}}\right); \quad i = 1, 2, 3, \dots, M, \tag{1}$$

here represents $\dot{x}_i = \frac{dx_i}{dt}$, $x_i \in \mathcal{R}^2$ the position of the i-th individual, $W = \left[w_{ij}\right] \in \mathcal{R}^{2x2}$ is the coupling matrix with w_{ij} elements of nonnegative integer for all $i, j = 1, 2, 3, \dots, M$. In this paper, matrix W is assumed to be symmetric, that is $w_{ij} = w_{ji}$ for all i, j and $w_{ii} = 0$ for all $i = 1, 2, 3, \dots, M$. $a, b, c,$ and r are positive constant with $a \ll r$ and $y = \sqrt{y^T\ y}$ is the Euclidean norm.

Referring to the multi-agent system (1), than we design the model multi-agent with precence of the leader by *tracking error dynamic* method:

$$\dot{\boldsymbol{x}}_1 = g\left(x_1, u\right)$$

$$\dot{\boldsymbol{x}}_i = -\sum_{j=1}^{M} w_{ij}\left(x_i - x_j\right)\left(a - \frac{r}{b + c x_i - x_j^{2}}\right), \quad i = 2, 3, \dots, M, \tag{2}$$

with $\boldsymbol{x}_1$ as leader and $\boldsymbol{x}_i$ as member.

It appears that $\boldsymbol{x}_1$ as a leader is not affected by the motion of the members, otherwise the movements of the members are influenced by the movement of the leader.

Defined a control system for leader $\boldsymbol{x}_1$:

$$\dot{x}_1 = -y_1\left(t\right)$$
$$\dot{y}_1 = -y_1\left(t\right) + u \tag{3}$$

Further, this movement is tracking γ path, which has been defined. Then, it is followed by the members (agents) movement. The path that followed by member is defined by the formula as follow $\gamma\left(t\right) = \left(\gamma_x\left(t\right), \gamma_y\left(t\right)\right)$.

THE CONTROL DESIGN OF THE LEADER FOR TRACKING OF DESIRED PATH

We define a tracking error $e(t)$ which is the difference between path $\gamma(t)$ and the path the leader passes through:

$$e(t) = \left[e_x(t)\ ,\ e_y(t)\right]^T = \left[x_1(t) - \gamma_x(t)\ ,\ y_1(t) - \gamma_y(t)\right]^T \tag{4}$$

Differentiating the system (4) with respect to time, one obtains:

$$\begin{aligned} \dot{e}(t) &= \left[\dot{x}_1(t) - \dot{\gamma}_x(t)\ ,\ \dot{y}_1(t) - \dot{\gamma}_y(t)\right]^T, \\ &= \left[-\left(y_1(t) + \dot{\gamma}_x(t)\right), -\left(y_1(t) + \dot{\gamma}_y(t)\right) + u\right]^T \end{aligned} \tag{5}$$

Now, we define the tracking error dynamics for leader F where $F = \left[f_x, f_y\right]^T$ and $f_j\left(e_j, \dot{e}_j\right) = 0,\ \ j = x, y$:

$$\begin{aligned} f_x(t) &= \dot{e}_x(t) + k\ e_x(t) = 0 \\ f_y(t) &= \dot{e}_y(t) + k\ e_y(t) = 0 \end{aligned} \tag{6}$$

where k is a positive constant.
Substitute equation (4) and (5) to (6) we result the control u :

$$u = y_1(t) - ky_1(t) + k\gamma_y(t) - \dot{\gamma}_y(t) \tag{7}$$

Furthermore each member (agent) $\boldsymbol{x}_i$, $i = 2, 3, \ldots, M$, will move following the motion of the leader. The motion of each agent itself is controlled by a pull factor a and a repelling factor r .

NUMERICAL SIMULATION

In this section, we present the result of numerical simulation from model (1) in the two-dimensional space, first of all, the formulation of the path that will be tracked is:

$$\begin{aligned} \dot{\gamma}_x(t) &= \frac{3}{20}t^2 - \frac{7}{10}t + 1 \\ \dot{\gamma}_y(t) &= \frac{3}{50}t^2 - \frac{1}{2}t + 15 \end{aligned} \tag{8}$$

Simulation is undertaken with six agents (one leader and five agents). The initial points of desired path and each agent are on Table 1.

Table 1. Initial points of $\gamma(t)$ and $x_i(t)$

$\gamma(0)$	$\boldsymbol{x}_1(0)$	$\boldsymbol{x}_2(0)$	$\boldsymbol{x}_3(0)$	$\boldsymbol{x}_4(0)$	$\boldsymbol{x}_5(0)$	$\boldsymbol{x}_6(0)$
(45,5)	(50,5)	(40,30)	(10,-15)	(20,10)	(50,10)	(100,-10)

This tracking is conducted from $t = 0$ to $t = 15$ with positive constants are $k = 150$, $a = 1$, $b = 1$, $c = 0.2$, and $r = 50$. The results of numerical simulations are shown in Figure 1 through Figure 4.

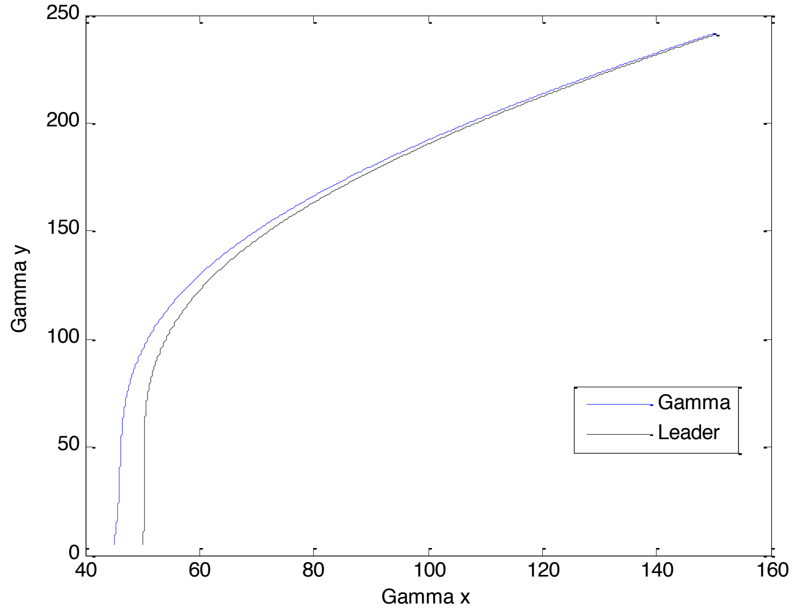

Figure 1. Multi-agent leader trajectory and $\gamma(t)$ path.

Figure1 it is seen that by giving the control u expressed in equation (7) to the leader control system (3), the leader is able to move to track the given path. Leaders can move closer to and follow the trajectory of well-defined trajectories. This is shown by the tracking error curve $e(t)$ of Figure 2., which is also reinforced by the tracking error data of leaders and paths given in Table 2. It is seen that the difference between the trajectory of the leader and the specified path trajectory is getting smaller zero and ultimately can be maintained at a certain distance.

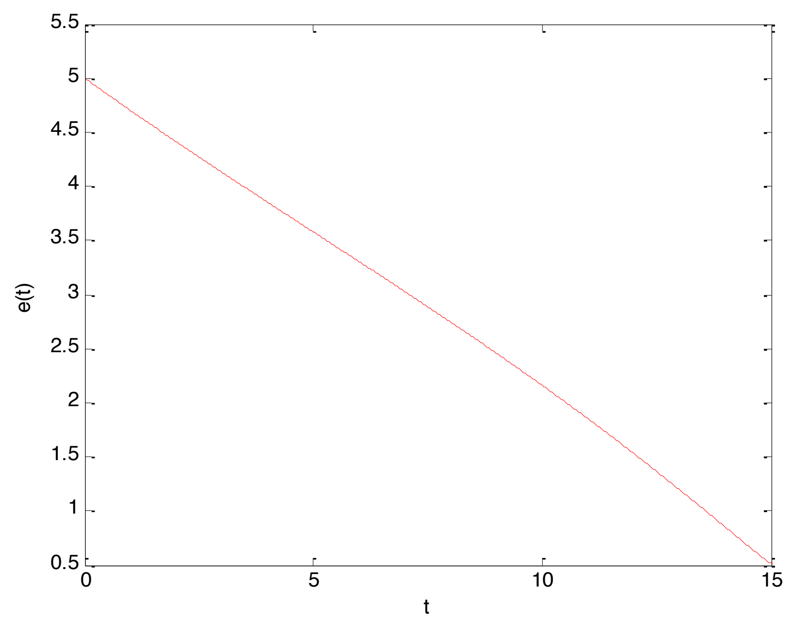

Figure 2. Curve of *tracking error* $e(t)$ of leader and $\gamma(t)$ path.

Table 2. Tracking error the leader x_1 and $\gamma(t)$ path

waktu (t)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Error	4.7071	4.4173	4.1354	3.8583	3.5828	3.3084	3.0317	2.7505

waktu (t)	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Error	2.4630	2.1656	1.8576	1.5368	1.2027	0.8565	0.5154

The numerical simulation results of the movement of agents tracking the path of the leader are shown in Figure 3. In this case simulations are performed on five agents with a remote starting position.

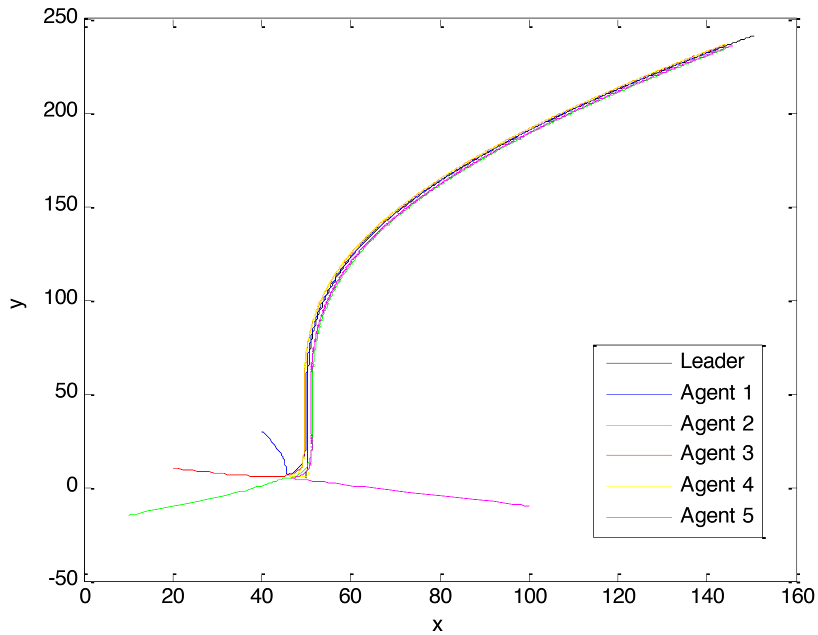

Figure 3. Multi-agent trajectory tracking the leader's movement

Seen to take it even though the initial position of each agent is far enough away from the leader's position, but each agent can move the leader's movement well. In addition, each agent is able to maintain their respective positions on the formation expected with a fairly safe distance. Figure 4. shows the position of each agent that can maintain its position at different times.

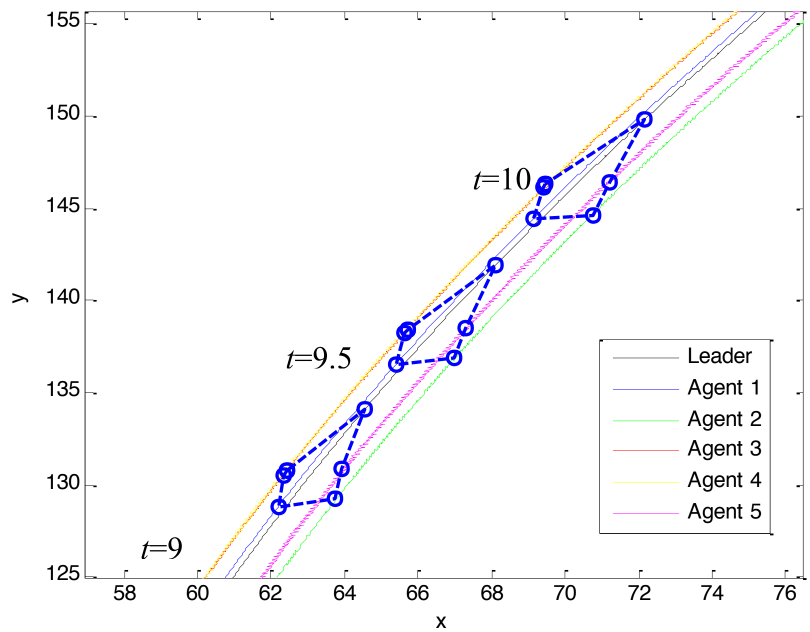

Figure 4. The position of the agent at time t = 9 ; 9,5 ; 10

REMARK

This paper discusses the multi-agent model and the influence of the leader through the swarm phenomenon. An analysis of the leader model produce a control design so that leaders can move to track the desired path. From the numerical simulation results it can be seen that tracking errors on the leader paths tracing the desired path are small. The distance between the leader path and the desired path is preserved. On the other hand, every agent moves to track the leader's movement by preserving the desired path to avoid a collision. This model is a simple model that includes the norm as a link factor.

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