카오스 이동 로봇의 상호 협조 제어를 위한 동기화 기법

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The Synchronization Method for Mutual Cooperation Control of Chaotic Mobile Robot

Youngchul Bae · Chunsuk Kim · Youngduk Koo

요 약

본 논문에서는 카오스 이동 로봇에서의 상호 협조 제어를 위한 동기화 기법을 제안하였다. 카오스 이동 로봇에서의 상호 협조 제어를 위한 동기화를 이루기 위하여 장애물을 가진 경우와 장애물을 가지지 않는 경우에 있어서 결합 동기 이론과 구동 동기 이론을 적용하였으며 두개의 로봇에서 동기화가 이루어짐을 확인하였다.

ABSTRACT

In this paper, we propose that the synchronization method for mutual cooperative control in the chaotic mobile robot. In order to achieve the synchronization for mutual cooperative control in the chaotic mobile robot, we apply coupled synchronization technique and driven synchronization technique in the chaotic mobile robot without obstacle and with obstacle.

키워드

Chaos robot, Chaos control, Obstacle avoidance, Synchronization, Cooperation control

Ⅰ. Introduction

Chaos theory has been drawing a great deal of attention in the scientific community for almost two decades. Remarkable research efforts have been spent in recent years, trying to export concepts from Physics and Mathematics into the real world engineering applications. Applications of chaos are being actively studied in such areas as chaos control [1-2], chaos synchronization and secure/crypto communication [3-7], Chemistry [8], Biology [9], and robots and their related themes [10].

Recently, Nakamura, Y. et al [10] proposed a chaotic mobile robot where a mobile robot is equipped with a controller that ensures chaotic motion and the dynamics of the mobile robot are represented by an Arnold equation. They applied obstacles in the chaotic trajectory, but they did not mentioned obstacle avoidance methods with mutual cooperative control.

In this paper, we propose the synchronization method for mutual cooperation control of a chaotic mobile robots that have unstable limit cycles in a chaos trajectory surface with Lorenz equation, n-double scroll equation.

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We assume that all obstacles in the chaotic trajectory surface have a Van der Pol equation with an unstable limit cycle. When chaos robots meet obstacles among their arbitrary wandering in the chaos trajectory, which is derived using chaos circuit equations such as the Lorenz equation or hyper chaos equation, the obstacles reflect the chaos robots. In order to achieve the synchronization for mutual cooperative control in the chaotic mobile robot, we apply coupled synchronization technique and driven synchronization technique in the chaotic mobile robot without obstacle and with obstacle.

Computer simulations also show multiple obstacles can be avoided by using mutual cooperative control with an Lorenz equation or hyper chaos equation.

Ⅱ. Chaotic Mobile Robot

2.1. Mobile Robot

As the mathematical model of mobile robots, we assume a two- wheeled mobile robot as shown in Fig. 1.

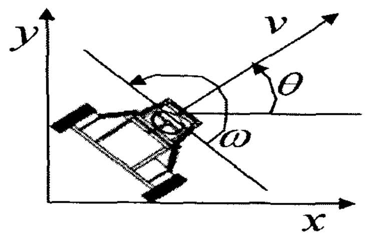


Fig. 1 Two-wheeled mobile robot

Let the linear velocity of the robot v [m/s] and angular velocity [rad/s] be the input to the system. The state equation of the four-wheeled mobile robot is written as follows:

$$\begin{pmatrix} \dot{x}_1 \\ \dot{y}_1 \\ \dot{\theta} \end{pmatrix} = \begin{pmatrix} \cos\theta & 0 \\ \sin\theta & 0 \\ 0 & 1 \end{pmatrix} \begin{pmatrix} v \\ w \end{pmatrix} \tag{1}$$

where (x,y) is the position of the robot and θ is the angle of the robot.

2.2 Chaos equations

In order to generate chaotic motions for the mobile robot, we apply some chaotic equations such as an Lorenz equation and hyper-chaos equation.

1) Lorenz equation

Lorenz equation describes the famous chaotic phenomenon. We define the Lorenz equation as follows:

$$\begin{aligned} \dot{x} &= \sigma(y-x) \\ \dot{y} &= \gamma x - y - xz \\ \dot{z} &= xy - bz \end{aligned} \tag{2}$$

where $\sigma = 10, \gamma = 28, b = 8/3$.

From equation (2), we can get time series and chaotic attractor as shown in Fig. 2 and Fig 3.

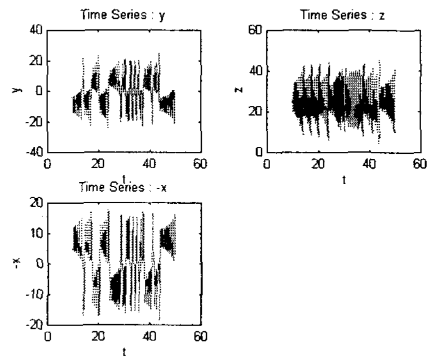


Fig. 2 Time series of Lorenz equation

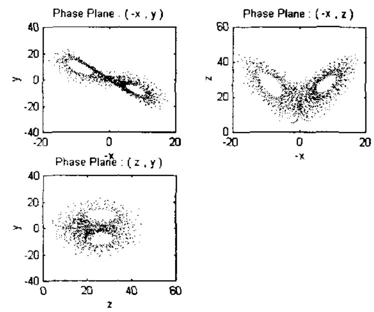


Fig. 3 Chaotic attractor of Lorenz equation

2) Hyper-chaos equation

Hyper-chaos equation is one of the simplest physical models that have been widely investigated by mathematical, numerical and experimental methods for complex chaotic dynamic. We can easily make hyper-chaotic equation by using some of connected N-double scroll. We can derive the state equation of N-double scroll equation as followings.

$$\begin{aligned} \dot{x} &= \alpha[y - h(x)] \\ \dot{y} &= x - y + z \\ \dot{z} &= -\beta y \end{aligned} \qquad (3)$$

Where,

$$h(x) = m_{2n-1}x + \frac{1}{2}\sum_{i=1}^{2n-1}(m_{i-1} - m_i)(|x + c_i| - |x - c_i|)$$

In order to make a hyper-chaos, we have compose to 1 dimensional CNN(Cellular Neural Network) which are identical two N-double scroll circuits and then we have to connected each cell by using unidirectional coupling or diffusive coupling. In this paper, we used to diffusive coupling method. We represent the state equation of x-diffusive coupling and y-diffusive coupling as follows.

x-diffusive coupling

$$\begin{aligned} \dot{x}^{(j)} &= \alpha[y^{(j)} - h(x)^{(j)}] + D_x(x^{(j-1)} - 2x^{(j)} + x) \\ \dot{y}^{(j)} &= x^{(j)} - y^{(j)} + z^{(j)} \\ \dot{z}^{(j)} &= -\beta y^{(j)}, \qquad j = 1, 2, \ldots L \end{aligned} \qquad (4)$$

y-diffusive coupling

$$\begin{aligned} \dot{x}^{(j)} &= \alpha[y^{(j)} - h(x)^{(j)}] \\ \dot{y}^{(j)} &= x^{(j)} - y^{(j)} + z^{(j)} + D_y(x^{(j-1)} - 2x^{(j)} + x) \\ \dot{z}^{(j)} &= -\beta y^{(j)}, \qquad j = 1, 2, \ldots L \end{aligned} \qquad (5)$$

where, L is number of cell.

From equation (3), (4) and, (5), we can get a chaotic attractor as shown in Fig. 4.

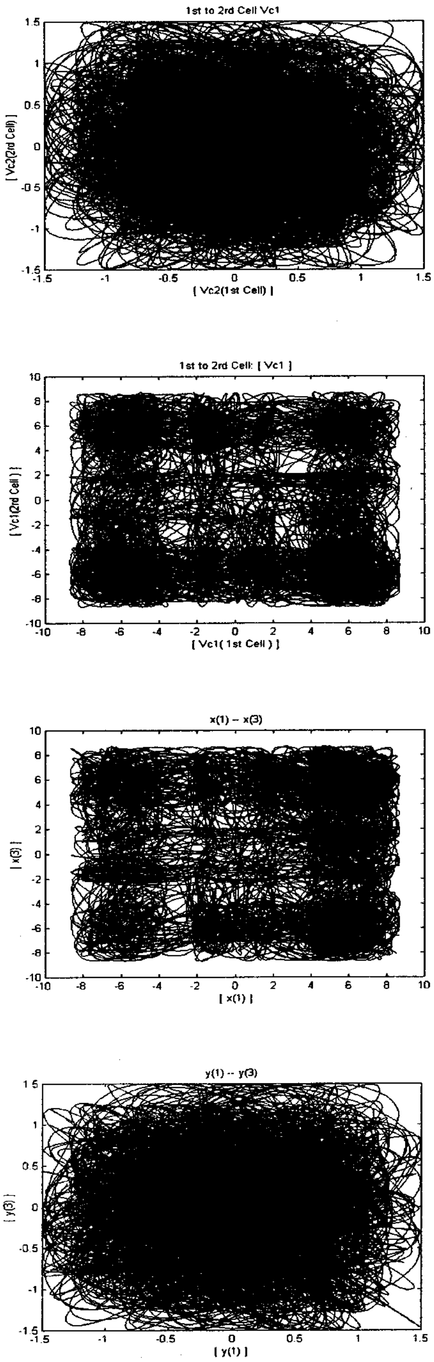


Fig. 4 Chaotic attractors of hyper-chaos equation

2.3 Embedding of Chaos circuit in the Robot

In order to embed the chaos equation into the mobile robot, we define and use an Lorenz equation or hyper chaos equation as follows.

1) Lorenz equation

Combination of equation (1) and (2), we define and use the following state variables:

$$\begin{pmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \\ \dot{x} \\ \dot{y} \end{pmatrix} = \begin{pmatrix} \sigma(y-x) \\ \gamma x - y - xz \\ xy - bz \\ v\cos x_3 \\ v\sin x_3 \end{pmatrix} \tag{6}$$

Eq. (6) is including Lorenz equation. The behavior of Lorenz equation is chaos. We can get chaotic mobile robot trajectory.

2) Hyper-chaos equation

Combination of equation (1) and (4) or (5), we define and use the following state variables (7) or (8)

$$\begin{pmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \\ \dot{x} \\ \dot{y} \end{pmatrix} = \begin{pmatrix} \alpha[y^{(j)} - h(x^{(j)}] + D_x(x^{(j-1)} - 2x^{(j)} + x^{(j+1)})) \\ x^{(j)} - y^{(j)} + z^{(j)} \\ -\beta y^{(j)} \\ v\cos x_3 \\ v\sin x_3 \end{pmatrix} \tag{7}$$

$$\begin{pmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \\ \dot{x} \\ \dot{y} \end{pmatrix} = \begin{pmatrix} \alpha[y^{(j)} - h(x^{(j)}] \\ x^{(j)} - y^{(j)} + z^{(j)} + D_y(x^{(j-1)} - 2x^{(j)} + x^{(j+1)}) \\ -\beta y^{(j)} \\ v\cos x_3 \\ v\sin x_3 \end{pmatrix} \tag{8}$$

Using equation (7) and (8), we obtain the embedding chaos robot trajectories with Hyper-chaos equation

Ⅲ. Chaotic Mobile Robot with VDP(Van der Pol) Obstacle and Mirror Mapping

3.1. VDP obstacle

In this section, we will discuss the mobile robot's avoidance of Van der Pol(VDP) equation obstacles. We assume the obstacle has a VDP equation with an unstable limit cycle, because in this condition, the mobile robot can not move close to the obstacle and the obstacle is avoided.

In order to represent an obstacle of the mobile robot, we employ the VDP, which is written as follows:

$$\begin{aligned} \dot{x} &= y \\ \dot{y} &= (1-y^2)y - x \end{aligned} \tag{9}$$

From equation (9), we can get the following limit cycle as shown in Fig. 5.

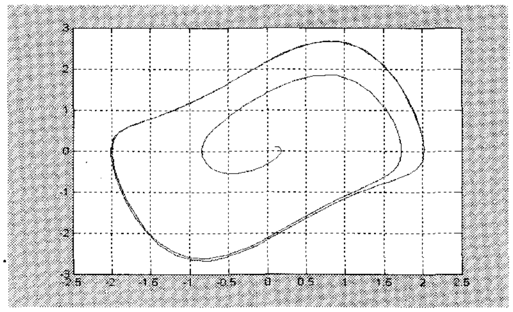


Fig. 5 Limit cycle of VDP

3.2 Mirror mapping

Equations (6) - (8) assume that the mobile robot moves in a smooth state space without boundaries. However, real robots move in space with boundaries like walls or surfaces of targets. To avoid a boundary or obstacle, we consider mirror mapping when the robots approach walls or obstacles using Eq. (10) and (11). Whenever the robots approach a wall or obstacle, we calculate the robots' new position by using Eq. (10) or (11).

$$A = \begin{pmatrix} \cos\theta & \sin\theta \\ \sin\theta & -\cos\theta \end{pmatrix} \tag{10}$$

$$A = \frac{1}{1+m}\begin{pmatrix} 1-m^2 & 2m \\ 2m & -1+m^2 \end{pmatrix} \tag{11}$$

We can use equation (10) when the slope is infinity, such as $\Theta=90$, and use equation (11) when the slope is not infinity.

3.3 Magnitude of Distracting force from the obstacle

We consider the magnitude of distracting force from the obstacle as follows:

$$D=\frac{0.325}{(0.2D_k+1)e^{3(0.2D_k-1)}} \qquad (12)$$

where D_k is the distance between each effective obstacle and the UAV.

We can also calculate the VDP obstacle direction vector as follows:

$$\begin{bmatrix}\overline{x_k}\\ \overline{y_k}\end{bmatrix}=\begin{bmatrix}x_0-y\\ 0.5(1-y_0-y)^2(y_0-y)-x_0-x\end{bmatrix} \qquad (13)$$

where (x_0,y_0) are the coordinates of the center point of each obstacle. Thenwe can calculate the magnitude of the VDP direction vector (L), the magnitude of the moving vector of the virtual UAV (I) and the enlarged coordinates (I/2L) of the magnitude of the virtual UAV in VDP(x_k,y_k) as follows:

$$\begin{aligned}&L=\sqrt[2]{(x^2_{v+\overline{y^2_v)dp}dp}}\\ &I=\sqrt{(x_r^2+y_r^2)} \qquad (14)\\ &x_k=\frac{\overline{x_k}}{L}\frac{I}{2},\quad y_k=\frac{y_k}{L}\frac{I}{2}\end{aligned}$$

Finally, we can get the Total Distraction Vector (TDV) as shown by the following equation.

$$\begin{pmatrix}\dfrac{\sum_k^n((1-\frac{D_k}{D_0})\overline{x}+\frac{D_K}{D_0}\overline{x_k}}{n}\\ \dfrac{\sum_K^N((1-\frac{D_k}{D_0})\overline{y}+\frac{D_k}{D_0}\overline{y_k})}{n}\end{pmatrix} \qquad (15)$$

Using equations (10)-(15), we can calculate the avoidance method of the obstacle in the Lorenz and hyper-chaos trajectories with one or more VDP obstacles.

Ⅳ. Mutual cooperative control by using synchronization methods

To achieve mutual cooperative control in the mobile robot, we applied the chaotic synchronization technique from the several mobile robot trajectories. Firstly, we applied coupled synchronization method and then we also applied driven synchronization method for mutual cooperative control between the several robots.

3.1 Coupled synchronization method

In order to accomplish mutual cooperative control in the several chaos mobile robots, we applied a coupled synchronization method proposed by Cuomo [11] in the Lorenz chaos mobile robots .

To applied coupled synchronization method in the Lorenz circuit, transmitter-receive state equations are following:

Transmitter state equation

$$\begin{aligned}\dot{x}&=\sigma(y-x)+k(x-y)\\ \dot{y}&=\gamma x-y-xz \qquad (16)\\ \dot{z}&=xy-bz\end{aligned}$$

Receiver state equation

$$\begin{aligned}\dot{x}&=\sigma(y-x)+k'(y-x)\\ \dot{y}&=\gamma x-y-xz \qquad (17)\\ \dot{z}&=xy-bz\end{aligned}$$

In order to accomplish synchronization of the Eq. (16), (17), we need to find stable coupled-register R_x value between the transmitter and the receiver.

3.2 Coupled mutual cooperative control in the Hypers chaos robot by using coupled synchronization

To accomplish synchronization of the two chaos robot embedding hyper chaos circuit, first we formed each state equation for Eq. (18), (19). Then found coupled coefficient k and k' by using stability criteria. After that, we applied k and k' within stable area to perform computer simulation.

Main chaos robot's state equation

$$\begin{aligned}
\dot{x}_1 &= \alpha[y^{(j)} - h(x^{(j)}] + D_x(x^{(j-1)} - 2x^{(j)} + x^{(j+1)})) + k \\
\dot{x}_2 &= x^{(j)} - y^{(j)} + z^{(j)} \\
\dot{x}_3 &= -\beta x_2 \\
\dot{x} &= v\cos x_3 \\
\dot{y} &= v\sin x_3
\end{aligned} \tag{18}$$

Sub chaos robot's state equation

$$\begin{aligned}
\dot{x}_1 &= \alpha[y^{(j)} - h(x^{(j)}] + D_x(x^{(j-1)} - 2x^{(j)} + x^{(j+1)})) + k' \\
\dot{x}_2 &= x^{(j)} - y^{(j)} + z^{(j)} \\
\dot{x}_3 &= -\beta x_2 \\
\dot{x} &= v\cos x_3 \\
\dot{y} &= v\sin x_3
\end{aligned} \tag{19}$$

3.3 Driven mutual cooperative control in the hyper chaos robot by using driven synchronization

To accomplish synchronization of the two chaos robot embedding hyper chaos circuit, first we formed each state equation for Eq. (13), (14). Then found driven coefficient k and k' by using stability criteria. After that, we applied k and k' within stable area to perform computer simulation.

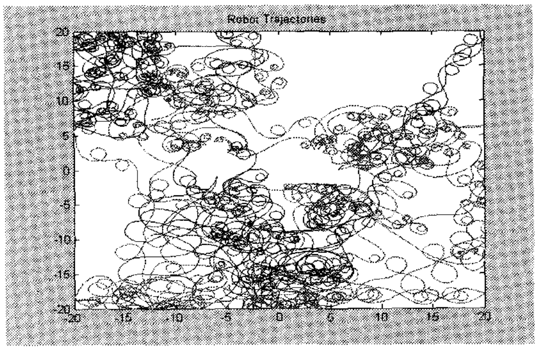
Main chaos robot's state equation

$$\begin{aligned}
\dot{x}_1 &= \alpha[y^{(j)} - h(x^{(j)}) \\
\dot{x}_2 &= x^{(j)} - y^{(j)} + z^{(j)} + D_y(x^{(j-1)} - 2x^{(j)} + x^{(j+1)} + k \\
\dot{x}_3 &= -\beta y^{(j)} \\
\dot{x} &= v\cos x_3 \\
\dot{y} &= v\sin x_3
\end{aligned} \tag{13}$$

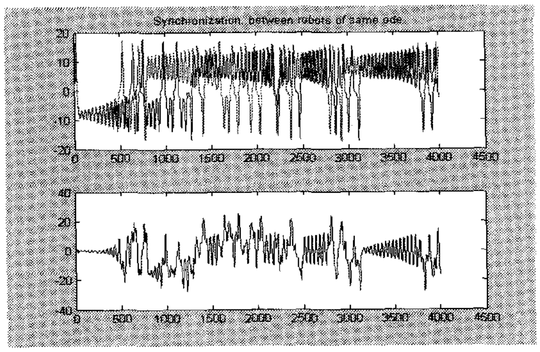
Sub chaos robot's state equation

$$\begin{aligned}
\dot{x}_1 &= \alpha[y^{(j)} - h(x^{(j)}) + k \\
\dot{x}_2 &= x^{(j)} - y^{(j)} + z^{(j)} + D_y(x^{(j-1)} - 2x^{(j)} + x^{(j+1)} + k' \\
\dot{x}_3 &= -\beta y^{(j)} \\
\dot{x} &= v\cos x_3 \\
\dot{y} &= v\sin x_3
\end{aligned} \tag{14}$$

The Fig. 6 and 7 showing synchronization of two hyper chaos robot after using Eq.(13) and (14). Fig. 6 is showing the result of synchronization at fixed obstacle.



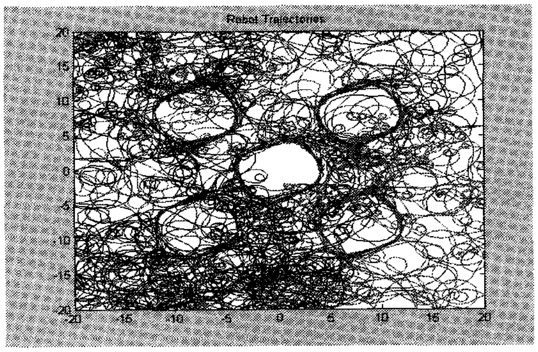
(a) Robot trajectory



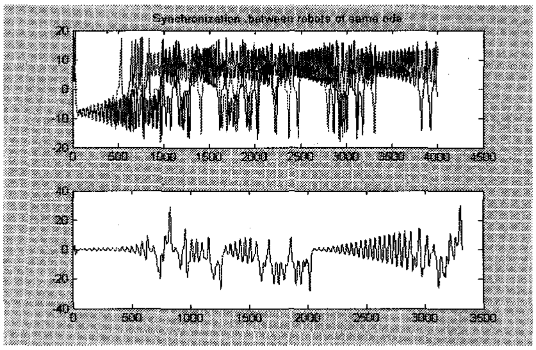
(b) The result of synchronization

Fig. 6 The result of synchronization in the Lorenz robot with fixed obstacles by using coupled mutual cooperative control

The Fig. 7 showing synchronization of two Lorenz chaos robot after using Eq.(13) and (14). Fig. 7 is showing the result of the synchronization after applying hidden obstacle, VDP.



(a) Robot trajectory



(b) The result of synchronization

Fig. 7 The result of synchronization in the hyper chaos robot with hidden obstacles using driven mutual cooperative control

V. Conclusion

In this paper, we proposed a chaotic robots, which employs a robots with Lorenz or hyper chaos equation trajectories, and also proposed a robot synchronization methods in which coupled-synchronization and driven synchronization.

We designed chaotic robot trajectories such that the total dynamics of the robots was characterized by a Lorenz or hyper chaos equation and also designed the chaotic robot trajectories to include an obstacle avoidance method. As a result, we realized that the result of synchronization is generalized synchronization.

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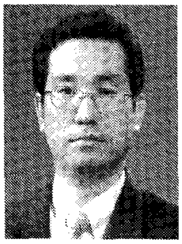
저자소개



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