카오스 이동 로봇에서의 장애물 회피 기법

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Obstacle Avoidance Technique for Chaotic Mobile Robot

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요 약

본 논문에서는 카오스 궤적 표면에서 불안정한 리미트 사이클을 가지는 장애물 회피 기법을 제안하였다. 카오스 궤적 표면의 모든 장애물은 불안정한 리미트 사이클을 가지는 Van der Pol 방정식으로 가정하였다. 하나 또는 몇 개의 Van der Pol 장애물과 고정 장애물을 로봇이 피해가는 과정을 결과로 나타내었다.

ABSTRACT

In this paper, we propose a method to avoid obstacles that have unstable limit cycles in a chaos trajectory surface. We assume all obstacles in the chaos trajectory surface have a Van der Pol equation with an unstable limit cycle. We also show computer simulation results of Arnold equation, Chua's equation, Hyper-chaos equation, Hamilton equation and Lorenz chaos trajectories with one or more Van der Pol obstacles.

키워드

Chaos robot, Chaos control, Obstacle avoidance

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 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 mention obstacle avoidance methods.

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In this paper, we propose a method to avoid obstacles using unstable limit cycles in the chaos trajectory surface. We assume that all obstacles in the chaos 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 Arnold equation, Chua's equation, hyper-chaos equation, Hamilton equation or Lorenz equation, the obstacles reflect the chaos robots.

Computer simulations also show multiple obstacles can be avoided with an Arnold equation, Chua's equation, hyper-chaos equation, Hamilton equation or Lorenz 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.

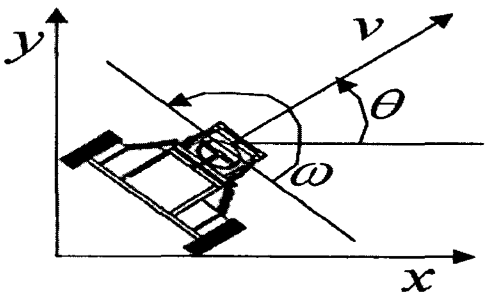


Fig. 1 Two-wheeled mobile robot

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 chaos equations such as an Arnold equation, Chua's equation hyper-chaos equation, Hamilton equation or Lorenz equation.

1) Arnold equation [10]

We define the Arnold equation as follows:

$$\begin{aligned} \dot{x}_1 &= A\ \sin x_3 + C\ \cos x_2 \\ \dot{x}_2 &= B\ \sin x_1 + A\ \cos x_3 \\ \dot{x}_3 &= C\ \sin x_2 + B\ \cos x_1 \end{aligned} \tag{2}$$

where A, B, C are constants.

2) Chua's equation

Chua's circuit is one of the simplest physical models that has been widely investigated by mathematical, numerical and experimental methods. We can derive the state equation of Chua's circuit.

$$\begin{aligned} \dot{x}_1 &= \alpha(x_2 - g(x_1)) \\ \dot{x}_2 &= x_1 - x_2 + x_3 \\ \dot{x}_3 &= -\beta x_2 \end{aligned} \tag{3}$$

where .

$$g(x) = m_{2n-1}x + \frac{1}{2}\sum_{k=1}^{2n-1}(m_{k-1} - m_{k)}(|x+c_k| - |x-c_k|)$$

3) 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.

$$\begin{aligned} \dot{x} &= \alpha[y - h(x)] \\ \dot{y} &= x - y + z \\ \dot{z} &= -\beta y \end{aligned} \tag{4}$$

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

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

y-diffusive coupling

$$\begin{aligned} \dot{x}^{(j)} &= \alpha[y^{(j)} - h(x)^{(j)}] \quad (6) \\ \dot{y}^{(j)} &= x^{(j)} - y^{(j)} + z^{(j)} + D_y(x^{(j-1)} - 2x^{(j)} + x) \\ \dot{z}^{(j)} &= -\beta y^{(j)}, \quad j = 1,2,....L \end{aligned}$$

where, L is number of cell.

4) Hamilton equation

Hamilton equation is one of the simplest physical models that have been widely investigated by mathematical, numerical and experimental methods. We can derive the state equation of Hamilton equation as follows.

$$\begin{aligned} \dot{x}_1 &= x_1(13 - x_1^2 - y_1^2) \quad (7) \\ \dot{x}_2 &= 12 - x_1(13 - x_1^2 - y_1^2) \end{aligned}$$

5) Lorenz equation

The Lorenz equation describes the famous chaotic phenomenon.

We define the Lorenz equation as follows:

$$\begin{aligned} \dot{x} &= \sigma(y - x) \quad (8) \\ \dot{y} &= \gamma x - y - xz \\ \dot{z} &= xy - bz \end{aligned}$$

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

2.3 Embedding of Chaos circuit in the Robot

In order to embed the chaos equation into the mobile robot, we define and use the Arnold equation, Chua's circuit equation, hyper-chaos equation, Hamilton equation and Lorenz equation as follows.

1) *Arnold equation*

We define and use the following state variables:

$$\begin{aligned} \dot{x}_1 &= D\dot{y} + C\cos x_2 \\ \dot{x}_2 &= D\dot{x} + B\sin x_1 \\ \dot{x}_3 &= \theta \end{aligned} \quad (9)$$

where B, C, and D are constant.

Substituting (1) into (2), we obtain a state equation on $\dot{x}_1$, $\dot{x}_2$, and $\dot{x}_3$ as follows:

$$\begin{aligned} \dot{x}_1 &= Dv + C\cos x_2 \\ \dot{x}_2 &= Dv + B\sin x_1 \\ \dot{x}_3 &= \omega \end{aligned} \quad (10)$$

We now design the inputs as follows [10]:

$$\begin{aligned} v &= A/D \\ \omega &= C\sin x_2 + B\cos x_1 \end{aligned} \quad (11)$$

Finally, we can get the state equation of the mobile robot as follows:

$$\begin{aligned} \dot{x}_1 &= A\sin x_3 + C\cos x_2 \\ \dot{x}_2 &= B\sin x_1 + A\cos x_3 \\ \dot{x}_3 &= C\sin x_2 + B\cos x_1 \\ \dot{x} &= V\cos x_3 \\ \dot{y} &= V\sin x_3 \end{aligned} \quad (12)$$

Equation (12) includes the Arnold equation.

2) Chua's equation

Using the methods explained in equations (9)-(12), we can obtain equation (13) with Chua's equation embedded in the mobile robot.

$$\begin{aligned} \dot{x}_1 &= \alpha(x_2 - g(x_1)) \\ \dot{x}_2 &= x_1 - x_2 + x_3 \\ \dot{x}_3 &= -\beta x_2 \\ \dot{x} &= V \cos x_3 \\ \dot{y} &= V \sin x_3 \end{aligned} \tag{13}$$

Using equation (13), we obtain the embedding chaos robot trajectories with Chua's equation.

3) Hyper-chaos equation

Combination of equation (1) and (5) or (6), we define and use the following state variables (14) or (15)

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

$$\begin{pmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \\ \dot{x} \\ \dot{y} \end{pmatrix} = \begin{pmatrix} \alpha[y^{(j)} - h(x^{(j)}] \\ x^{(j)} - y^{(j)} + z^{(j)} + D_y(x^{(j-1)} - 2x^{(j)} + x^{(j+1)}) \\ -\beta y^{(j)} \\ v\cos x_3 \\ v\sin x_3 \end{pmatrix} \tag{15}$$

Using equation (14) and (15), we obtain the embedding chaos robot trajectories with Hyper-chaos equation.

4) Hamilton equation

Combination of equation (1) and (7), we define and use the following state variables:

$$\begin{pmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x} \\ \dot{y} \end{pmatrix} = \begin{pmatrix} x_1(13 - x_1^2 - y_1)^2 \\ 12 - x_1(13 - x_1^2 - y_1^2) \\ v\cos x_1 \\ v\sin x_1 \end{pmatrix} \tag{16}$$

Using equation (16), we obtain the embedding chaos robot trajectories with Hamilton equation.

5) Lorenz equation

Combination of equation (1) and (8), we define and use the following state variables:

$$\begin{pmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \\ \dot{x} \\ \dot{y} \end{pmatrix} = \begin{pmatrix} \sigma(y - x) \\ \gamma x - y - xz \\ xy - bz \\ v\cos x_3 \\ v\sin x_3 \end{pmatrix} \tag{17}$$

Eq. (17) is including Lorenz equation. The behavior of Lorenz equation is chaos. We can get chaotic mobile robot trajectory.

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:

$$\begin{aligned} \dot{x} &= y \\ \dot{y} &= (1 - y^2)y - x \end{aligned} \tag{18}$$

From equation (18), we can get the following limit cycle as shown in Fig. 2.

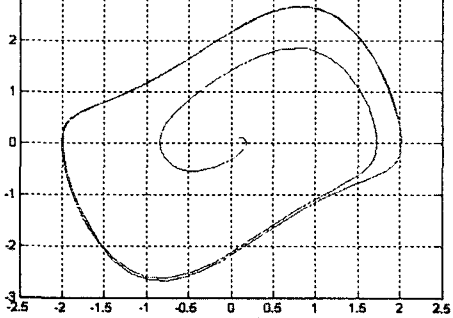


Fig.2 Limit cycle of VDP

3.2 Mirror mapping

Equations (12) - (17) 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. (18) and (19). Whenever the robots approach a wall or obstacle, we calculate the robots' new position by using Eq. (18) or (19).

$$A = \begin{pmatrix} \cos\theta & \sin\theta \\ \sin\theta & -\cos\theta \end{pmatrix} \tag{18}$$

$$A = \frac{1}{1+m}\begin{pmatrix} 1-m^2 & 2m \\ 2m & -1+m^2 \end{pmatrix} \tag{19}$$

We can use equation (18) when the slope is infinity, such as $\theta = 90$, and use equation (19) 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:

$$D = \frac{0.325}{(0.2D_k+1)e^{3(0.2D_k-1)}} \tag{20}$$

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

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

$$\begin{bmatrix} \overline{x_k} \\ \overline{y_k} \end{bmatrix} = \begin{bmatrix} x_0 - y \\ 0.5(1-y_0-y)^2(y_0-y)-x_0-x \end{bmatrix} \tag{21}$$

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:

$$\begin{aligned} L &= \sqrt[2]{(\overline{x_{vdp}}^2 + \overline{y_{vdp}}^2)} \\ I &= \sqrt{(x_r^2 + y_r^2)} \\ \overline{x_k} &= \frac{x_k}{L}\frac{I}{2}, \quad y_k = \frac{y_k}{L}\frac{I}{2} \end{aligned} \tag{22}$$

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

$$\begin{pmatrix} \dfrac{\sum_k^n((1-\frac{D_k}{D_0})\overline{x} + \frac{D_K}{D_0}\overline{x_k}}{n} \\ \dfrac{\sum_K^N((1-\frac{D_k}{D_0})\overline{y} + \frac{D_k}{D_0}\overline{y_k})}{n} \end{pmatrix} \tag{23}$$

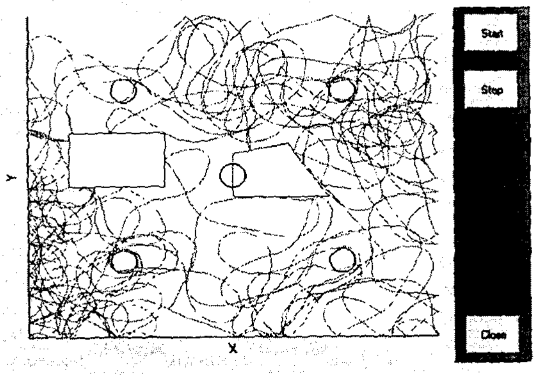
Using equations (20)-(23), we can calculate the avoidance method of the obstacle in the Arnold equation, Chua's equation, hyper-chaos , Hamilton and Lorenz trajectories with one or more VDP obstacles.

Ⅳ. Obstacle Avoidance in the Chaotic Mobile Robot

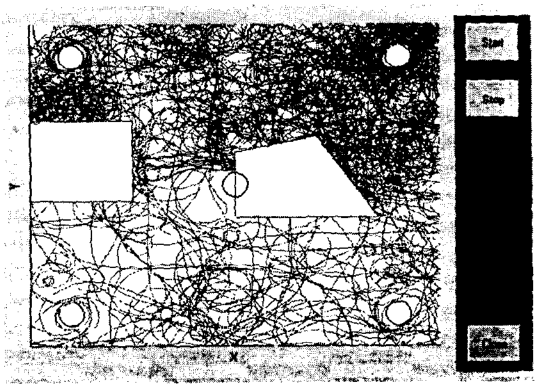
In this section, we proposed a new obstacle avoidance method which is according to dangerous degree with Lorenz equation, Hamilton equation, hyper-chaos equation.

We have to ensure against robot risk with distance limit, if there is a dangerous situation when robots are avoid to obstacle. To do this, we constrained approach obstacle distance for the degree of robots.

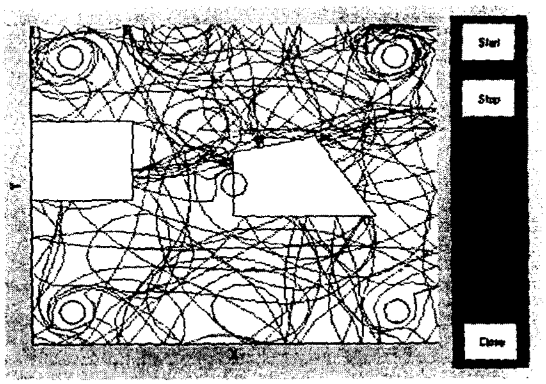
In Fig. 3, we can see the robot trajectories of obstacle avoidance results, (a) Arnold robot, (b) Chua robot, (c) hyper-chaos robot, (d) Hamilton robot, (e) Lorenz robot trajectories respectively.



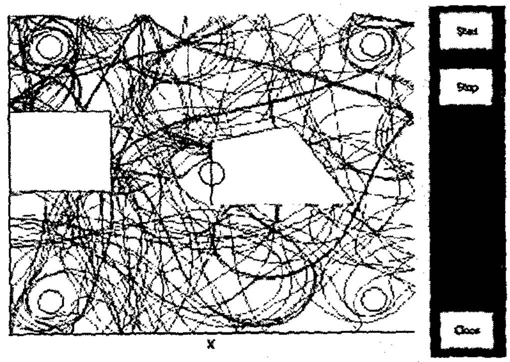
(a) Arnold robot trajectories



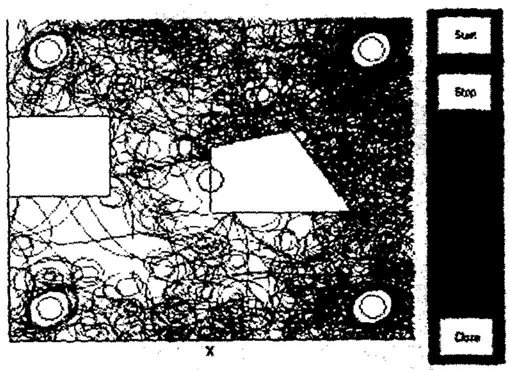
(b) Chua's robot trajectories



(c) Hyper-chaos robot trajectories



(d) hamilton robot trajectories



(e) Lorenz robot trajectories

Fig 3. Robot trajectory

V. Conclusion

In this paper, we proposed a chaotic mobile robot, which employs a mobile robot with Arnold equation, Chua's equation, Hyper-chaos equation, Hamilton equation and Lorenz equation trajectories, and also proposed an obstacle avoidance method in which we assume that the obstacle has a Van der Pol equation with an unstable limit cycle.

We designed robot trajectories such that the total dynamics of the mobile robots was characterized by an Arnold equation, Chua's equation, Hyper-chaos equation, Hamilton equation and Lorenz equation and we also designed the robot trajectories to include an obstacle avoidance method with fixed obstacle and VDP obstacle. By the numerical analysis, it was illustrated that obstacle avoidance methods with a Van der Pol equation that has an unstable limit cycle gave the best performance.

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