The Collision Avoidance Method in the Chaotic Robot with Hyperchaos Path

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ABSTRACT

In this paper, we propose a method to avoid obstacles that have unstable limit cycles in a Hyperchaos trajectory surface. We assume all obstacles in the chaos trajectory surface have a Van der Pol equation with an unstable limit cycle. When a chaos robot meets an obstacle in a hyper-chaos equation trajectory, the obstacle reflects the robot. We also show computer simulation result of hyperchaos equation trajectories with one or more Van der Pol obstacles.

KEYWORD

chaos, mobile robot, hyperchaos equation, SC-CNN

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.

In this paper, we propose a method to avoid obstacles using unstable limit cycles in the hyperchaos trajectory surface. We assume that all obstacles in the hyperchaos trajectory surface have a Van der Pol equation with an unstable limit cycle. When chaos robots meet obstacles among their arbitrary wandering in the hyperchaos trajectory, which is derived using hyperchaos circuit equations such as N-double scroll equation or SC-CNN, obstacles reflect the chaos robots.

Computer simulations also show multiple obstacles can be avoided with a hyperchaos equation.

Ⅱ. Chaotic Mobile Robots Equation

2.1 Mobile Robot

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

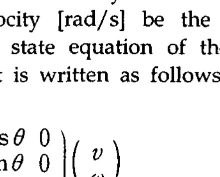


Fig. 1 Two-wheeled mobile robot

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

$$\begin{pmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{pmatrix} = \begin{pmatrix} \cos\theta & 0 \\ \sin\theta & 0 \\ 0 & 1 \end{pmatrix} \begin{pmatrix} v \\ \omega \end{pmatrix} \quad (1)$$

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

2.2 Hyperchaos Equations

To create a hyperchaos circuit, we use the n-double scroll using the weak coupling method[11]

1) n-double scroll circuit

In order to synthesize a hyperchaos circuit, we first consider Chua's circuit modified to an n-double scroll attractor. The electrical circuit for obtaining n-double scroll, according to the implementation of Arena et al. [12] is given by

$$\begin{aligned}\dot{x}&=\alpha[y-h(x)]\\ \dot{y}&=x-y+z \\ \dot{z}&=-\beta y\end{aligned} \tag{2}$$

with a piecewise linear characteristic

$$h(x)=m_{2n-1}x+\frac{1}{2}\sum_{i=1}^{2n-1}(m_{i-1}-m_i)(|x+c_i|-|x-c_i|) \tag{3}$$

consisting of 2(2n-1) breakpoint, where n is a natural number. In order to generate n double scrolls one takes $\alpha=9$ and $\beta=14.286$. Some special cases are:

1-double scroll

$m_0=-1/7,\ m_1=2/7,\ c_1=1$

2-double scroll

$m_0=-1/7,\ m_1=2/7,\ m_2=-4/7,$
$m_3=m_1,\ c_1=1,\ c_2=2.15,\ c_3=3.6$

3-double scroll

$m_0=-1/7,\ m_1=2/7,\ m_2=-4/7,$
$m_3=m_1,\ m_4=m_2,\ m_5=m_3,\ c_1=1,$
$c_2=2.15,\ c_3=3.6,\ c_4=8.2,\ c_3=13$

2) Hyperchaos Circuit Equation

To synthesize a hyperchaos circuit, we consider one-dimension Cellular Neural Network(CNN) with n double scroll cell[12]. The following equations describe a one-dimensional CNN consisting of identical n-double cell with diffusive coupling as

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

or

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

where L denotes the number of cells. We impose the condition that $x^{(0)}=x^{(L)},\ x^{(L+1)}=x^{(1)}$ for equation (4) and (5). For the coupling constants, $K_0=0, K_j=K(j=1,\ldots,L-1)$ and positive diffusion coefficients D_x, D_y are chosen base on stability theory.

2.3. Embedding of Hyperchaos Equation in the Robot

In order to embed the hyperchaos equation into the mobile robot, we define and use the Hyperchaos equation as follows.

$$\begin{aligned}\dot{x}^{(j)}&=\alpha(y^{(j)}-h(x^{(j)}+D_x(x^{(j-1)}-2x^{(j)}+x^{(j+1)})\\ \dot{y}^{(j)}&=x^{(j)}-y^{(j)}+z^{(j)}\\ \dot{z}^{(j)}&=-\beta y^{(j)}\\ \dot{x}&=v\cos x_3\\ \dot{y}&=v\sin x_3\end{aligned} \tag{6}$$

Using equation (6), we obtain the embedding hyperchaos robot trajectories

Fig. 2 shows the phase plane of the incremental component of the mobile robot.

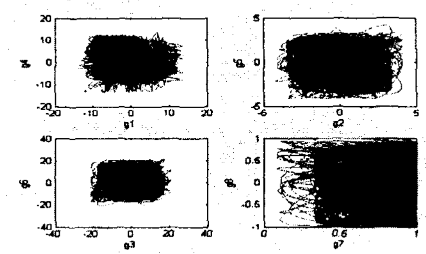


Fig. 2 Phase portrait of variation components (dx, dy, dz) trajectories in Hyperchaos circuit.

2.4 Mirror Mapping.

Equation (7) and (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 obstacles. To avoid a boundary or obstacle, we consider mirror mapping when the robots approach walls or obstacles using Eq. (7) and (8).

Whenever the robots approach a wall or obstacle, we calculate the robots' new position by using Eq. (7) or (8).

$$A=\begin{pmatrix} \cos\theta & \sin\theta \\ \sin\theta & -\cos\theta \end{pmatrix} \tag{7}$$

$$A=\frac{1}{1+m}\begin{pmatrix} 1-m^2 & 2m \\ 2m & -1+m^2 \end{pmatrix} \tag{8}$$

We can use equation (7) when the slope is infinity, such as , and use equation (8) when the slope is not infinity.

Fig. 3 Mirror mapping

III The Chaotic Behavior of Hyperchaos Robot with Mirror

In this section, we will study avoidance behavior of a hyperchaos trajectory with obstacle mapping, relying on the Hyperchaos.

Fig. 4 show that a hyperchaos robot can avoid obstacles with mirror mapping Eq. (7) and (8), relying on equation (6). The chaos robot has two fixed obstacles, and we can confirm that the robot adequately avoided the fixed obstacles in the Hyperchaos trajectories.

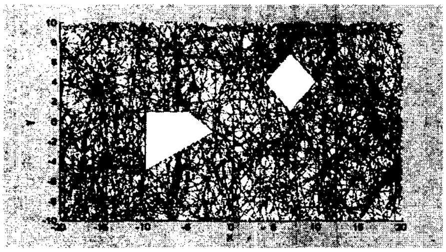


Fig. 4 Hyperchaos equation trajectories of chaos robot with obstacle

IV The Mobile Robot with Van der Pol Equation 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.

4.1 VDP Equation as an Obstacle

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

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

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

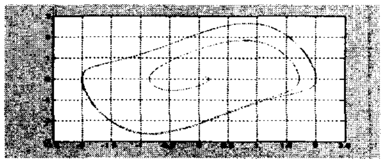


Fig. 5 Limit cycle of VDP

4.2. Magnitude of Distracting Force from the Obstacle

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

$$|D|=\sum_{k=1}^{n}\frac{0.325n}{(0.2D_k+1)e^{3(0.2D_k-1)}} \tag{10}$$

where is the number of obstacles within a constant distance to mobile robot , and is the distance between each effective obstacle and the mobile robot.

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

$$\begin{aligned} \vec{x}&=x_0-y \\ \vec{y}&=(1-(y_0-y^2)(y_0-y)-(y_0-y) \end{aligned} \tag{11}$$

where are the coordinates of the center point of each obstacle. Then we can calculate the magnitude of the VDP direction vector (L), the magnitude of the moving vector of the virtual robot (I) and the enlarged coordinates (I/2L) of the magnitude of the virtual robot in VDP(,) as follows:

$$\begin{aligned} L&=\sqrt{x_{vdpx}^2+y_{vdpy}^2} \\ I&=\sqrt{x_r^2+x_r^2} \\ x_k'&=\frac{x_k}{L}\frac{I}{2},\ y_k'=\frac{y_k}{L}\frac{I}{2} \end{aligned} \tag{12}$$

Finally, we can get the Total Distraction

Vector (TDV) as shown by the following equation.

$$\sum_{k=1}^{n}((1-\frac{D_k}{D_0})x+\frac{D_k}{D_0}x_k)$$
$$\sum_{k=1}^{n}((1-\frac{D_k}{D_0})y+\frac{D_k}{D_0}y_k) \quad (13)$$

Using equations (6) and (7)-(13), we can calculate the avoidance method of the obstacle in the Hyperchaos equation trajectories with one or more VDP obstacles.

In Fig. 6, the computer simulation result shows that the chaos robot has two robots and a total of 6 VDP obstacles, including two VDP obstacles at the origin in the Hyperchaos equation trajectories. We can see that the robot sufficiently avoided the obstacles in the Hyperchaos equation trajectories.

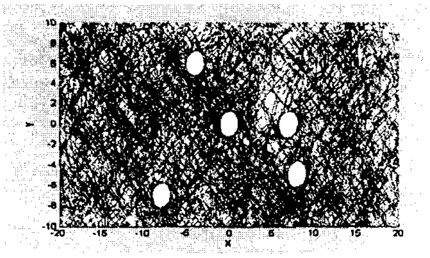


Fig. 6 Computer simulation result of obstacle avoidance with 2 robots and 5 obstacles in Hyperchaos equation trajectories.

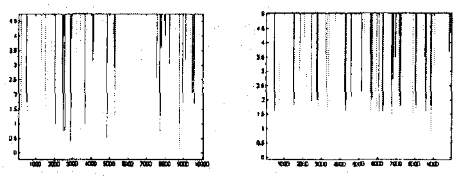
4.3. The relationship between two mobile robots

At this point, we consider two mobile robots that have VDP trajectories. If the two mobile robots do not have VDP trajectories, they may happen to collide. However, here if the two robots approach each other, because they have a VDP equation with an unstable limit cycle, the two robots repel each other. As a result, the two robots never happen to collide.

We assume that if the distance between the two robots is less than 0.5 m, the possibility of collision is higher than if the distance between the two robots is more than 0.5m. Thus, we can say that two robots with less than 0.5m between them have collided.

In Fig 8(a), we can see that when VDP trajectories are not applied to the Hyperchaos equation trajectory of each robot, the robots approach to each other very closely.(1500S, 2500S, 4600S, 5300S, 8800S, 8950S etc.).

In order to avoid collision, we applied a VDP equation to the Hyperchaos equation trajectory of each robot. In Fig 8(b), we can see that there is no point when the robots collided. So, in order to avoid collision between the two robots, we need to apply a VDP equation in the Hyperchaos equation trajectories.



(a) (b)

Fig. 8 When VDP trajectories are not applied to the Hyperchaos equation trajectory of each robot (a), when they are applied (b).

VI Conclusion

In this paper, we proposed a chaotic mobile robot, which employs a mobile robot with hyperchaos equation 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.

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