Obstacle avoidance method in the UAV

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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. When a chaos UAVs meet an obstacle in an Arnold equation or Chua' s equation trajectory, the obstacle reflects the UAV.

Key words : Chaos, Chua's equation, UAV, Arnold equation

1. 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 obsta le avoidance methods.

In this paper, we propose a method to obstacle avoidance 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 UAV(Unmanned Aerial Vehicles) meet obstacle among their arbitrary wandering in the chaos trajectory, which is derived using chaos circuit equations such as the Arnold equation, Chua' s equation, the obstacle reflective the chaos UAVs.

2. Chaotic UAV Equation

2.1 UAV[24]

We assume that each UAV is equipped with standard autopilots for heading hold and mach hold. In order to focus on the essential issues, we will assume that altitude is held constant. Let $(x, y), \psi,$ and v denote the inertial position, heading angle, and velocity for the UAV respectively. Then the resulting kinematics equations of motion are

$$\begin{aligned} \dot{x} &= v\cos(\psi) \\ \dot{y} &= v\sin(\psi) \\ \dot{\psi} &= \alpha_{\psi}(\xi^{c} - \psi) \\ \dot{v} &= \alpha_{v}(v^{c} - v) \end{aligned} \quad (1)$$

where ψ^c and v^c are the commanded heading angle and velocity to the autopilots, and α_{ψ} and α_v are positive constraints [22,23].

Assuming that α_v is large compared to α_{ψ}, Eq. (1) reduces to

$$\begin{aligned} \dot{x} &= v\cos(\psi) \\ \dot{y} &= v\sin(\psi) \\ \dot{\psi} &= \alpha_{\psi}(\xi^{c} - \psi) \end{aligned} \quad (2)$$

Letting $\psi^{c} = \psi + (1/\alpha_{\psi})\omega$ and $v^c \approx v$, Eq. (2) becomes

$$\begin{aligned} \dot{x} &= v\cos(\psi) \\ \dot{y} &= v\sin(\psi) \\ \dot{\psi} &= \omega \end{aligned} \tag{3}$$

Eq.(3) rewritten as follows,

$$\begin{pmatrix} \dot{x} \\ \dot{y} \\ \dot{\psi} \end{pmatrix} = \begin{pmatrix} \cos\theta & 0 \\ \sin\theta & 0 \\ 0 & 1 \end{pmatrix} \begin{pmatrix} v \\ \omega \end{pmatrix} \tag{4}$$

Eq. (3) is similar to two wheel mobile robot equation (5).

$$\begin{pmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{pmatrix} = \begin{pmatrix} \cos\theta & 0 \\ \sin\theta & 0 \\ 0 & 1 \end{pmatrix} \begin{pmatrix} v \\ \omega \end{pmatrix} \tag{5}$$

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

2.2 Arnold equation

We define the Arnold equation as follows:

$$\begin{aligned} \dot{x}_1 &= A\sin x_3 + C\cos x_2 \\ \dot{x}_2 &= B\sin x_1 + A\cos x_3 \\ \dot{x}_3 &= C\sin x_2 + B\cos x_1 \end{aligned} \tag{6}$$

where A, B, C are constants.

2.3 Chua' s equation

We define the Chua's equation as follows:

$$\begin{aligned} \dot{x}_1 &= \alpha(x_2 - g(x_1)) \\ \dot{x}_2 &= x_1 - x_2 + x_3 \\ \dot{x}_3 &= -\beta x_2 \end{aligned} \tag{7}$$

where

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

2.4. Embedding of Chaos circuit in the UAV

In order to embed the chaos equation into the UAV, we define and use the Arnold equation and Chua' s circuit equation as follows.

1) Arnold equation

We define and use the following state variables:

$$\begin{aligned} \dot{x}_1 &= D\dot{y} + C\cos x_2 \\ \dot{x}_2 &= D\dot{x} + B\sin x_1 \\ \dot{x}_3 &= \theta \end{aligned} \tag{8}$$

where B, C, and D are constant.

Substituting (4) into (8), we obtain a state equation on $\dot{x}_1$, $\dot{x}_2$, and $\dot{x}_3$ as follows:

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

We now design the inputs as follows [10]:

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

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

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

Equation (12) includes the Arnold equation.

2) Chua' s equation

Using the methods explained in equations (8)-(12), we can obtain equation (13) with Chua' s equation embedded in the UAV.

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

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

2.5 Mirror Mapping

Basically, equation (5) is assumed that the mobile robot moves in a smooth state space without boundary. However, real robot movies in space with boundary like walls or surfaces of obstacles. To avoid a boundary or obstacle, we consider mirror mapping when the robot approach walls or obstacles using the Eq. (14) and (15). Whenever the robot approaches a wall or obstacle, we calculated the robot new position

$$A = \begin{pmatrix} \cos\theta & \sin\theta \\ \sin\theta & -\cos\theta \end{pmatrix} \tag{14}$$

$$A = 1/1+m \begin{pmatrix} 1-m^2 & 2m \\ 2m & -1+m^2 \end{pmatrix} \tag{15}$$

We can use equation (14) when slope is infinitive such as $\theta = 90$ and also use equation (15) when slope is not infinitive.

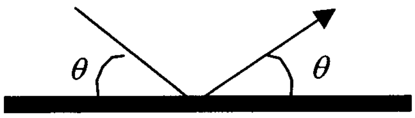

Fig. 1 Mirror mapping

2.6 Van der Pol equation as obstacle.

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

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

$$\begin{aligned} \dot{x} &= y \\ \dot{y} &= (1 - y^2)y - x \end{aligned} \tag{16}$$

From equation (16), we can get the following limit cycle as shown in Fig. 2.

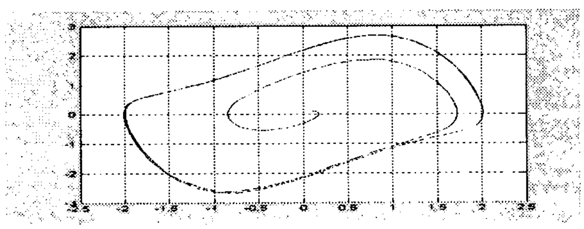

Fig. 2 Limit cycle of VDP

3. A Obstacle Avoid in the UAV

In this section, we proposed a obstacle avoidance method with Arnold equation, and Chua' s equation in the any surface. We designed obstacle avoidance methods which if the UAV has been find the obstacle, the UAV defined any radius around obstacle and then the UAV has been to avoided obstacle within the defined radius.

3.1 Arnold equation

In Fig. 3, we can see the UAV trajectories of obstacle avoidance result with hidden obstacle in the Arnold chaos UAV.

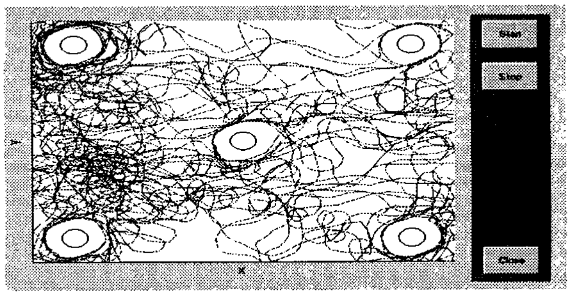

Fig. 3 Computer simulation result of obstacle avoidance with 2 UAVs and 5 obstacles in Arnold equation trajectories.

3.2 Chua's equation

In Fig. 4, we can see the UAV trajectories of target searching result with hidden obstacle in the Chua' s chaos UAV.

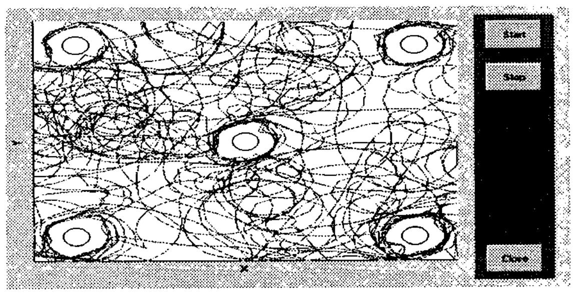

Fig. 4 Computer simulation result of obstacle avoidance with 2 UAVs and 5 obstacles in Chua's equation trajectories.

4. Conclusion

In this paper, we proposed a chaotic UAV, which employs a UAV with Arnold equation and Chua' s equation trajectories, and also proposed a obstacle avoidance method in which we assume that the obstacle have a Van der Pol equation with an unstable limit cycle.

We designed UAV trajectories such that the total dynamics of the UAV was characterized by an Arnold equation and Chua' s equation and we also designed the UAVs trajectories to include an obstacle avoidance method. By the numerical analysis, it was illustrated that obstacle avoidance methods with a Van der Pol equation that have an unstable limit cycle gave the best performance.

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