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Parameter value selection strategy for complete coverage path planning based on the Lü system to perform specific types of missions

Key words: Chaotic mobile robot; Lü system; Complete coverage path planning (CCPP); Parameter value selection strategy; Lyapunov exponent; Pearson correlation coefficient

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Motivation

1. The mobile robots with chaotic characteristics of topological transitivity and sensitive dependence on initial conditions can meet the need of performing the specific types of missions.

2. There is a lack of systematic research on the system parameters and the chaotic and random characteristics of the variables used.

3. We want to select the optional values of the system parameters and chaotic variables with the best random performance to construct a chaotic robot to produce the trajectory with higher randomness and coverage rate.

Main idea

1. The coverage rates of the trajectory generated by the chaotic robot, which are constructed by different values of parameters and variables, are different at the same time; they are also distinct under the same set of values due to sensitivity characteristics.

2. Selecting the parameter values for chaotic system is a complex problem. Any method is not enough to determine the best value range. Therefore, it is necessary to comprehensively consider various methods to determine the system parameter values.

Method

1. We introduce a comprehensive selection strategy based on the Lü system to gradually determine the optional value range of its parameter value.

2. We study the change in chaotic performance with the system parameter value varying by analyzing the dissipative system, the Lyapunov exponents, the phase plane, and the Pearson correlation coefficients of the variables.

3. We construct a chaotic mobile robot by combining the Lü system using the chosen chaotic variables and the parameter values with the kinematic equation of the robot to perform the CCPP task for the specific types of missions.

Major results

- Value range of parameter *c* of being a dissipative system

$$\nabla V = \frac{\partial \dot{x}}{\partial x} + \frac{\partial \dot{y}}{\partial y} + \frac{\partial \dot{z}}{\partial z}. \qquad (3)$$

$$\nabla V = \frac{\partial \dot{x}}{\partial x} + \frac{\partial \dot{y}}{\partial y} + \frac{\partial \dot{z}}{\partial z} = -a + c - b = -36 + c - 3 = -39 + c < 0$$

The good range of the parameter: $c < 39$

Major results (Cont’d)

- Analysis of L_E spectrum of the Lü system

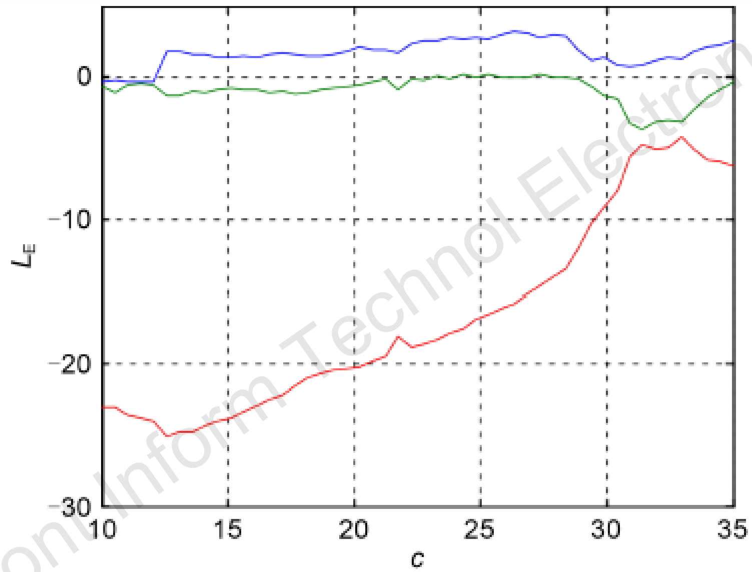

Fig. 2 L_E spectrum of the Lü system

The three lines represent the maximum, medium, and minimum indices of L_E from top to bottom, which are represented by L_{E1}, L_{E2}, and L_{E3}, respectively

The good range of the parameter: $c \in [14, 35]$

Major results (Cont'd)

- Analysis of phase plane

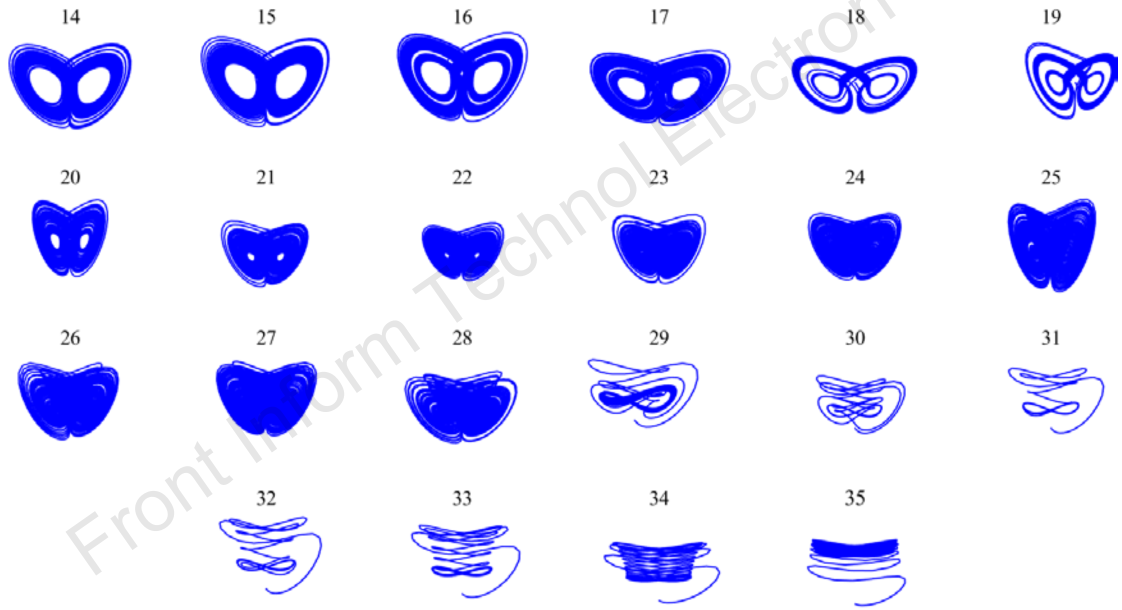

Fig. S4 The phase planes of *x*-*z* at each integer value of system *c* of the Lü system (*c*∈[14, 35])

The good range of the parameter: *c*∈[20, 28]

Major results (Cont'd)

- L_E analyzing

Table 1 L_E values when $c \in [20, 28]$

c	L_{E1}	L_{E2}	L_{E3}
20	1.898	−0.461	−20.296
21	2.042	−0.480	−19.465
22	2.185	−0.040	−19.070
23	2.511	−0.016	−18.434
24	2.740	0.207	−17.897
25	2.884	0.170	−17.020
26	3.002	0.132	−16.105
27	3.209	0.002	−15.191
28	2.893	0.054	−13.936

The good range of the parameter: $c \in [24, 27]$

Major results (Cont'd)

- Pearson correlation coefficient

$$\begin{cases} \bar{X} = \dfrac{1}{N}\sum_{i=1}^{n} X_i, \\ \bar{X}' = \dfrac{1}{N}\sum_{i=1}^{n} X_i'. \end{cases} \quad (4)$$

$$\begin{cases} D(X) = \dfrac{1}{N}\sum_{i=1}^{N} (X_i - \bar{X}), \\ D(X') = \dfrac{1}{N}\sum_{i=1}^{N} (X_i' - \bar{X}'). \end{cases} \quad (5)$$

$$\mathrm{Cov}(X, X') = \frac{1}{N}\sum_{i=1}^{N} (X_i - \bar{X})(X_i' - \bar{X}'). \quad (6)$$

$$P_{XX'} = \frac{\mathrm{Cov}(X, X')}{\sqrt{D(X)D(X')}}. \quad (7)$$

Major results (Cont'd)

- Pearson correlation coefficient

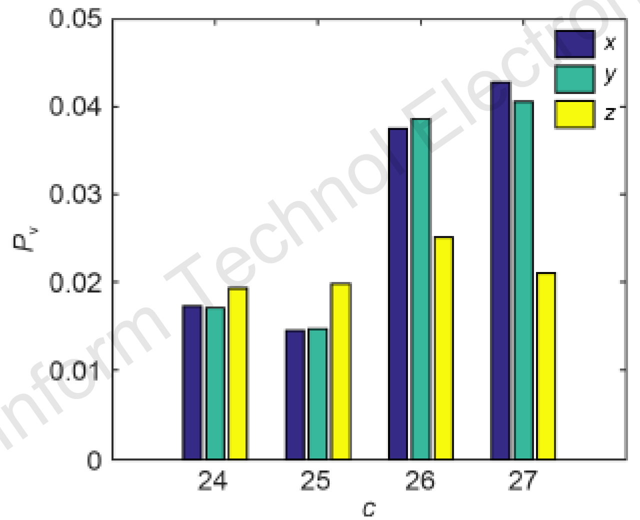

Fig. 3 Comparison of P_v of the Lü system

The good range of the parameter: $c \in [24, 25]$

The good variables of the system: *x* or *y*

Major results (Cont’d)

- Construction of the chaotic mobile robot

$$\begin{cases} \dot{x} = a(y - x), \\ \dot{y} = cy - xz, \\ \dot{z} = xy - bz, \\ \dot{x}_r = v_{rt}\cos x, \\ \dot{y}_r = v_{rt}\sin x. \end{cases} \qquad (9)$$

Major results (Cont’d)

- Coverage performance evaluation of chaotic robot

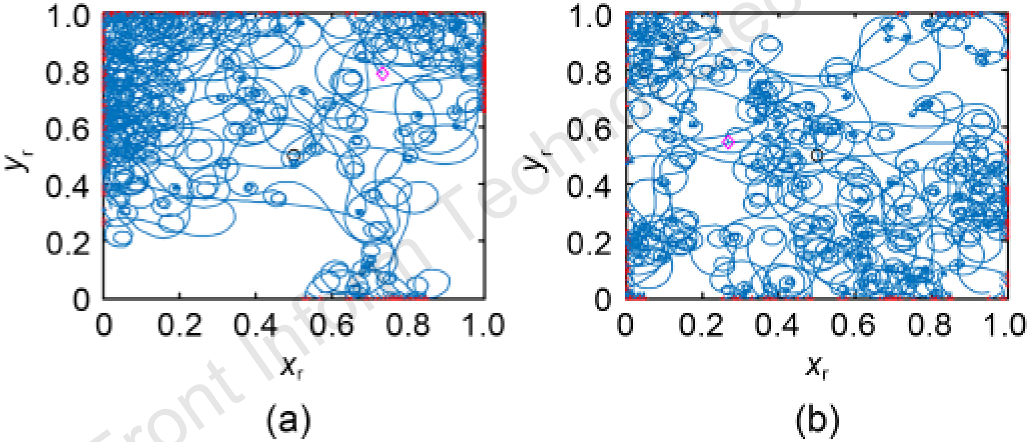

Fig. 7 Coverage trajectories formed after static obstacle avoidance based on the Lü system: (a) c=20; (b) c=24

Major results (Cont'd)

- Coverage performance evaluation of chaotic robot

Table 3 The mean coverage rate of the constructed chaotic robot based on the Lü system when $c \in [24, 27]$

c	x (%)	y (%)	z (%)	c_{xyz} (%)
24	97.1	96.5	95.1	96.2
25	97.6	96.6	95.5	96.5
26	88.5	89.1	92.2	89.9
27	83.8	86.9	92.6	87.7

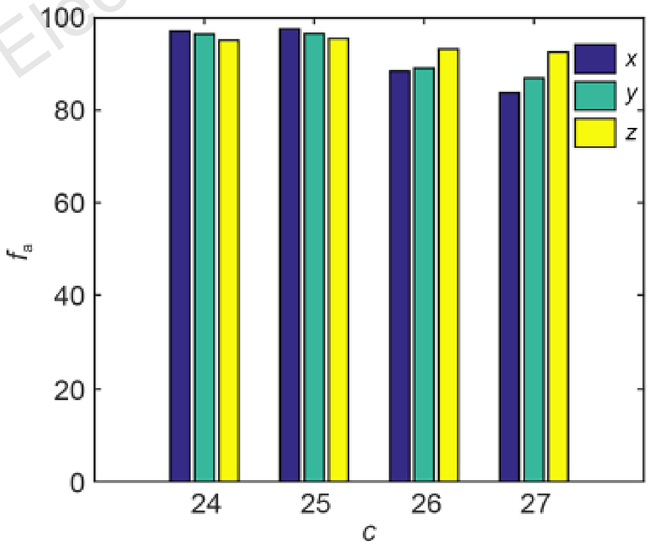

Fig. 8 Comparison of the mean coverage rate based on the Lü system when $c \in [24, 27]$

Conclusions

1. It is easier to generate the coverage trajectory with good randomness and high coverage rate to choose the Lü system as the construction equation of the chaotic robot due to its better chaotic performance and randomness.

2. Combining the deterministic system, phase plane, L_E index, and Pearson correlation coefficient can gradually reduce the selection range of parameters and finally determine the best values of parameters and variables to construct a chaotic robot with high randomness and coverage rate.

Conclusions (Cont'd)

3. The system parameters and variables with a high coverage rate can be chosen by considering only the chaotic characteristics and randomness of the system and variables.

4. The system can also obtain better distribution characteristic of individual variables in the positions where the parameter combinations have a lower value of L_E and the average coverage rate is low. The value of the average coverage rate is basically consistent with that of L_E.

Conclusions (Cont'd)

5. This method is universal. It is applicable not only to Lü and Lorenz systems, but also to Arnold, Rössler, Chua and other three-dimensional chaotic systems that can be used to construct the chaotic robot to perform the CCPP task.

Caihong LI received her BS degree in Industrial Automation from Southwest University of Science and Technology, Mianyang, China, in 1993, MS degree in Control Science from Shandong University of Science and Technology, Jinan, China, in 2000, and PhD degree in Detection Technology and Automation Device from Shandong University, Jinan, China, in 2007. She is currently a professor with the School of Computer Science and Technology, Shandong University of Technology, China. Her research interests include intelligent mobile robot control, path planning for the mobile robot, and the applications of chaotic theory in the complete coverage path planning.

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