Automatic Track Control Method for Multi-UAV Based on Embedded System

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Abstract. In the case of multiple UAVs, the navigation area of UAV is planned to effectively improve the accuracy of track control and ensure the navigation safety. Because there are some problems such as track deviation and delay of obstacle avoidance when using traditional methods to control the multi-UAV track, it is difficult to meet the requirements of track control accuracy and safety, an automatic control method of multi-UAV track based on embedded system is proposed. The mathematic model of UAV track control is designed based on the fuzzy algorithm, in order to obtain the route deviation parameters accurately, and the area range of UAV track is standardized according to the calculation results, and the control steps of UAV track are planned within the track range, so as to achieve the automatic control target of multi-UAV track. The experimental results show that the embedded multi-UAV track automatic control method can effectively solve the problem of large track deviation, and can avoid navigation obstacles and achieve the research goal of effective control of multi-UAV track. The experimental results show that the UAV under the control of this method can avoid obstacles accurately, solve practical problems effectively, it can effectively solve the problems of the traditional methods in track control and obstacle avoidance, it shows that the proposed method has practical application value.

Keywords: Embedded · Uav · Track control · Fuzzy algorithm

1 Introduction

UAV has the characteristics of light weight, low cost and strong adaptability. It has become a research hotspot in many countries in the world. In the current local battle dominated by information technology, UAV can achieve ideal results in reconnaissance, monitoring, guidance and strike. More and more countries also put the research and development of UAV into their military development strategy. With the rapid development of national economy, the flight area of UAV is becoming narrower and narrower, which makes it difficult to meet the requirements of track control accuracy and safety [1]. In order to improve the control accuracy of UAV's lateral track, the research results of excellent researchers at home and abroad in this field were investigated and analyzed [2].

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In reference [3], a three-dimensional path planning method based on the improved ispo algorithm is proposed, which applies the ispo algorithm to the path planning, and on this basis, the attraction effect between sub vectors is introduced, which effectively overcomes the defect that the algorithm is easy to fall into the local optimal solution. The simulation results show that the improved ispo algorithm has better precision and ability in track planning, but there is a certain track deviation. In reference [4], a new method of automatic acquisition of UAV's illegal navigation trajectory data is studied. The model of lidar signal and target scene's action process is established. The mapping part of each laser beam on the target scene surface is regarded as the laser footprint, and the convolution calculation of the response function of the corresponding laser footprint of the laser beam and the time distribution function of the laser radar's transmitted signal is completed, The echo signal of the corresponding target area of the laser footprint and the feedback of the laser radar signal are obtained. The distribution model of the single imaging echo peak point trajectory is established based on the feedback echo signal, and the navigation trajectory data of the UAV is obtained. For the actual navigation trajectory and the predefined navigation trajectory of the UAV, the optimized modified Hausdorff distance formula (MHD) is used to measure the matching degree of the trajectory data, According to the experience setting threshold, if the matching degree exceeds the threshold, it is considered that the actual trajectory does not match the preset trajectory of the UAV, and the corresponding actual trajectory is regarded as the illegal trajectory of the UAV, and the data of the illegal trajectory is captured. The results show that the proposed method can detect the illegal trajectory of the UAV in time, but the trajectory deviates from the actual trajectory.

In response to the above problems, the control method of UAV's lateral track was studied with embedded method. A mathematical model of track control based on fuzzy algorithm is proposed. The track control equation of UAV is solved by controlling the track of UAV, and the running state of UAV is described and controlled. In the case of multiple UAVs, the navigation area of UAV is planned, and different control schemes are proposed according to the requirements of different precision navigation control, so as to effectively improve the accuracy of track control, ensure navigation safety and fully meet the research objectives.

2 Automatic Track Control Method for Multi-UAV Based on Embedded System

2.1 Mathematical Model of UAV Track Deviation

The track of multiple UAVs is complex, so it is necessary to control the track coordinates with embedded method. In order to achieve the goal of precise track control, firstly, the track range of UAV is positioned by using the fuzzy algorithm and coordinate situation.

If z is the standard track, P and Q are the maximum and minimum DOF ranges of the standard track, and U represent the resistance during navigation, then the standard range of plane motion of UAV can be calculated by combining the fuzzy algorithm.

$$\begin{cases} x = U(\overline{a} - ct^2 - \frac{1}{2}m) \\ y = P(\overline{a} - ct^2 - m) \\ z = Q(\overline{a} - ct^2 - 2m) \end{cases} \tag{1}$$

In the formula, $\overline{a}$ represents the route control system, c represents the moment of inertia of the UAV's centroid, the origin is centroid m, and t represents the inertia of unmanned aerial vehicle during navigation. In the course of route control, it is necessary to input the change of navigation deviation E in time, and adjust the parameter coordinates in time by using the principles of adaptive proportional unit, integral unit and differential unit. Let φ_z represents the output of the controller, N represents variable parameters, and A represents non-linear functions. If the error variable range is $\{f_1, f_n\}$, the input and output variables are uniformly distributed, and the adaptive output characteristic formula is given.

$$\Delta N(\alpha) = E_1 \Delta\varphi_z(x) + E_2 \Delta\varphi_z(y) + E_3 \Delta\varphi_z(z)[A - N]\Delta(f_n - 1) \tag{2}$$

If T is the accuracy of proportional coefficient control system, α is the stability index of integral coefficient control system and τ is the dynamic characteristics of differential coefficient control system.

$$\begin{aligned} \Delta T(\delta) &= \Delta N(\alpha) - \Delta\varphi(\tau - 1) \\ \Delta T(\delta - 1) &= \Delta N(\alpha - 1) - \Delta\varphi(\tau - 2) \end{aligned} \tag{3}$$

So far, the design of the mathematical model of track control has been completed. According to the above attribute model, the method of effective multi-UAV track control can be optimized [5, 6].

2.2 Area Range Control of Multi-UAV Track

Combined with the above algorithm, the embedded route tracking control device is optimized to better stabilize the UAV heading and ensure the UAV navigation safety. Combining the embedded method, the route information is rearranged and classified, the UAV joint communication data is integrated, and the multi-UAV track is planned. The data rearrangement method is as follows: Assuming that there are n data UAV paths in the data integration system of multi-UAV network, K represents the transmission vector of a certain target state, and its target state model algorithm is as follows:

$$L = N_s C_n^i (SK_n + H) \tag{4}$$

In the formula, S represents the process vector with an average value of 0, C represents the state transition vector of UAV operation information transmission, H represents the impact of noise control in the process of path information transmission, and i represents the number of UAVs in operation [7–9].

C_{n-1}^{i} can be expressed by formula (5):

$$C_{n-1}^{i} = S_n H^i / L \tag{5}$$

According to the above algorithm, UAV path transmission data are rearranged to effectively control the hierarchical integration state of path management data. Further calculation shows that the regional information transmission nodes can be judged by obtaining the ranking results of information, so as to realize the hierarchical integration of data of Multi-warship joint communication module. The track distribution of regional information is shown in Fig. 1:

As shown in the Fig. 1, the UAV track automatic control system simplifies and decomposes the complex track range into three closed-loop cascade modules, ensures the rapid and accurate control and management of UAV course, defines three standard control parameters in the track range, constitutes a fuzzy adaptive controller to control the UAV track, and budget the UAV navigation deviation in order to control and manage the UAV course quickly and accurately. In order to ensure the accurate and effective control of multi-UAV track, UAV should be detected and corrected in time when deviation occurs.

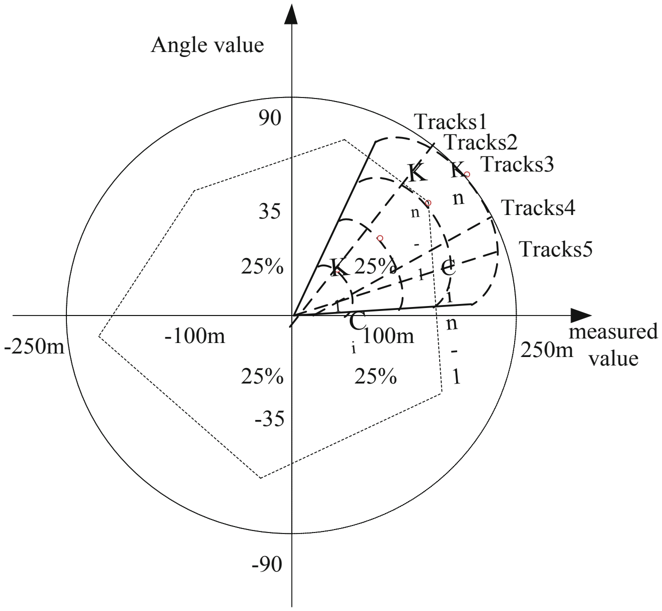

Fig. 1. Multi-UAV track area range management.

2.3 Realization of Automatic Track Control Method for Multi-UAV

In order to ensure the UAV's stable operation, the UAV's motion control system is planned [10, 11]. Accurate acquisition and accurate analysis of environmental data, combined with the multi-UAV track area environment to develop the corresponding navigation path. The route planning method of UAV is shown in Fig. 2:

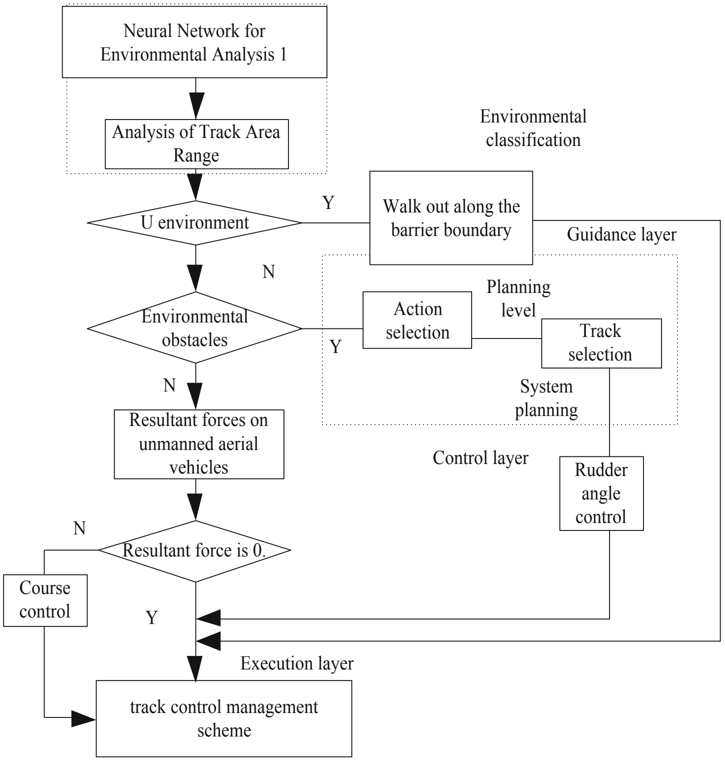

Fig. 2. UAV track control steps.

Usually, obstacles in the process of UAV moving will repel the action of UAV and form potential energy. Through investigation and analysis, it is found that the closer the UAV is to the obstacle, the bigger the potential energy is, and vice versa, the smaller the potential energy is. It can be concluded that the potential energy between the UAV and the obstacle is inversely proportional to the distance. The UAV can move to the target point quickly and accurately through the route planning step [12, 13]. It can be concluded that the potential energy between UAV and obstacle is inversely proportional to the distance. The potential energy function algorithm is as follows:

$$U_{\mathrm{n}} = \left\{ \begin{array}{ll} C_{n-1}^{i}/S_n E_{\max}, & (S_n \neq 0, E_{\max} \neq 0) \\ 0, & others \end{array} \right\} \tag{6}$$

In the formula, n represents the distance between the point where the UAV is located and the obstacle, and S_n is the weighted coefficient. $E_{\max}$ is the maximum range of the two. When the value of E is not fixed, the repulsion force W affected by the obstacle when the UAV collides with the obstacle is:

$$W = -grad(U_n)\left\{\begin{array}{ll} S_n/E^2, & E \leq E_{\max}(E_{\max} \neq 0) \\ 0, & others \end{array}\right\} \tag{7}$$

In order to avoid collision between UAV and obstacles, a minimum safety distance of E_0 can be set. At this time, the repulsion force W affected by obstacles when UAV collides with obstacles can be modified as follows:

$$W = \left\{\begin{array}{ll} \frac{S_N}{E - E_0} - \frac{S_N}{E_{\max} - E_0} & (E \leq E_{\max}) \\ 0, & others \end{array}\right\} \tag{8}$$

Among them, the size of W is affected by the size, speed of UAV and the sparseness of obstacles in the environment [14–16].

Through the above steps, the control of UAV track can be accurately completed, and the research requirements for the automatic control of multi-UAV track can be achieved.

3 Simulation Experiment and Summary

In order to verify the operation effect of UAV track automatic control system, the control parameters of classical UAV course controller are used as initial data, and environmental interference factors are added into the simulation environment. The comparative detection experiments of UAV's track control deviation and route control effect distribution were carried out, and the test data were recorded. Firstly, the comparative detection experiments are carried out under the same environment, and the track control deviation tracking data of the traditional method and the present method are recorded respectively for comparison. The specific data are shown in the Table 1 and Table 2.

Table 1. Data monitoring of trajectory control deviation tracking by traditional method.

Experiment number	Self-propelled Real-time Position			Deviation data	
	x coordinate/m	y coordinate/m	z coordinate/m	Track deviation n/m	Heading angle deviation/ψ
1	0.45	0.75	0.65	0.16	22.89°
2	0.49	1.42	0.82	0.12	18.98°
3	2.45	1.26	0.71	0.33	12.21°
4	1.71	0.94	0.64	0.21	7°
5	1.62	0.18	0.64	0.54	9.24°
6	1.96	0.87	0.51	0.41	12.95°
7	1.70	0.63	0.49	0.52	13.41°

Table 2. Embedded track control deviation tracking data monitoring.

Experiment number	Self-propelled Real-time Position			Deviation data	
	x coordinate/m	y coordinate/m	z coordinate/m	Track deviation n/m	Heading angle deviation/ψ
1	0.15	0.08	0.05	0.002	8°
2	0.29	0.07	0.02	0.07	10°
3	0.12	0.04	0.01	0.08	6°
4	0.08	0.02	0.04	0.09	0°
5	0.06	0.03	0.07	0.06	3°
6	0.07	0.06	0.09	0.05	5°
7	0.06	0.04	0.08	0.04	4°

According to the data from the Table 1 and Table 2, compared with the traditional method, the overall deviation rate loudness of the proposed control method is relatively low, and the accuracy of track control is relatively higher. This is because the method in this paper combines with fuzzy algorithm to design the mathematical model of UAV track control, using this model can accurately obtain route deviation parameters, according to the deviation parameters can effectively correct the flight path of UAV, so as to improve the accuracy of track control.

In order to further test the effect of the embedded multi-UAV track automatic control method, the experimental environment is set as the route deviation environment. At the same time, two corners are designed for the UAV, which are distributed as follows: $\varphi_z < 90^\circ$ small corner and $\varphi_z > 90^\circ$ big corner. In the same environment and detection time, compared with the traditional method and the method in this paper, the effect of track integration control is tested. The test results are shown in Table 3:

Table 3. Comparison of the return effect of UAV in the case of navigation deviation.

UAV Control	Proposed method	Traditional method
Data interface	RS–422	RS–422
Communication rate	9.2	9.0
Horizontal perspective	180/270	100/180
Scanning interval angle	0.9°	0.6°
Scan cycle	30 ms	40 ms
Work environment	–20 °C–70 °C	–20 °C–70 °C
Volume	145 * 170 * 140	145 * 170 * 140
Correction time	23.45 s	8.87
Overshoot	7.12 s	2.10
Speed	308 m/s	297 m/s
Angular velocity	0.2981 m/s	0.2981 m/s
Euler angles	80	60

According to the above test results, it is found that the overall control effect of this method is still higher than that of the traditional method under the same basic equipment information such as data interface and number of data. This proves that compared with the traditional method, the proposed method has better correction effect in the case of navigation deviation.

Compare the track control effects of different methods in barrier free environment, and the results are shown in Fig. 3.

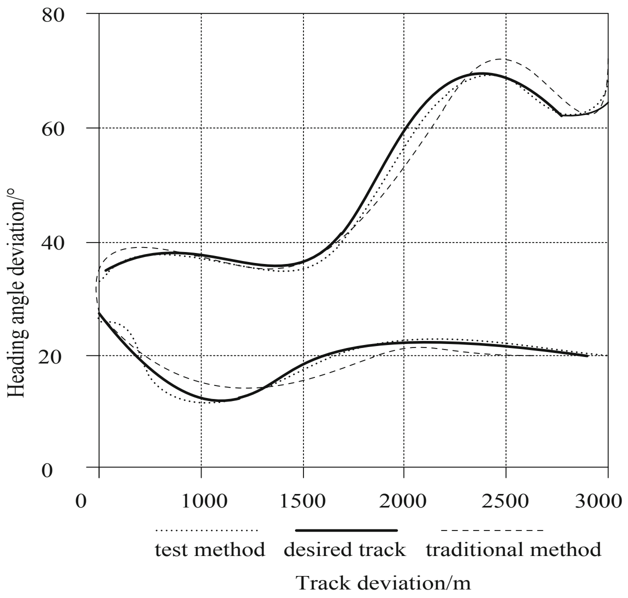

Fig. 3. Comparison of tracking accuracy in barrier free environment.

It can be seen from the analysis of Fig. 3 that in the barrier free environment, the actual navigation paths of the traditional UAV track control method and the control method in this paper are respectively compared and detected. According to the observation and detection results, there is little difference between the traditional method and the control method. It shows that in the barrier free environment, the traditional method and the method in this paper can guarantee the accuracy of the route. This is because in the process of UAV track control, the environmental factors are fully considered. On this premise, the UAV motion control system is accurately planned and the reasonable navigation path is formulated.

In the process of UAV track control, due to the complex environment, in order to ensure that the obstacles are corrected and controlled in time in the course of multi-UAV route, and to avoid deviation, the contrastive detection of the track accuracy of obstacle environment is further designed under the same link, and the test results are integrated and plotted. The specific test results are shown in the following Fig. 4.

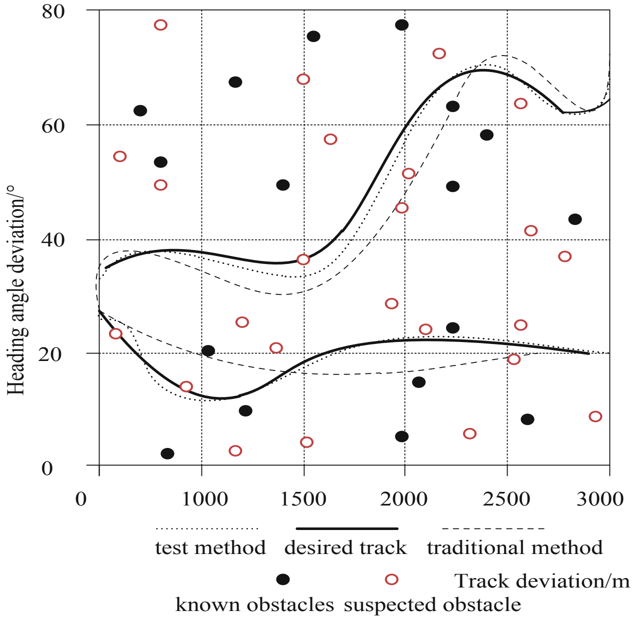

Fig. 4. Comparison of tracking accuracy in obstacle environment.

As shown in the Fig. 4, the traditional UAV track control method and the actual flight path of the control method in this paper are compared and detected in obstacle environment. Observed results show that, compared with the traditional method, the overall track of the control method in this paper is more consistent with the expected track. In order to avoid obstacles effectively and ensure the safety of UAV navigation, there will be small route deviation in the case of suspected track failure.

The analysis and comparison of the experimental results show that the overall control accuracy of the embedded multi-UAV trajectory automatic control method is relatively higher, which can effectively achieve the research objectives of solving the trajectory deviation and avoiding navigation obstacles. The overall control effect is much higher than the traditional method, and fully meets the research requirements.

4 Conclusion

Due to the fact that UAV is greatly influenced by the navigation environment shadow and other factors, it is easy to cause track deviation and other problems, which is not conducive to the safety and stability of UAV navigation. Therefore, an automatic control method of UAV track based on fuzzy algorithm is proposed. The track of UAV is tracked and controlled based on the indirect straight path of UAV navigation, so that the track deviation of UAV can be corrected in time. In order to verify the effectiveness of this method, a simulation experiment is designed. However, due to the limited time and the limited number of times, the experimental results show that this method has high accuracy, and the track control of UAV is much better than the traditional method.

In addition to the conclusions summarized above, there are still some areas to be improved if the method is to conduct real flight test, such as not verifying the influence of constant wind on tracking speed in the actual flight process, not considering the delay of communication, etc., which will be gradually improved in the future research.

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