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Unmanned aerial vehicle (UAV) intelligent wayfinding system based on inertial navigation technology

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Abstract. In the modern war, UAVs play an important role. With the increasing complexity of the war environment, the army's demand for unmanned aerial vehicle systems is getting higher and higher. In this paper, the inertial navigation technology of unmanned aerial vehicle (UAV) and the technical problems of intelligent wayfinding system were studied. According to the algorithm characteristics of inertial navigation path, the ant colony fusion particle algorithm was designed, and the calculation method of inertial guided solution was discussed. Based on the inertial navigation technology, the related algorithms and the simulation of the intelligent navigation system were studied. The verification results show that the intelligent wayfinding system designed in this paper has good reliability.

Key words. Unmanned aerial vehicle (UAV), inertial navigation, intelligent algorithm.

1. Introduction

Compared with manned aircraft, UAVs can save a lot of money in terms of design, manufacturing and training maintenance. UAVs are relatively light and agile in operation, and have strong air combat capability, which can be used for radar attack in the course of reconnaissance operations [1]. Infrared detectors are installed on UAVs to acquire information about each other's operations in the air. In combination with the above performance characteristics, UAVs are irreplaceable in military power. UAVs need to avoid military threats in the air during their actual use. Because they do not have the air-to-air combat strike capability, the enemy's air strike firepower should be predicted in advance [2]. Therefore, unmanned aerial vehicle (UAV) requires intelligent navigation of the flight path for man-machine safety, so as to perform the task efficiently. Scientific UAV path guidance system is the safeguard of UAV's reconnaissance operations. Intelligent flight operations of UAVs can be realized only by using optimizing intelligent algorithms and calculating the optimal flight path in the process of air operation. In order to achieve the

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strategic role of UAVs in the air, it is necessary to have a predetermined optimal flight path reference and combine intelligent precise navigation system to provide precise location information for UAVs [3]. In order to improve the flight reliability of UAVs, the UAV navigation guidance system should be equipped with sensors. Therefore, the requirement for the precision of the UAV intelligent navigation system is higher [4]. More and more researches have been done on the precision promotion of the intelligent navigation and wayfinding system of UAVs, and the problem has become a hot research topic.

2. State of the art

The intelligent wayfinding problem of UAVs also belongs to the optimal path problem, which means that under certain environmental constraints, the UAV navigation system can plan the path algorithm and accomplish the best flight path from the starting flight position to the end point [5]. The path selection and planning of combat UAVs are different from those of conventional trajectory planning problems. The optimal solution for the variability of the three-dimensional space and the complex features of the environment makes the optimal planning process of the flight path more difficult [6]. The UAV flight path planning problem can be divided into the following steps. The simulation system of UAV flight environment should be established. In addition, the optimal route of flight path should be evaluated. In order to ensure the safety performance of flight, a reasonable planning algorithm must be adopted to calculate the safe and efficient flight path [7]. UAV flight path planning algorithm needs a certain evaluation to complete. And it is necessary to predict the flying distance and the threats that may occur in the flight path. In order to verify the superiority of UAV flight path planning method, a certain path evaluation condition and principle should be established.

The UAV mission planning is the main part of the UAV design, which is composed of many modules, and can form comprehensive and detailed functions through different functions and task planning [8]. The initialization function module contains the preset settings for related parameters of the job, the maximum flight angle of the UAV and the corresponding constraints. In the course of flight, in order to avoid radar detection and protect its flight concealment, the flying radar detection blind zone should be set up in the UAV flight guidance system [9]. Although a radar network composed of several radars can narrow the detection blind area, it cannot completely eliminate the blind area. UAVs usually fly close to the ground, and such a flight may experience ups and downs of the terrain. However, in order to satisfy the concealment and flight safety, it is necessary to make such a challenging flight strategy [10]. The navigation system studied in this paper is close to the actual situation, and the environment threat module is established. Finally, the flight environment of UAV in 3D space is effectively fused, and then the real combat flight characteristics of UAVs can be simulated completely.

2.1. Methodology

The navigation control system of unmanned aerial vehicle (UAV) is the main link to realize the scheduled flight target. The requirements for the flight performance of UAVs are relatively high, so that UAVs need to exhibit specific performance for different battlefield environments. In order to realize the intelligent navigation system of UAV, it is necessary to analyze and discuss the navigation control system of unmanned aerial vehicle (UAV). Figure 1 shows a control chart of an UAV navigation and wayfinding system. In order to control the UAV to fly effectively, the control system and navigation system need excellent performance, and each module needs to work cooperatively. In a real combat environment, UAVs need to overcome the interference environment, thus putting forward higher requirements for the intelligent navigation system of UAVs.

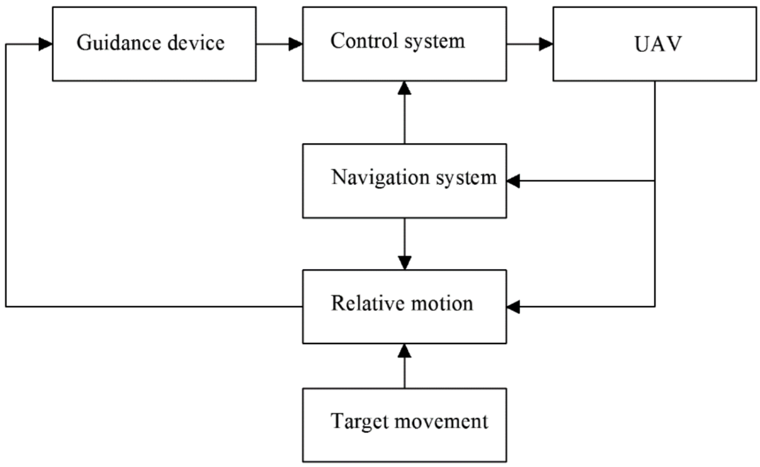

Fig. 1. Control chart of UAV navigation and wayfinding system

The particle swarm optimization (PSO) algorithm for the flight path choice of UAVs is a computational method proposed in the 1990s. The principle of this method is derived from the competition mechanism among microscopic particles, and the optimal solution is selected by competition elimination. In the particle swarm optimization algorithm, firstly, the population of particles should be initialized. The feasible solution of the search space is expressed by random particles in the population, and is endowed with a special fitness function. By random motion, the particle has a regular change of position trajectory, representing the degree of motion fitness of particles. And according to the degree of motion fitness of particles in the trajectory, the optimal solution of particles in motion and in the whole trajectory can be searched. Each movement updates the particle, and eventually the synthetic optimal solution is obtained [11].

It is assumed that the range of motion of the particles in three-dimensional space is represented by D. The total number of particles is represented by m, and the coordinates of the particles in the three-dimensional space are represented by

$x_i,\ i = 1, 2, 3$. The optimal value of the particle motion and the optimal value of the swarm are updated with the coordinates of p_g. The trajectory of particles in three-dimensional space is regular. According to the update speed of the particle's own optimal solution, the updating formula for the optimal solution of particles is established as follows:

$$x_{id}(t+1) + x_{id}(t) + v_{id}(t+1)\,, \tag{1}$$

$$v_{id}^{k+1} = wv_{id}^{k} + crand_1^k(pbest_{id}^k - x_{id}^k) + crand_2^k(gbest_d^k - x_{id}^k)\,. \tag{2}$$

In the formula, v_i denotes the velocity vector, subscript d means that the dimension of the particle has the degree d, superscript k represents the number of iteration, r_1 and r_2 stand for the stochastic constants between [0,1] ω is the adaptive weight factor, c_1 is the self learning factors, including self learning ability, and learning environment factor c_2 regulates the social learning ability. From the above formulae, it can be seen that the particle search results are limited by three levels of factors. The three factors are the particle velocity, particle self learning ability, and other learning ability of particles. The particle motion rate can balance the global search ability of particles, and the self reinforcement ability of particles can avoid the falling into [12] in the process of particle movement.

The design of ant colony algorithm, inspired by ants foraging in groups, belongs to an optimization method for simulating bionics. Through the transformation of several feasible solutions in space, a series of operator transformations and corresponding transformations, finally, the optimal solution can be obtained. Ants release information and receive information from other ants in the course of a random path, which is the information sharing process of ant colony algorithm. The movement of the ant colony will be concentrated with the colony effect of the ant colony, and the ants will move constantly toward a large amount of information [13]. Ant colony algorithm has the mechanism of effective information feedback. The more the selection path, the greater the amount of information will be, and the higher the probability of eventually obtaining the optimal solution will be. The expression of the path selection probability of ant colony algorithm is

$$p_{ij}^k(t) = \frac{[\tau_{ij}(t)]^\alpha [\eta_{ij}]^\beta}{\sum_{j\in U}[\tau_{ij}(t)]^\alpha [\eta_{ij}]^\beta}\,. \tag{3}$$

In the formula, p indicates the movement rate of ants from one point to another, τ_{ij} represents the basic strength of the trajectory, η_{ij} denotes an inducer, and U represents the collection of all trajectories.

Ants may form a concentration gradient in the course of movement. Therefore, in the process of ant movement, the concentration of information at random locations will change, and the formula for calculating the concentration of information is. There holds

$$\tau_{ij}(t+n) = \rho\tau_{ij}(t) + \Delta\tau_{ij}\,, \tag{4}$$

and

$$\Delta\tau_{ij} = \sum_{k=1}^{m} \Delta\tau_{ij}^{k} \,. \tag{5}$$

In the above formulae, $\Delta\tau_{ij}^{k}$ describes the information intensity that ants release at the edges of trajectories and ρ indicates that the retention strength of information may change over time.

By analyzing the characteristics of ant colony algorithm and particle swarm algorithm, it can be found that particle swarm optimization method can achieve relatively strong search results, but it may fall into the loop of search. Ant colony algorithm is not easy to fall into the loop, but the early calculation speed is slow and the latter calculation speed is faster. In this paper, combining the advantages of the two algorithms, the global search feature of particle swarm optimization algorithm was utilized to carry out the global search. Then, the ant colony algorithm is used to calculate the optimal solution.

In order to give full play to the maximum performance of the two algorithms, the computational advantages of the two algorithms should be complementary. The key of calculation is the grasp of the computational time node, which refers to the critical value of particle swarm optimization and ant colony algorithm. The confirmation of the time point of the two algorithms will affect the overall application of the fusion algorithm. Figure 2 shows the convergence rate of the particle swarm optimization method and the ant colony algorithm. As illustrated in Fig. 2, in the practical T range, the convergence of particle swarm optimization method is more obvious, and as time goes on, the rate of convergence is speeding up. Over the T range, the ant colony algorithm is better. Therefore, from the point of view of fusion calculation, the method of particle swarm optimization is adopted within the range of T, and after the time is greater than T, the ant colony algorithm can be adopted.

In this paper, the flight path planning of unmanned aerial vehicle (UAV) in three-dimensional space is analyzed. It is considered that before the plane takes off, according to the existing information, the fusion method of particle swarm algorithm and ant colony algorithm can be used to obtain the optimal path of UAV from the starting position to the termination position. In this paper, the particles are divided into sub layer particles and low dimensional particles according to the flight state of UAVs. When the particle search of the parent layer is completed, the particle is transferred to the sub layer. Finally, the sub layer completes the search process of the parent layer and guides the optimal solution to find the location.

Figure 3 shows the principle frame diagram of an inertial navigation system. As shown in Fig. 3, the gyroscope is used to determine the acceleration of the UAV in the inertial navigation system. After the acceleration is measured, the two are compensated for the error control, and the result is used as the effective input of the four element method. The effective output of the four element method is the attitude matrix. The attitude angle is calculated by inertial navigation system, and after the integral solution, the velocity and position information of the final calculation point can be obtained.

In inertial navigation system, the result of signal measurement based on inertial

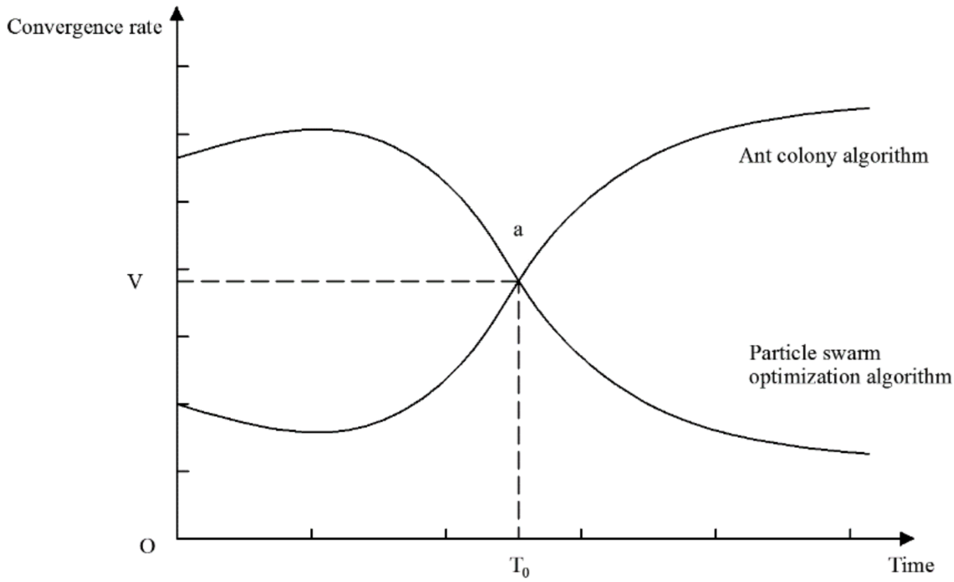

Fig. 2. Convergence rate diagram of particle swarm optimization method and ant colony algorithm

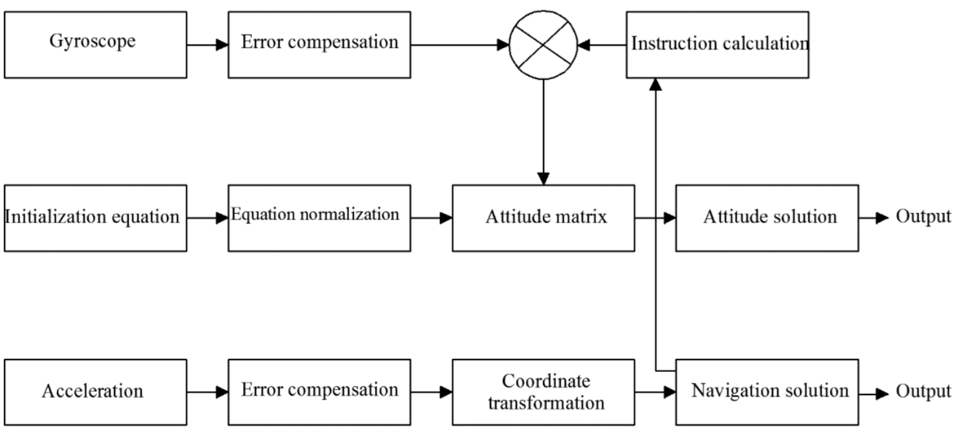

Fig. 3. Principle frame diagram of inertial navigation system

component is the key of attitude angle position information. In a coordinate system of an inertial component, the signal is converted into the data of the navigation coordinate system. There is a certain degree of data association between the navigation coordinate system and the carrier coordinate system. And a relative coordinate system can be established by the angle of flight deviation and the rolling angle of the

UAVs. The four element method is used to solve the inertial navigation algorithm:

$$C_b^n(q) = \begin{bmatrix} C_{11} & C_{12} & C_{13} \\ C_{21} & C_{22} & C_{23} \\ C_{31} & C_{32} & C_{33} \end{bmatrix}. \tag{6}$$

The method for calculating the optimal flight path of unmanned aerial vehicle (UAV) was given. The working mechanism of inertial navigation system was analyzed by combining the particle swarm calculation method and ant colony algorithm, and the algorithm of inertial navigation system's working mechanism was studied. It is necessary to design an intelligent and digital simulation system to simulate the above algorithms and the UAV intelligent wayfinding system. And then in the MTALAB platform, the system calculation method can be verified scientifically, and the structure of the system is shown in Fig. 4. UAV intelligent wayfinding simulation system based on inertial navigation technology is divided into: path calculation module, emulator module, anaphase solution module and data output module.

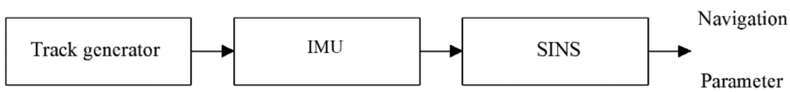

Fig. 4. Composition structure of the system

3. Result analysis and discussion

In order to verify the excellent algorithm performance after the fusion of particle swarm algorithm and ant colony algorithm, in this study, the fusion method and standard ant colony algorithm and standard particle computing method were compared and analyzed. It was assumed that the flying environment of UAVs was a number of overlapping peaks. And the central position of a mountain peak was different. In order to facilitate the simulation, cone structure was used to replace the mountain structure between peaks. The central coordinates between peaks were (22, 67), (23, 19), (44, 54), (44, 26), (54, 78), (74, 26), (76, 68), (82, 44). The starting position of the UAV was (0, 0), and the terminal position was (89, 69). The parameters of each algorithm should be pre-set, and the particle self-learning factor and other self-learning factors were constant 2 in the particle swarm optimization method. The total number of particles was set to 50, the number of iterations was 5500, and the total number of searches was 6 layers. In ant colony computation, the number of ants was 50, and the total number of iterations was 5500. The constant parameter values of the fusion method were consistent with the standard calculation methods, and the iteration times of the two methods were 2900 and 2600 times respectively. According to the operating parameters, the simulation curves obtained in the MATLAB simulation platform are shown in Fig. 5.

It can be seen from the simulation results that the standard particle computing method can't completely solve the problem of unmanned aerial vehicle (UAV) in

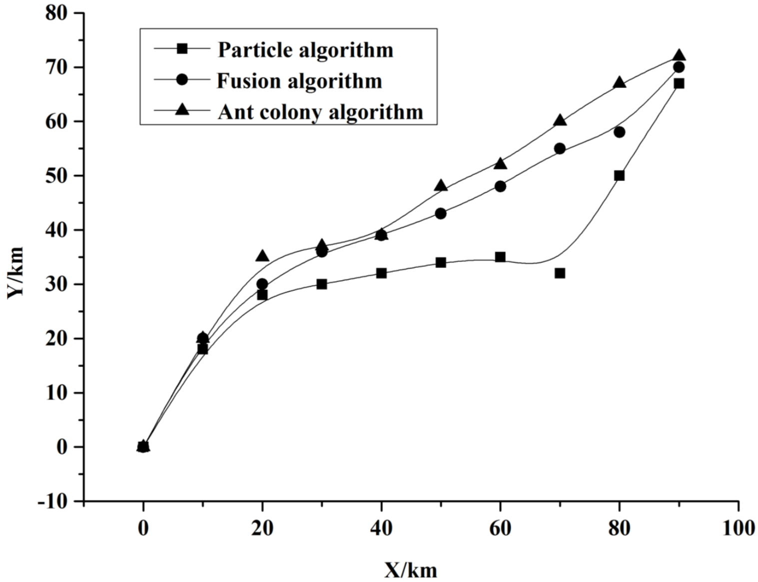

Fig. 5. Simulation curves of different calculation methods

case of emergency danger, and the UAV flight path planning is relatively long, even the route is also relatively tortuous; although the path calculated by the standard ant colony algorithm is relatively smooth, it can also minimize the possibility of an emergency. However, the flight path is still relatively long; while the fusion method allows the planning of the nearest flight path, thus making the use time shortest. The experimental results show that the convergence performance of the global optimization algorithm can be obtained by the fusion method. To sum up, the fusion computing method can obtain a better flight path planning scheme for UAVs.

The flight path of unmanned aerial vehicle (UAV) can be obtained through the UAV flight path simulation calculation. By varying the associated analog parameters, different flight trajectories can be set. And the flight path is generated by UAV trajectory generator, including attitude angle, acceleration and other flight parameter data. The actual output of the simulated gyroscope is completed by the IMU simulation accelerator. And then in the process of actual use, the calculation model of the error is added to the calculation model of gyroscope. Figure 6 is the result of acceleration related information obtained by using the IMU simulator. As can be seen from Fig. 6, the true output of the X axis forms a straight line curve, the output data of the Y axis and the Z axis forms a wave curve; the output data of the X axis and the Y axis of the acceleration line forms straight lines, and the true output of the Z axis is the curve. As can be seen from Fig. 6, the IMU simulation element designed in this research can truly reflect the flight situation of UAVs, and the data of acceleration and gyroscope is closer to the real state of operation. By calculating the drifting characteristics, the two are of great value in actual use.

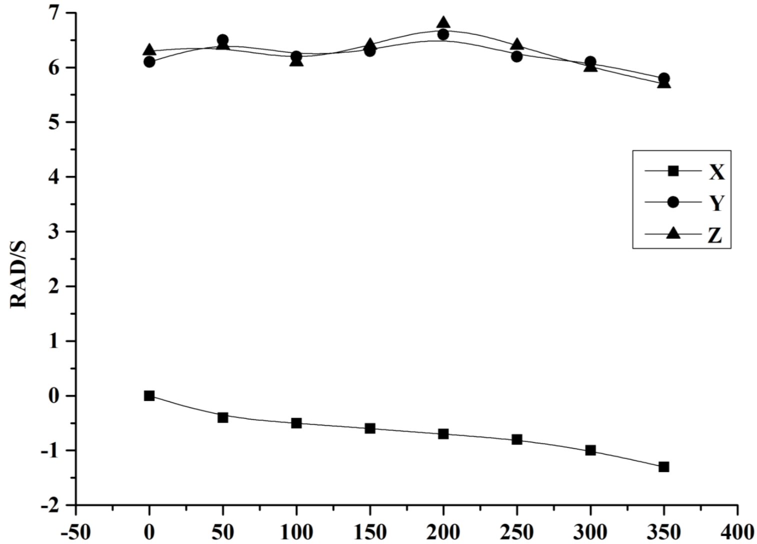

Fig. 6. Results of acceleration related information

4. Conclusion

The flight path of unmanned aerial vehicle (UAV) has always been the focus of research on UAV navigation technology. In this paper, the segmented fusion method of particle algorithm and ant colony algorithm was proposed for UAV trajectory calculation. Subsequently, the simulation of related algorithms was studied. From the theoretical and practical point of view, inertial navigation technology and intelligent wayfinding system were organically combined. Then the characteristics of particle swarm optimization and ant colony algorithm were analyzed. The fusion method proposed can not only complement the disadvantages of the two methods, but also retain the advantages. In addition, in the MATLAB platform environment, the performances of two independent algorithms and fusion algorithms were compared and analyzed. Simulation results show that the fusion method combined with inertial navigation system can perform great performance in UAV navigation design. Due to the limitation of time, the experimental simulation research of UAV's hardware in the loop navigation system has not been completed in this paper. Therefore, in engineering practice, further empirical analysis and discussion are needed.

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