



# Decentralized Control Method for UAV Arriving Simultaneously Based on Large Data Analysis

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**Abstract.** Due to the limitation of the control method during the conventional simultaneous arrival control drone, a certain deviation is caused. In order to solve such problems, a research on the decentralized control method of simultaneous arrival drone based on big data analysis is proposed. Fusion of decentralized information is achieved through information filtering. Based on this, decentralized coordination of formations is controlled. The optimal path and convergence speed are calculated by calculation. Decentralized control methods are implemented through communication delay constraints. The proposed method is used for simulation experiments and it is found that the method can effectively reduce the error, which fully proves the feasibility of the control method.

**Keywords:** Large data analysis · UAV · Decentralized control

## 1 Introduction

With the advent of the era of big data, big data analysis has also emerged. Big data analysis refers to the analysis of large-scale data. Big data has the characteristics of large amount of data, fast speed, multiple types, value, and truth. Big data is the hottest vocabulary of the IT industry, and the subsequent use of data warehouse, data security, data analysis, data mining, etc., around the commercial value of big data has gradually become the focus of profit sought by industry professionals [1]. Nowadays, big data analysis technology has been applied in many fields, and certain results have been obtained. For example, by predicting demand to help enterprises deal with practical problems, in recent years, enterprises need to not only acquire customers, but also understand customer needs in order to improve Customer experience and develop long-term relationships. By sharing data, customers lower the privacy level of data usage, expecting companies to understand them, form corresponding interactions, and provide a seamless experience at all touch points. With the popularization of big data analysis technology, it is gradually adopted by the country's work and business, and the application of drones is becoming more and more extensive. UAVs are unmanned aircraft operated by radio remote control equipment and self-provided program control devices, or operated completely or intermittently autonomously by onboard computers.

When multiple drones are operating at the same time, many problems will arise due to improper coordination. For example, multiple drones often need to reach the same or different target locations at the same time when completing tasks in coordination, or multiple drones taking off from different locations. UAVs gather in a certain position to form a close formation. This problem has been studied in many fields. However, compared with other hardware facilities, UAVs have their unique characteristics and applications. They move in three-dimensional space. It has a positive speed limit and cannot stop waiting or retreat. You can increase the path length by circling flight, and you can also adjust the flight speed within its allowable range. Reference [2] proposes a UAV control method based on acceleration feedback enhancement. This method introduces angular velocity and linear velocity feedback control on the basis of the original controller structure of the UAV to improve the disturbance suppression capability of the UAV. However, the control effect of this control method still needs to be further improved.

In order to solve the problem of the simultaneous arrival of UAVs, a decentralized control method is introduced. It adopts the basic design ideas of decentralized control, centralized operation and management, and adopts a multi-level hierarchical, cooperative and autonomous structure. Its main feature is its centralized management and decentralized control. The simultaneous arrival of multiple drones is a typical collaborative control problem, which usually includes two aspects of research content: one is path planning, that is, the path is planned for each drone under the conditions of environmental constraints and collaborative constraints; the other is trajectory Control, that is, by controlling the heading and speed of the UAV to make the UAV reach the target position along the planned path at the same time. This method can obtain the global optimal solution, but it is essentially a centralized control method. When calculating coordination variables, the coordination function information of all UAVs must be obtained. When some UAVs are affected by sudden threats, they must re-coordinate route plan.

## 2 Design of Decentralized Control Method for UAV

It is assumed that in a certain mission,  $n$  UAVs are expected to arrive at a predetermined  $k$  target positions at the same time, of which  $n \leq k \leq 1$ . The initial position of UAV is the actual position of its current time, which may be arbitrarily distributed in space. Each UAV has and only has a definite target position. The target positions of different UAVs may be the same or different. In addition, it is assumed that UAV can obtain information about threats and obstacles (no-fly zone) in advance or in real time, and can independently plan the path offline or online, and give real-time estimates of the path length, and can autonomously fly along the planned path. The goal of multi-UAV simultaneous arrival is to find a control method or strategy to achieve the above tasks, and try to avoid the impact of adverse factors, such as path errors, sudden threats and so on. Seven of them have to reach two targets at the same time in order to attack two targets at the same time. In the process, UAVs have to avoid threats and no-fly zones [3]. Because the flight path and speed of UAV are not fixed, it can be guaranteed to arrive at the same time by adjusting the path length and flight speed. The UAV is

regarded as a particle moving in two-dimensional plane without considering the change of flight altitude. The simplified motion model of UAV is taken as follows:

$$\begin{pmatrix} x_i \\ y_i \\ \theta_i \end{pmatrix} = \begin{pmatrix} \cos \theta_i \\ \sin \theta_i \\ 0 \end{pmatrix} v_i + \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} \omega_i, i \in \{1, 2, \dots, n\} \tag{1}$$

Among them,  $i \in \{1, 2, \dots, n\}$  is the UAV number,  $(x_i, y_i)$  is the position of UAV  $i$ , and  $\theta_i$  is the direction angle of UAV  $i$ . The control input variables are linear velocity  $v_i$  and angular velocity  $\omega_i$  of UAV  $i$ . Let  $r_i = (x_i, y_i)$ ,  $u_i = (u_{xi}, u_{yi})$ , the system kinematics equation can be linearized by feedback, and the system model in the form of first order integral can be obtained.

$$\begin{bmatrix} \dot{x}_i \\ \dot{y}_i \end{bmatrix} = \begin{bmatrix} u_{xi} \\ u_{yi} \end{bmatrix} \tag{2}$$

$u_i$  is the virtual control input of UAV. The relationship between the virtual control input and the actual control input variables is as follows:

$$v_i = \sqrt{u_{xi}^2 + u_{yi}^2} \tag{3}$$

$$\omega_i = \frac{u_{xi}\bar{u}_{yi} - u_{yi}\bar{u}_{xi}}{u_{xi}^2 + u_{yi}^2} \tag{4}$$

The decentralized control structure of multiple UAVs relying only on local information interaction is shown in Fig. 1, where  $\theta_i(i \in V)$  is the coordination variable of the  $i$  UAV, and each UAV receives only the coordination variable information of its neighbors.

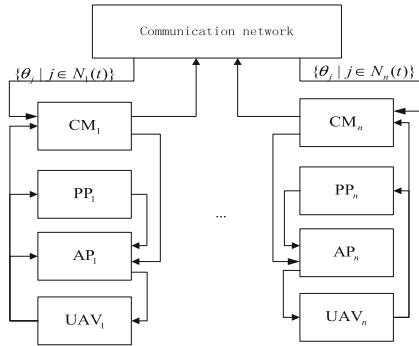


Fig. 1. Decentralized control structure

In the decentralized control structure shown in Fig. 1, all UAVs are equally positioned and connected by directed communication connections [4]. Among them, the lowest UAV module represents the UAV entity, which is the control object of the autopilot and outputs state information to the outside. The autopilot module AP represents a flight control system with heading and speed maintenance functions. It provides an instruction interface to the coordination module CCM and the path planner module PP. The path planner module can carry out path planning according to UAV status and environmental information, and output course angle instructions to the autopilot module to enable UAV to fly along the planned path, and output the estimated value of the remaining path length at the current time to the coordination module. Coordination module receives all neighbors' coordination variable information, then calculates speed instructions based on consistency algorithm and outputs them to autopilot module, and updates local coordination variables.

## 2.1 Decentralized Information Fusion

For the decentralized control of UAV, first of all, the flight information of all the target UAVs that need to arrive at the same time needs to be collected, counted and processed in a unified way. The UAV parameters to be counted are shown in Table 1.

**Table 1.** UAV information fusion parameters

Parameter	Specific information
Aircraft model	Wing Flying Kenong A6-160 Agricultural Plant Protection UAV, Phantom 3 SE, Mapping Eagle Trimble UX5, etc.
Flight Mode	GPS mode: suitable for beginners. Fixed-point positioning, attitude mode: NAZA is not equipped with GPS, can only fly in this mode. Usage rate is general, can not be fixed point but can be set high. The attitude needs to be revised to suit players with certain flight experience. Manual mode: can determine whether the center of gravity of the aircraft is appropriate, legend can rescue aircraft, or experienced experts for 3D flight, few people use. No fixed point, no automatic attitude correction
Fuselage parameter	Including aircraft type, reserve weight, wingspan, wing area, geometric size, airframe material, etc.
Battery	Including battery type and battery power
Flight parameters	Supporting flight time, average flight altitude, flight speed range, historical flight path, wind resistance, etc.
Take off and land	Including takeoff type, takeoff speed, landing type, landing speed, etc.
DTM	Point spacing, plane accuracy, elevation accuracy, etc.

The basic information of UAV is fused by information filtering. According to the type and characteristics of information, the information is divided into linear analysis and nonlinear analysis. The linear information is expressed as:

$$x(k) = F(k)x(k-1) + G(k)w(k) \quad (5)$$

Among them,  $x(k)$  pseudo-weir state vector;  $F(k)$  is state transfer matrix;  $G(k)$  pseudo-noise input transfer matrix;  $w(k)$  pseudo-zero mean uncorrelated Gauss white noise;  $Q(k)$  pseudo-noise variance matrix. Nonlinear information is expressed as:

$$z(k) = h(kx(k)) + v(k) \quad (6)$$

Among them,  $Z(k)$  is the measured value;  $V(k)$  is zero, variance is  $R(k)$  Gauss white noise;  $h()$  pseudo-nonlinear measurement model.

Kalman filter obtains target state estimation  $\chi^2$  variance  $P$ , while information filter obtains information state  $y$  and Fisher information  $Y$  satisfying relation.

$$y = P^{-1}x \quad (7)$$

$$Y = P^{-1} \quad (8)$$

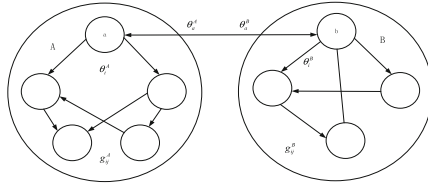
$$I(k) = H^T(k)B^{-1}(k)H(k) \quad (9)$$

$$i(k) = H^T(k)R^{-1}(k)(z(k) - h(x(k|k-1))) + H(k)x(k|k-1) \quad (10)$$

Among them,  $i(k)$  is the information state distribution of the observation vector  $Z(k)$ , and  $I(k)$  pseudo information matrix.  $i(k)$  and  $I(k)$  are only related to the target state dimension, but not to the sensor measurement dimension. When updating  $y(k|k)$  and  $Y(k|k)$ , the decentralized information fusion algorithm considers not only the  $I(k)$  and  $i(k)$  of the UAV itself, but also the communication information of the nearby UAV. The decentralized information fusion algorithm based on information filtering can fuse the information of other UAVs through simple algebraic sum, so it has good scalability, heterogeneity and dynamic reconfigurability. The information filtering algorithm has good robustness to the selection of initial values. When the exact initial statistical characteristics of the system are not obtained, the small non-zero initial values can be selected to calculate iteratively, thus overcoming the problem that Kalman filtering algorithm is sensitive to the selection of initial values [5].

## 2.2 Decentralized Coordination Control of Formation

During the flight, UAV members will join at any time, and UAV exits due to single point failure. In this case, all UAV equipment need to be reconciled and formed in time to ensure that all UAVs can arrive at the same time. This decentralized coordination control is divided into the decentralized coordination within the formation and the decentralized coordination between the formation. Its principle is shown in Fig. 2.



**Fig. 2.** Principle of decentralized

Suppose  $\theta_i(t)(i = 1, 2, \dots, n)$  is the coordinated information of the  $i$  platform at  $t$ -time, i.e. the coordinated variable, if satisfied:

$$\lim_{t \rightarrow \infty} \|\theta_i(t) - \theta_j(t)\| = 0 (\forall \theta_i(0), \theta_j(0), i, j \in n) \tag{11}$$

Platform  $i$  and platform  $j$  are respectively called information pairs. The results are consistent. Decentralized coordination strategies are as follows:

$$\theta_i(t) = - \frac{1}{\sum_{j \in \Omega_i(t)} \alpha_{ij}(t) g_{ij}(t)} \cdot \sum_{j \in \Omega_i(t)} \alpha_{ij}(t) g_{ij}(t) \{ \theta_j(t) - [\theta_j(t - \tau_{ij}) + v_{ij}] \} \tag{12}$$

Among them,  $\Omega_i(t)$  is the set of all platforms that send information to the platform  $i$  at  $t$ -time;  $g_{ij}(t)$  is the communication topology at  $t$ -time;  $\alpha_{ij}(t) > 0$  is the reliability or importance of transmitting information from the platform  $j$  to the platform  $i$  at  $t$ -time; and  $\tau_{ij}$  is the communication noise between the platform  $j$  and the platform  $i$ . The distributed information coordination process of platform system is essentially an achievable condition of dynamic decentralized coordination consistency and convergence speed, which are related to communication topology, communication noise and so on [6]. Decentralized coordination among formations is the coordination between A and B in Fig. 2, which is deduced according to the mode of decentralized coordination within formations. In Fig. 1, A and B are the root nodes of the internal communication topology of Formation A and B, and the communication between Formation A and B is realized by the communication between Platform A and B.

### 2.3 Optimal Path Selection

After the formation of UAVs, the path of each UAV is planned separately. There are several principles to follow when planning the route: no overlap with other UAV flight paths; no roadblocks on the route. On the basis of these principles, the direction of flight is determined, and the path is calculated. On the basis of not violating the principle, the route with less energy consumption is chosen as far as possible, that is, the path with shorter distance. Considering the characteristics of fixed-wing UAV, a decentralized formation flight control strategy based on information consistency and relative position control is proposed under the assumption that the position, velocity and course of UAV are almost the same at the initial time.

$$v_i^c = \bar{v}_i^c \delta_i \Delta v_i^c \quad (13)$$

$$\psi_i^c = \bar{\psi}_i^c \delta_i \Delta \psi_i^c \quad (14)$$

The decentralized formation flight control strategy consists of two parts, one is  $v_i^c$  and  $\psi_i^c$ , which synchronize speed and course using relative velocity and course information between UAVs, the other is  $\Delta v_i^c$  and  $\Delta \psi_i^c$  which use relative position information between UAVs to form and maintain formation. In the formula,  $\delta_i \in \{0, 1\}$  is a binary switching variable and is defined:

When  $\delta_i = 0$ , only position and course are synchronized, and formation control is not started; when  $\delta_i = 1$ , both position and course are synchronized and formation control is started.

When  $\delta_i = 0$ ,  $v_i^c = \bar{v}_i^c$ ,  $\psi_i^c = \bar{\psi}_i^c$  the aim is to make the flight speed and heading angle of all UAVs converge. For this purpose, the following decentralized heading synchronization control is given:

$$\bar{v}_i^c = v_i + \frac{1}{\alpha_{v,i}} \sum_{j \in N_i} a_{ij} (v_j - v_i) \quad (15)$$

$$\bar{\psi}_i^c = \psi_i + \frac{1}{1 + |N_i|} \sum_{j \in N_i} (\psi_j - \psi_i) \quad (16)$$

It can be seen from the formula that the velocity command  $\bar{v}_i^c$  of the first UAV and the heading angle command  $\bar{\psi}_i^c$  are only related to its neighbors, and can be obtained only by obtaining the relative speeds and heading angles of all neighbors. If the neighborhood set is empty, the speed and heading angle of the UAV will remain unchanged [7]. It can be seen that the formula is a decentralized control strategy using only local relative state information feedback.

Given course angle command  $v_i^c$ , the first UAV can turn from the current course angle to the command course angle clockwise along path 1 or counter-clockwise along path 2. In the graph, the deflection angle along path 1 is less than  $\pi$ , which is expected, while the deflection angle along path 2 is greater than  $\pi$ , which is not expected. In order to make UAV fly along the planned route in practical application, sometimes it is necessary to introduce external reference signal or virtual Leader. When UAV is far from the target position, try to adjust the path length through path planning so that it can fly at the appropriate speed, so as to retain a large margin of speed adjustment and better respond to path errors and sudden threats. When the UAV approaches the target position, the speed control is the main method, which can ensure the precise and simultaneous arrival.

## 2.4 Convergence Rate Calculation

In the minimum control speed in the air, both the longitudinal and lateral control of the aircraft are involved. The UAV must not only meet the conditions of simultaneous

arrival, but also be higher than the minimum flight speed. The angular velocity of flight is expressed by formula (17):

$$v \geq \frac{V}{\sqrt{nw}} \quad (17)$$

The  $V$  is the speed obtained at the first maximum when the acceleration of the elevator is less than 11 s per knot and the load coefficient of the aircraft is corrected to the speed obtained at the first maximum.  $n$  is found overload coefficient in track coordinate system at  $V$ .  $w$  is the weight of the aircraft, in units of  $N$ .  $S$  is the aerodynamic reference area of the wing. The initial trimming speed of the aircraft is not less than 1.13  $V$ . The calculation method of convergence rate can be obtained. Preliminary estimates of the stall speed of the aircraft are as follows:

$$v = \sqrt{\frac{2W}{\rho SC}} \quad (18)$$

Among them,  $\rho$  is the air density and  $C$  is the critical lift coefficient of the aircraft. The trim angle of attack, throttle and elevator deflection of the UAV flying straight and flat at 1.13  $V$  are calculated. Keeping the throttle unchanged, the final convergence speed can be obtained by deviating the elevator from the balancing position by one degree.

## 2.5 Communication Delay Constraints for Decentralized Control

From the time when UAV updates the coordination variable to the time when its neighbors use the coordination variable information to calculate the speed command, there must be a time difference, which is equivalent to introducing a time delay to the coordination variable [8, 9]. The time delay is determined by computing time, computing period and transmission time. The effect of time delay is equivalent to introducing deviation, which prevents UAV from arriving at the same time. Reducing the calculation period, predicting and compensating can weaken the effect of time delay [10].

UAV2 makes its flight speed far away from the limit by hovering flight. UAV also changes its flight speed and increases its speed adjustment margin [11, 12]. When a sudden threat occurs, four UAVs still reach the target position at the same time.

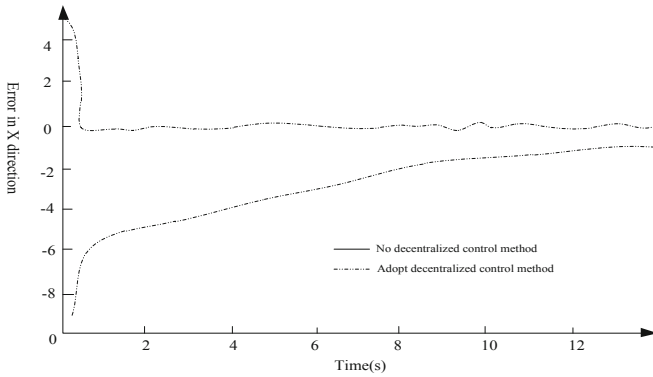
## 3 Simulation Experiment

In order to verify the effectiveness of the decentralized flight control method for UAV arriving at the same time, simulation experiments are carried out. In order to ensure the uniqueness of the test variables, assuming that all UAV models are the same, they have the same characteristic parameters and initial states as shown in Table 2.

**Table 2.** Characteristic parameters and initial states of a UAV

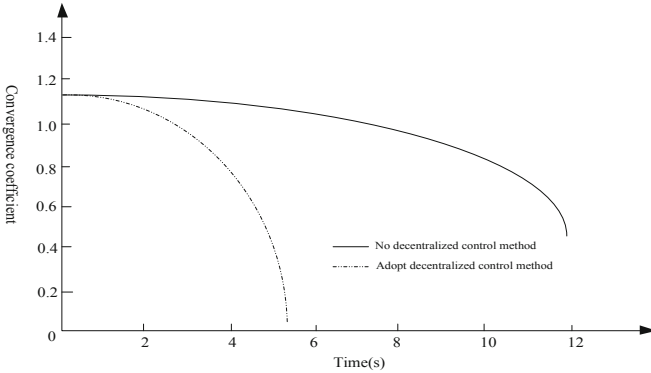
	UAV1	UAV2	UAV3	UAV4
Position (m, m)	(0, 0)	(-1000, 2000)	(1000, 1000)	(1000, 0)
Speed (m/s)	165	212	198	201
Heading angle rad	$\pi/4$	$\pi/6$	$3\pi/8$	$\pi/8$
Minimum flight speed	150	150	150	150
Maximum speed of flight	250	250	250	250
Minimum acceleration	-8	-8	-8	-8
Maximum acceleration	8	8	8	8

In order to ensure the rigor of the test, the error in the x direction is counted and compared with that in the experiment without the control method. The results are shown in Fig. 3.

**Fig. 3.** Experimental comparison of decentralized control methods

It can be seen from the simulation results that the decentralized control method has a significant impact on the UAV target results and error convergence. The error in the x direction is divided into positive and negative directions. At the beginning of the flight, there will be a certain error value regardless of whether the method is used. The error value will gradually become smaller as the flight time passes, but the decentralized control method is adopted. The error can be adjusted to near the normal value within 2 s, and it can be maintained until the error value is approximately equal to 0.

In order to obtain more comprehensive experimental results, under the above experimental conditions, the convergence rate is used as the experimental comparison index to compare the method. The comparison results of the convergence rate of the proposed method and the comparison method are shown in Fig. 4.



**Fig. 4.** Convergence rate comparison results

It can be seen from Fig. 4 that under the decentralized control method, the convergence rate control effect is better, indicating that the decentralized control method has a better control effect, while the convergence results of the decentralized control method are very unsatisfactory and time-consuming long. Therefore, it fully shows that the performance of the proposed decentralized control method is highly improved.

## 4 Conclusion

Only relying on the decentralized control structure of local information interaction reduces the need and difficulty of communication, and avoids single point failure. The combination of path planning and speed control can achieve complementary advantages, better cope with the impact of adverse factors such as path errors and unexpected threats to ensure that UAVs can arrive at the same time, and also has a certain feasibility in practical work.

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