Research on Simulation Approximate Solution Strategy for Complex Kinematic Models

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***Abstract*—In order to meet the needs of military, road construction, multimedia industry and other aspects, UAVs are gradually given more functions. As the basic function of UAV applications, the fixed-point delivery problem model has higher and higher accuracy requirements. However, in the actual scene, the UAV delivery problem is affected by the interaction of various factors such as flight height, air resistance, and dive angle, which makes it difficult to achieve high stability and high hit accuracy. This paper will analyze the complex motion model based on the fixed-point delivery of explosives by UAV, study the relationship between the stability of UAV delivery and the hit accuracy, and analyze the influence of relevant parameters on the problem by using modeling. In this paper, a multivariate nonlinear continuous time change model is proposed, and a continuous time slice discretization idea operation model is introduced to approximate the time slice splitting inside the UAV launch motion. Secondly, the design quantified evaluation index reaction the initial velocity of the explosive, the launch Angle, the height off the ground and other parameters to analyze the model. Finally, the best scheduling strategy is obtained and verified by using the idea of variable traversal and trial-and-error simulation. The experimental results show that the variation of UAV flying height, speed, depression and other interference factors is consistent with the prediction of score and hit accuracy, according to the environment setting of this model, when the UAV is 300 meters above the ground and 290 meters away from the target horizontal position, the delivery speed is 250m/s, and the pitch angle is about 27°, the fixed-point delivery of explosives is the best strategy.**

Keywords-Nonlinear Model; Traversal Search; Trial And Error Simulation; Continuous Time Discretization

I. INTRODUCTION

Thanks to the rapid development of science and technology, the functions of all kinds of unmanned intelligent machines are increasingly rich, and more and more industries have put unmanned intelligent machines into social production and daily use. Among them, UAVs (Unmanned Aerial Vehicle) are widely used in military, special industries, consumer and other fields to achieve fixed-point delivery tasks due to their strong performance and minimal restrictions on terrain roads [1]. Because the UAV is affected by gravity and external environmental factors during flight, and the artificial control method is not easy to maintain the stability of the fuselage for a long time, resulting in the failure to accurately achieve the fixed-point delivery task [2]. Therefore, it is urgent to study the UAV fixed-point delivery task and improve its precision.

The stable delivery of UAVs is a combination problem [3], which needs to consider the flight characteristics and requirements of UAVs, the demand for materials and the environmental factors on site [4]. The operational stability of the UAV will also affect the completion of the mission. In this paper, the discretization execution and ergodic analysis model of continuous time nonlinear problems with multivariate variables are constructed, and the discretization simulation model of continuous system is designed to solve the continuous time state problem. Then a trial-and-error simulation model is built, and all possible values are traversed through the trial-and-error mechanism, and the relationship between variables is analyzed [5]. Finally, a multivariate weighted evaluation model and a random disturbance reaction simulation test model are proposed to evaluate the relationship between stability and hit conditions by using scores and Gaussian random probability number perturbations, and to design corresponding scheduling strategies.

II. RELEVANT RESEARCH

UAVs have shown significant strategic and practical value in the field of geological exploration and mining as well as the analysis of blasting movement in the military field. In geological exploration and mining, combined with the application of machine vision, intelligent algorithms and sensor technology, drones can achieve a high degree of monitoring and evaluation of blasting operations, improve the safety and efficiency of operations, and promote the digital and intelligent transformation of mining blasting operations. This provides a sustainable solution for environmental protection and resource utilization. In the military field, the motion analysis of the targeted delivery of explosives by UAS achieves highly intelligent and accurate strikes by integrating technology such as machine learning, visual navigation and intelligent countermeasures system, which improves the adaptability and survival ability of UAS in complex battlefield environments [6]. At the same time, the research on path planning algorithm, military ethics and compliance with international regulations also provides scientific support for the safe and efficient operation of UAV targeting explosives.

In the aspect of motion analysis of UAV targeted explosive delivery, the literature review deeply discusses the flight trajectory and motion characteristics of UAV in dynamic environment, as well as the important influence of external factors on stability and accuracy [7]. Through the comparison and evaluation of different technologies, the key factors to improve the hit accuracy are revealed, which provides an important theoretical basis and technical support for improving the combat effectiveness. In the future, with the continuous development of technology, UAV blasting motion analysis will be more combined with artificial intelligence, big data and other technologies to achieve more accurate and efficient management and control of blasting operations [8], and promote continuous innovation and development in the field of military science and technology and geological exploration.

III. EXPERIMENTAL MODEL AND DESIGN

The delivery task of the UAV is set as "delivering explosives", that is, launching spherical explosives into the corresponding target through the launching cylinder installed at the front end of the UAV. Since the launch speed of the explosives is very large, even larger than the flight speed of the UAV, when measuring the distance, the actual initial speed of the explosive should be calculated by adding the speed of the UAV and the launching speed of the explosive relative to the UAV. For the explosive, these two do not need to be split. Since the explosion of explosives has a certain spread range, the UAV needs to maintain a certain distance from the target point [9], but it can not be too far away and lead to launch deviation [10].

When the explosive is launched, the launch port carried by the drone directly powers the explosive to obtain a large initial speed. After leaving the launch port, the drone device no longer exerts any force on the explosives, so the explosives are only subjected to the effect of vertical downward gravity, vertical upward air buoyancy, and air resistance in the opposite direction of movement [11].

A. Discretization strategy

In calculus theory, integrating a continuous curve of change can be divided into several small pieces, each of which is treated as a rectangle for discrete computation. When the width of each piece is small enough, the discrete rectangular synthesis is transitioned into a continuous curve integral.

In the computer control algorithm, time slice rotation is a classic scheduling strategy, which controls the scheduling process according to the unit time. Each time slice either repeats a certain operation or executes the corresponding operation for an individual process.

According to the idea of calculus and computer time slice rotation scheduling algorithm, the continuous physical process of variable force and variable velocity is decomposed into several discrete time slices [12], each time slice is regarded as a simple constant force kinematic process. An appropriate and sufficiently small time slice length is selected, and all processes are connected in series and accumulated to obtain the final approximate result.

B. Monte Carlo replacement tree search

In the calculation of the model, the drop distance *L*, flight height *H*, flight speed v_0 and air resistance *Fz* of the UAV can be calculated by the accumulation of the above modeling process, in which the air resistance changes with time and speed in a fixed scene, one of the other three variables is set as a variable according to the form of Monte Carlo tree search, and the other two are related to each other. As shown in Figure 1. The fixed and constant parameters are called quantification, the first variable is called the independent variable, and the second variable is called the dependent variable. Air resistance is named as a variable.

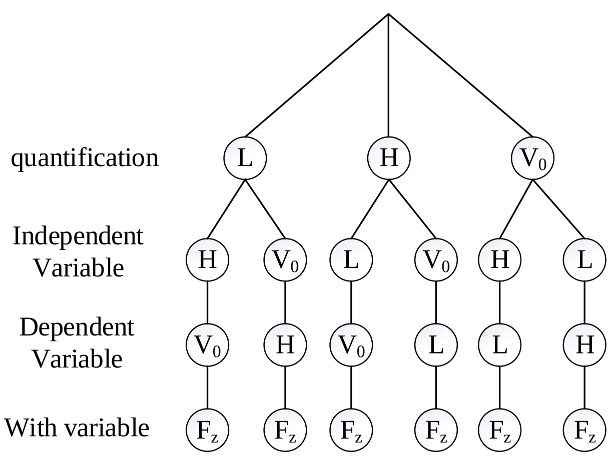


Figure 1. Monte Carlo tree search strategy model

The whole process of the model is based on the mechanical analysis of the interaction and the motion analysis [13]. According to the setting of the time slice, the motion state in each time slice is approximately regarded as the uniformly variable motion, which is convenient to calculate the relevant variables. The process in the time slice is shown in the following formula, and the flow chart is shown in Figure 2.

$$\begin{Bmatrix} v \\ L \end{Bmatrix} \rightarrow \theta \rightarrow F \rightarrow a \rightarrow \begin{Bmatrix} v' \\ L' \end{Bmatrix} \tag{1}$$

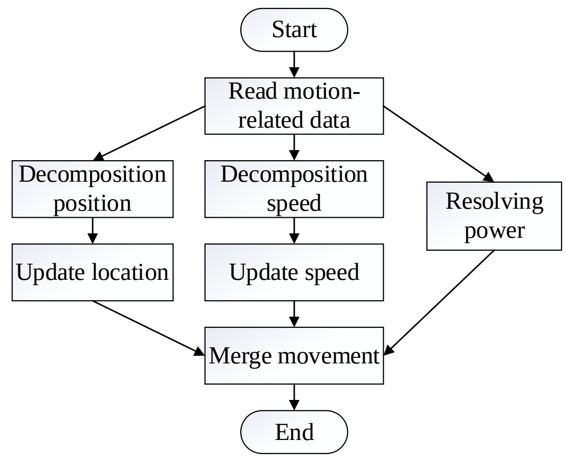


Figure 2. Program flow chart in time slice

C. Height-distance model

Based on the analysis of the basic physical model, it is found that the UAV delivery task is a multi-variable nonlinear model, not a simple univariate relationship, and it is difficult for strategy analysis to directly compress the global variables into one relationship. Therefore, the model designed with fixed parameter traversal is a nonlinear model that analyzes multiple variables.

Based on the analysis requirements of UAV launch distance, flight height, dive Angle and initial velocity of explosives (UAV flight speed plus explosive launch speed), this paper makes a comparative analysis according to the idea of control variable experiment and the traversal idea of search tree.

Due to the shock wave range of the blasting explosive and considering the UAV mission efficiency, distance-related constraints should be set into the model, as shown in the following formula (2) and (3).

$$H \in [H_{\min}, H_{\max}] \tag{2}$$

$$L \in [L_{\min}, L_{\max}] \quad (3)$$

The minimum height H_{min} is the minimum height of the UAV, the maximum height H_{max} is the starting height of the UAV, and the range of L is set as the distance range limit between the UAV and the target.

The length L_{plat} of the level flight stage of the UAV is designed as the difference between the horizontal distance L of the take-off point and the horizontal distance L of the drop point, as shown in the following formula (4).

$$L_{plat} = L_0 - L \quad (4)$$

D. Objective function

In the case of known wind speed v_{wind}, altitude range H, distance range L, projectile muzzle velocity v_0 and initial departure position L_0 of the UAV, the acquisition function of the flight scheduling strategy of the UAV is represented by the following formula (5), where p () represents the implementation and acquisition strategy process of the above model.

$$P = P(H, L, L_0, v_{wind}, v_0) \quad (5)$$

Among them, the initial speed of the blasting explosive is the UAV flight speed v_{fly} plus the launch speed v_{shoot}, as shown in the following formula (6).

$$v_0 = v_{fly} + v_{shoot} \quad (6)$$

E. Traverse the simulation strategy

The background setting of this problem involves two indeterminate variables, the height range and the distance range of UAV delivery. In the multivariate nonlinear analysis, the analysis form is complex, and because the internal forces change with time, or even with the different time slice width Settings, so it is difficult to directly analyze the results from a mathematical analysis Angle.

The traversal simulation trial-and-error strategy is adopted. The process is shown in Figure 3. One of the variables is traversed through the value, corresponding to another quantity is obtained, and then the conditions that meet the conditions are screened in the results.

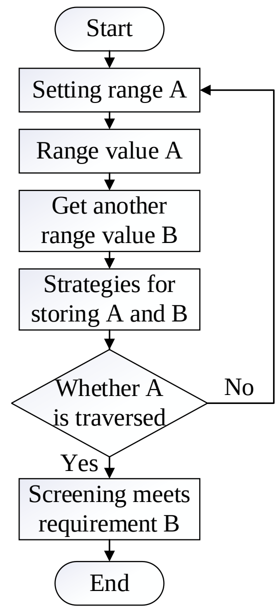


Figure 3. Traversal trial-and-error flow chart of multi-range variables

F. Quantitative analysis of stability

In the stability analysis of UAV, the influence of manufacturing technology and operating technology of UAV is excluded, and the environmental influence factors are mainly considered [14]. Therefore, the factors affecting the stability of the UAV include wind speed, wind direction, UAV flight height and depression Angle. Wherein, the wind direction design is integrated into the wind speed design, and the wind speed is represented as v_{wind}, the flight height of the UAV is H_0, the flight speed of the UAV is v_{fly}, and the depression Angle of the UAV is β.

Stability directly affects the accuracy of the hit. The main principle is that stability will cause the UAV to shake in position, affecting the accurate grasp of height, the accurate grasp of horizontal distance, the control of tilt Angle, and the size of flight and launch speed. This affects the state of the explosive launched, and ultimately affects the accuracy of the detonation point.

The quantitative score index of stability is used to react on the initial velocity, launch Angle, ground height and other indicators of explosives, and simulation tests are carried out to design the evaluation system of positioning accuracy, and the relationship between stability and positioning accuracy is analyzed.

1) Multivariate weighting

The relevant values of wind speed, UAV flight height and flight speed are evaluated in turn according to the 100 score standard, and the values are deducted from the 100 score according to the multi-weighted design strategy, and the evaluation results are finally obtained. The expression is as follows formula (7).

$$Score = 100 - f_1(v_{wind}) - f_2(H_0) - f_3(v_{fly}) - f_4(\beta) \quad (7)$$

Considering that the wind speed has a relatively large impact on the stability of the UAV, the weight is set to 1, that is, the function is expressed as follows formula (8).

$$f_1(v_{wind}) = v_{wind} \quad (8)$$

Consider the design in a relatively balanced state, the higher the height, the greater the impact, the weight is set to 1/50, The expression is as shown in the following formula (9).

$$f_2(H_0) = \frac{H_0}{50} \quad (9)$$

The speed of the UAV itself also has a greater impact on the stability. The greater the speed, the greater the impact. The weight is set to 1/20, then the function block is as shown in the following formula (10).

$$f_3(v_{fly}) = \frac{v_{fly}}{20} \quad (10)$$

The impact of depression Angle on the stability of UAV is also the greater the Angle, the greater the impact, The expression is as follows formula (11).

$$f_4(\beta) = 20(1 - \cos\beta) \quad (11)$$

2) Hit accuracy setting

There are two strategies for the design of hit accuracy, absolute accuracy and relative accuracy. Absolute precision indicates the distance between the landing point and the planned point. In general, the longer the distance you need to travel in the launch process, the lower the probability of your own hit. That is, the accuracy of the hit should be evaluated by the deviation relative to the firing distance. Therefore, the relative accuracy has more evaluation significance.

The horizontal distance between the drop point and the target point is X_0, and the horizontal distance between the actual landing position of the explosive and the original drop point is X', then the expression of absolute accuracy u is as shown in the following formula (12).

$$u = \left| X_0 - X' \right| \quad (12)$$

Relative accuracy $u\%$ is as follows formula (13).

$$u\% = \frac{u}{X_0} \times 100\% = \frac{\left| X_0 - X' \right|}{X_0} \times 100\% \quad (13)$$

G. Random disturbance strategy

In the modeling of numerical simulation, the core of simulation stability and hit accuracy is analyzed, and the random changes of initial parameters under the influence of stability factors are analyzed. Considering that certain Gauss disturbance *Gauss* is generated for the height H, flight speed v and depression Angle β of the UAV, the actual initial test parameters of blasting explosive delivery during launch state are as follows:

$$v_0 = v_{shoot} + v_{fly} + Gauss_v\left(score\right) \quad (14)$$

$$H_0 = H_0 + Gauss_H(score) \tag{15}$$

$$\beta = \beta + Gauss_\beta(score) \tag{16}$$

The Gaussian perturbation is a random Gaussian distribution related to the stability score. The velocity, height and depression Angle have corresponding perturbation values to adapt to the parameter values. The Gaussian perturbation is set to produce a mean of 0, and the variance is determined by the object and score of the corresponding perturbation. Where, the disturbance variance of depression Angle and velocity is regarded as acting on the horizontal component velocity at the same time, and is set as (100-*score*)/10, and the disturbance variance of height is (100-*score*).

In the overall simulation model, the hits before and after the impact of stability score will be calculated respectively, and the results before and after will be input into the accuracy measurement model to evaluate the hit accuracy, so as to link the score with the hit accuracy. The process is shown in Figure 4.

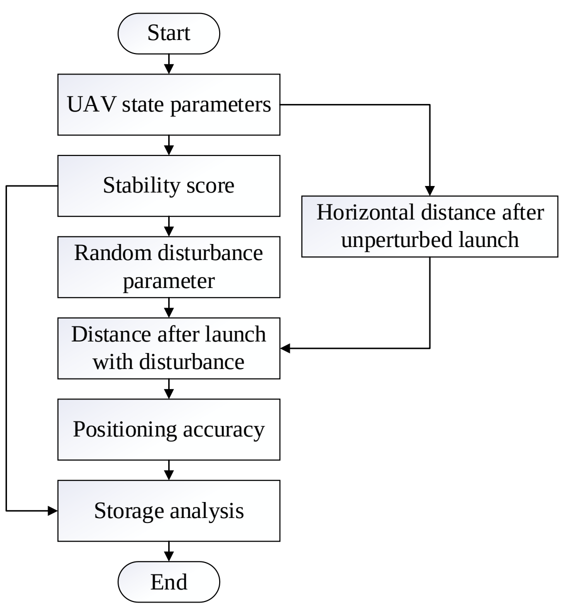


Figure 4. Simulation strategy of stability score and hit accuracy

When the stability score is associated with the hit accuracy, then the analytical solution is carried out, and the objective function is to obtain the maximum stability score under the condition of meeting the requirements of the scene, The expression is as follows formula (17).

$$Goal \to \left(Score_{\max} \middle| H, L, L_0, v_{wind}, v_{fly}, v_{shoot}, \beta\right) \tag{17}$$

Because the strategy of this model is a multi-variable nonlinear model, it is difficult to obtain direct analytical solutions, so the simulation strategy modeling is a more practical and operational strategy. Under the limitation of preset conditions, it is necessary to find the best strategy, still adopt the idea of traversal, and try all possible values to find the best scheduling scheme. The flow chart is shown in Figure 5.

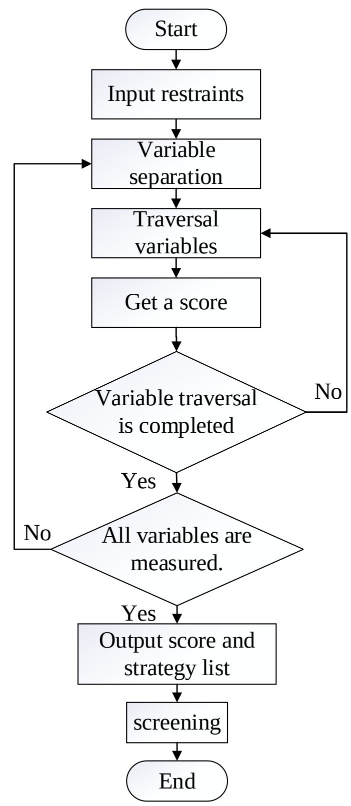


Figure 5. Traversal variable simulation strategy of multi-variable nonlinear model

IV. EXPERIMENTAL TEST AND RESULT ANALYSIS

A. Experimental platform

The model designed in this paper is based on python programming ideas and is programmed and implemented in jupyter platform.

B. Experimental test

1) Generate the initial throw state in order

To generate parameters that can be calculated and simulated for testing, set the range of parameters as shown in Table 1.

TABLE I. VARIABLE SETTINGS

Variable name	Range of variable
Launch height	100~1000
Flight speed	100~300
Launching velocity	250
Horizontal component velocity (Represents the change in depression Angle)	Half of the initial speed - initial speed (depression Angle 60 degrees -0 degrees)
Wind speed effect	-6~6

2) Stability score calculation

According to the calculation strategy of stability, the influence factors of height, speed, wind speed and depression Angle are subtracted from 100 points. Finally, the stability score of each set of parameters is obtained. According to the scoring rules, the higher the height, the higher the speed, the greater the wind speed, and the greater the depression Angle, the score will also decrease.

3) Planning point

Without the influence of stability score, according to the original emission parameters, the horizontal distance from the launching point to the landing point is 185 meters when there is no interference.

4) Random disturbance

The stability score is converted into the influence on the velocity, height and depression Angle of the launch in the form of random disturbance, and the test is tried several times. The random disturbance takes the form of generating random numbers with a mean of 0 as interference.

5) Accuracy measurement

After ten random perturbations and fall point tests on the parameters that measure the stability score, the results shown in table 2 are obtained. Because of the great chance of random disturbance, the hit accuracy is different among different simulations.

100 simulated disturbance positioning tests for the above parameters were performed and the results were plotted in Figure 6. Although there are still great accidental factors in the simulation of 100 times, it can be preliminarily seen that the hit error revolves around the overall trend of a value fluctuation.

TABLE II. THE SIMULATION RESULTS OF A CERTAIN PARAMETER AFTER 10 DISTURBANCES

Time	Height	Horizontal initial velocity	Landing distance	Absolute accuracy	Relative accuracy
1	459.5609	193.9832	178.7461	5.741393	3.112076
2	565.9514	202.8413	192.8809	8.393398	4.543575
3	484.5841	203.5067	188.4999	4.012370	2.174874
4	478.3433	191.5439	178.4841	6.003414	3.254103
5	481.6434	201.0121	186.3224	1.834916	0.994602
6	519.0507	199.4992	187.8286	3.341048	1.810989
7	510.4967	207.1368	193.2061	8.718591	4.725843
8	491.1663	203.0071	188.5453	4.057764	2.199479
9	477.7795	198.9608	184.3180	0.169518	0.091886
10	561.1234	198.3617	189.0825	4.594944	2.490653

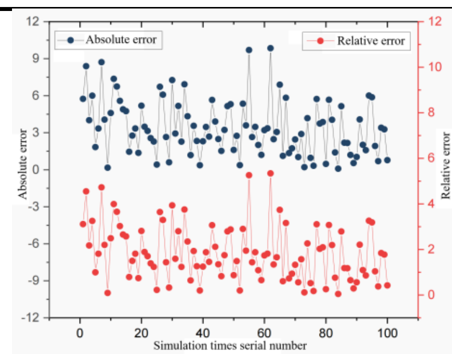


Figure 6. Absolute and relative hit errors of 100 simulations of a certain parameter

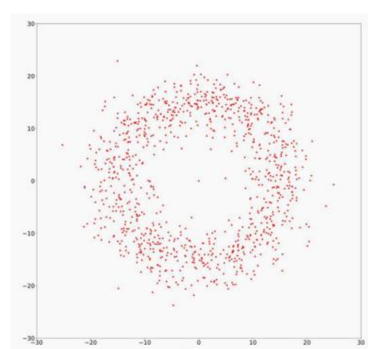


Figure 7. Distribution of drop points for 1000 simulations

Figure 7 shows the simulated distribution of 1000 perturbations under fixed emission parameters, where the center point is the exact landing point without disturbance. The simulation results show that a single point cannot directly explain the global situation. Among all the simulation points, some are close to the theoretical drop point, and some deviate greatly, but the overall point of fall can form a roughly circular distribution around the argument.

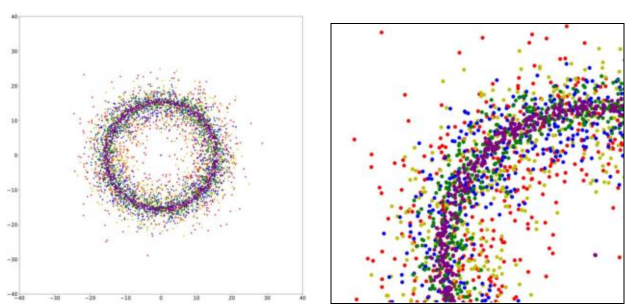
C. Analysis of experimental results

1) Simulation verification

The higher the stability score, the less interference to the initial state of the projectile, so the theoretical hit accuracy is smaller. In the set launch parameters scenario, the score is from 50 to 100, each score is traversed 100 times, and its average hit error is calculated, as shown in Figure 8.

Figure 8. Average hit error of 100 simulations with different scores

The relationship between the score and the hit error showed a downward trend. With the increase of stability score, the hit error gradually decreases, that is, the hit accuracy gradually increases, which accords with the prediction of stability and hit accuracy in the modeling stage.



a) Total distribution b) Detail distribution

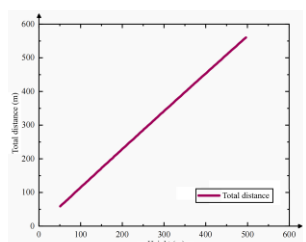
Figure 9. Comprehensive analysis of the landing points of 1000 simulations with different scores

Figure 9 shows the hit position of 1000 tests with different scores under fixed launch parameters. The red dot represents the score of 55 points, the yellow dot represents the score of 65 points, the blue dot represents the score of 75 points, the green dot represents the score of 85 points, the purple dot represents the score of 95 points, and the middle point of the ring is the original falling point.

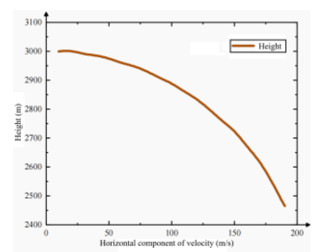
With the increase of the score, due to the decrease of the disturbance, the distribution range of the falling point is gradually accurate and gradually indents to the center of the circle. Therefore, it can be obtained that the higher the stability score, the smaller the disturbance, and the higher the hit accuracy; the lower the stability, the higher the disturbance, the wider the range of the landing point, the more inaccurate.

2) Model strategy simulation test

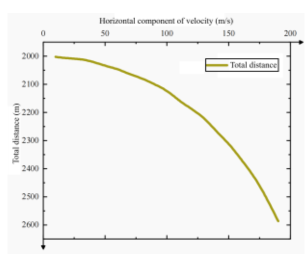
Taking the speed after the combination of flight speed and launch speed as the initial speed of the explosive launch time, the quantitative variable grouping analysis is adopted, the simulation test of the model is carried out, and the drawing analysis is carried out. The meaning of each diagram is presented in the name of the small diagram in the table, as shown in Figure 10.



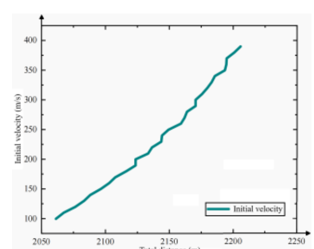
(a) The relationship between total distance and height when velocity and depression are fixed



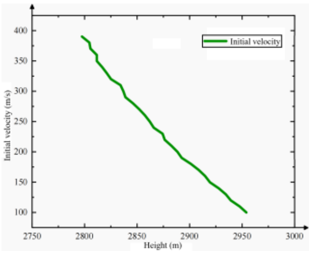
(b) Relationship between height and horizontal component of velocity when total delivery distance and initial velocity are fixed



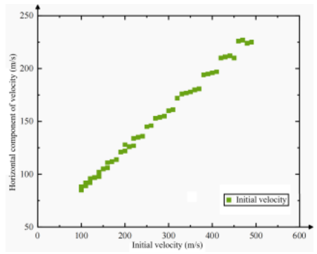
(c) The relationship between the total distance and the horizontal velocity component when the initial velocity and the drop height are fixed



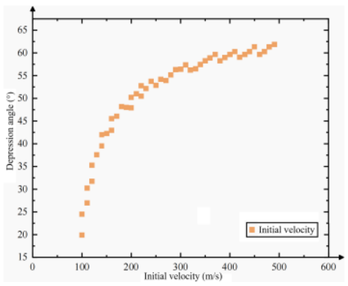
(d) The relationship between the total distance and the initial velocity when the depression Angle and the drop height are fixed



(e) The relationship between the initial velocity and the drop height when the dip Angle and the total drop distance are fixed



(f) The relationship between velocity and horizontal sub-velocity when the height and distance are fixed



(g) The relationship between velocity and depression Angle when the height and distance are fixed

Figure 10. Variable relationship analysis of delivery distance, delivery height, delivery speed and dive Angle

It can be concluded that when the speed and dive Angle are fixed, the delivery height and delivery distance are positively correlated, and close to the linear positive correlation trend.

When the delivery distance and initial velocity are fixed, with the increase of the horizontal velocity component (that is, the dive Angle decreases), the horizontal distance of the delivery object in the air will also increase, so the delivery height will decrease. When the initial speed and drop height are fixed, as the horizontal velocity component increases, the horizontal drop distance also increases, so the total distance also increases.

When the dive Angle and delivery height are fixed, the total drop distance increases with the increase of the initial speed. When the depression Angle and the total delivery distance are fixed, the initial velocity is negatively correlated with the delivery height. With the increase of the required delivery height, the time in the air of the explosive increases, but the horizontal distance should decrease, so the initial velocity should decrease.

When the delivery height and delivery distance are fixed, the initial velocity and the horizontal initial velocity component almost show a standard positive correlation, but from the Angle of depression, the dive Angle should gradually increase, and then tend to balance.

Obviously, the smaller the dive Angle, the larger the horizontal component of the initial velocity, the smaller the vertical component, when the height is determined, the more time can be moved in the air, the longer the horizontal movement time is relatively longer, the greater the horizontal movement distance, the greater the delivery distance. The other variables showed a roughly positive correlation.

3) *Adjustment strategy*

According to the stability scoring strategy and the relationship between various factors affecting the movement of the UAV, the height is required to be as low as possible, the depression Angle and the flight speed of the UAV are as small as possible, and the wind speed is 6m/s, the flight speed of the UAV is 300km/s-400km/s, and the launch speed is 500km/s. That is, the blasting speed range is 222m/s-250m/s. Therefore, the best delivery parameters are as follows.

The height is 300 meters, the delivery speed is 250m/s(900km/h), the horizontal distance is 290 meters, the horizontal component speed is set to 225m/s, and the cosine value of the depression Angle is 8/9.

According to the strategic planning, the drone from the height of 800 meters, first dropped to 300 meters, and then in the horizontal position of 290 meters away from the target, the height of 300 meters, the delivery distance of about 417 meters, the maximum flight speed of the drone, and the horizontal direction into the cosine value of 8/9 Angle, about 27 degrees, the launch of explosives is the best.

V. CONCLUSIONS

This model has shown many advantages in the process of design and implementation. First, the model analyzes the relevant factors affecting the UAV mission from the perspective of kinematics. Secondly, the continuous system is discretized, the continuous time system is processed in slices, and the calculation results are simulated step by step through calculus thinking, so that the model can accurately reflect the continuous changes of the system. Thirdly, the approximate strategy is adopted inside the time slice, which enables the complex continuous system to be processed. In addition, the model designs a multivariate analysis strategy based on Monte Carlo replacement tree search. Through traversing all cases and conducting simulation tests, convincing quantitative analysis results are obtained.

The innovative trial-and-error simulation strategy enables the model to find the required strategy in the actual scene and discover the law between the variables. Finally, the model uses multivariate weighted scoring mechanism to quantitatively analyze the stability, which provides convenience for the simulation comparison between the stability parameters and the precision parameters. In summary, this model not only has high theoretical accuracy and engineering practicability, but also has certain innovation and flexibility, which can provide important reference and guidance for the research and application in related fields.

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