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ALGORITHM FOR PRECISE PAYLOAD DROP FROM FPV DRONE WITH ACCOUNT OF WIND STRENGTH AND AUTOMATIC POSITION CORRECTION

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Abstract**—*The work is devoted to the development of an automatic system for dropping cargo from an FPV drone. An analysis of approaches to the construction of this type of system was performed. It is proven that this problem has not been fully solved, which requires the development of new approaches. In order to increase accuracy, it is proposed to use mathematical models that describe the process of cargo unloading. Mathematical models are given that connect such variables as Height, wind speed, drone speed, cargo weight, cargo surface area, wind direction angle relative to the drone, air density. The use of the obtained mathematical models allows you to calculate the coordinates of the reset point. The developed approach was tested in real conditions. The obtained results showed a significant improvement in the accuracy of dropping the load in the presence of a constantly acting wind.*

Index Terms—Unmanned aerial vehicle; automatic payload drop system; position correction; cargo delivery; ground control station.

I. INTRODUCTION

First Person View (FPV) drones are increasingly used in various fields, from military operations to rescue missions, agriculture and logistics. The ability of FPV drones to perform precise maneuvers in real time makes them extremely effective in performing specialized tasks, including delivering and dropping payloads. However, one of the main technical problems faced by these systems is to ensure high accuracy of dropping the load in the conditions of external influences, such as wind speed, wind direction, flight altitude and the dynamics of the UAV itself.

Usually, the accuracy of the cargo drop depends strongly on the environmental conditions, which can lead to significant deviations of the fall trajectory. Traditional approaches to this problem, based on static calculations of the drop point, do not take into account changes in meteorological parameters or aerodynamic properties of the cargo in real time. This creates difficulties in cases where the cargo needs to be delivered precisely to the specified destination in changing or adverse weather conditions.

Traditional approaches to the payload drop problem are often based on static drop point calculations that do not take into account the changing environmental conditions during flight. However, in the actual flight conditions of FPV drones, especially at medium and high altitudes, external factors such as changes in wind speed or adverse weather conditions can significantly affect the trajectory of the cargo fall. These deviations in the predicted trajectory often lead to the fact that the cargo does not reach the target point with the necessary accuracy, which can be critical in some cases, for example, when delivering military equipment or medical supplies to an emergency area.

The main problem is that most existing systems are not capable of dynamically adjusting the reset coordinates in real time, taking into account external changes in the environment. The lack of effective algorithms that can take these variables into account during flight significantly limits the accuracy of cargo drop, especially in cases where high accuracy is required and flight conditions change.

To solve this problem, it is necessary to develop a system capable of dynamically correcting the position of the drone and the coordinates of the cargo drop point based on variables such as wind speed and direction, flight altitude, and aerodynamic properties of the cargo. The system should use mathematical models that describe the movement of cargo after unloading and automatically adjust coordinates depending on changes in the environment.

In addition, it is necessary to ensure the integration of such a system with the on-board equipment of the drone, including the navigation system and the flight control system, in order to ensure continuous acquisition of data from sensors and conducting calculations in real time. The algorithm should also take into account the possibility of manual adjustment by the operator in the event of unforeseen situations.

This study is devoted to the development of an algorithm for dynamically adjusting the position of an FPV drone during cargo unloading, which allows for high delivery accuracy even in difficult meteorological conditions.

II. Problem Statement

As soon as the FPV drone hovers over the object, the trajectory of dropping the payload is determined as the trajectory of the body's movement under the influence of gravity and air resistance. To ensure accurate damage to the target, it is necessary to take into account the force of the wind, the height of the drone, its speed, as well as the mass and aerodynamic characteristics of the payload.

Thus, the formulation of the problem has the following form.

The coordinates of the drone's current position (x, y, h), current speed (V_x, V_y, V_h), wind characteristics, direction (α) and speed (w), target coordinates (x, y, 0) are known.

It is necessary to determine the coordinates of the drop point, taking into account the time of movement to the target (x_t, y_t).

Let's consider the known ways of problem solution.

III. Related Works

A review of the literature indicates significant interest in the use of UAVs for precision and automated operations such as search and rescue missions and cargo delivery. In particular, Waharte and Trigoni investigated the capabilities of UAVs to support rescue operations, thus proving the need for such systems to perform high-precision tasks [1]. Naidoo and Stopforth also emphasized the importance of developing UAVs for search and rescue operations, citing their effectiveness and reliability even in difficult conditions [2]. According to a study by Hugli and Yakimenko, precise controlled releases of UAVs are promising for military applications, which is directly related to the development of algorithms for accurate cargo drop [3].

In addition, Parker's works study the movement of bodies taking into account air resistance, which is crucial for understanding the trajectory of payload falling from a UAV [4]. Matthiesen's research suggests approaches for high-precision UAV payload drop, which resonates with the goals of this research [5]. Another important aspect is the modeling of wind effects on UAV movement, which was studied in detail by Shi and his colleagues [6]. Finally, Bird and McLain provide a comprehensive understanding of the principles of navigation and flight control for small unmanned systems in their theoretical framework, which can also be applied to the development of accurate reset algorithms [7].

Analysis of the above robots shows that the approaches described in them do not provide sufficient accuracy of cargo drop from the FPV drone.

IV. Problem Solution

The solution proposed in this work is based on the development of an algorithm that allows taking into account both static and dynamic factors during cargo unloading. The algorithm uses a mathematical model of the movement of the cargo after the drop, which includes such variables as wind speed and direction, the speed of the drone relative to the ground, the flight altitude, as well as the mass and aerodynamic characteristics of the cargo. Thanks to the use of this model, the system is able to automatically adjust the drop point of the cargo in real time, which allows to minimize the error during delivery.

In addition, the algorithm provides for the possibility of correcting the drone's flight path depending on external conditions. During the flight, the FPV drone receives data on the coordinates of the target, wind speed, and other important parameters. Using this data, the system adjusts the trajectory of the drone, providing passage over the target point. Before dropping the load, the algorithm calculates the necessary correction, taking into account the wind force and the predicted time of the fall of the load. This allows you to compensate for the displacement of the cargo trajectory under the influence of external factors and guarantee the accuracy of delivery.

Calculation algorithm:

1) We define the initial parameters

a. the speed of the drone relative to the ground u;

b. the height of the drone above ground level H;

c. wind speed relative to the ground w;

d. the angle between the wind direction and the flight line α;

e. mass of payload m;

f. payload surface area A;

g. resistance coefficient C_d;

h. air density ρ.

2) We calculate the coefficient q

$$q = \frac{1}{2}\rho \cdot C \cdot A. \quad (1)$$

3) Iterative process of range calculation.

We choose the time interval Δt = 0.02 *s* and the maximum number of iterations $N = 3000$.

We begin the iterative process to determine the position.

$$a_x = -\frac{q}{m}\cdot v_x^2 + \frac{w\cdot\cos(a)}{m}, \quad (2)$$

$$a_y = g - \frac{q}{m}\cdot v_y^2 - \frac{w\cdot\sin(a)}{m}. \quad (3)$$

We calculate the new velocity components

$$v'_x = v_x + a_x\cdot\Delta t, \quad (4)$$

$$v'_y = v_y + a_y\cdot\Delta t. \quad (5)$$

We calculate the horizontal and vertical displacement of the payload:

$$x' = x + v_x\cdot\Delta t + \frac{1}{2}\cdot a_x\cdot(\Delta t)^2, \quad (6)$$

$$y' = y + v_y\cdot\Delta t + \frac{1}{2}\cdot a_y\cdot(\Delta t)^2. \quad (7)$$

We update the values of coordinates and time:

$$x = x' y = y' t = t + \Delta t.$$

We check the condition of reaching the ground ($y = 0$). If the condition is fulfilled, we fix the landing point of the cargo R_x, R_y and exit the iteration cycle.

We determine the coordinates of the cargo drop point (R_{Plat}, R_{Plon}) according to the current coordinates of the target ($\text{Target}_{\text{lat}}$, $\text{Target}_{\text{lon}}$) and the calculated radius R:

$$\tan\theta = \frac{\text{Target}_{\text{lon}} - \text{Current}_{\text{lon}}}{\text{Target}_{\text{lat}} - \text{Current}_{\text{lat}}}, \quad (8)$$

$$R_{\text{Plat}} = \text{Target}_{\text{lat}} - R\cdot\sin(\theta), \quad (9)$$

$$R_{\text{Plom}} = \text{Target}_{\text{lon}} - R\cdot\cos(\theta). \quad (10)$$

To ensure that the FPV drone will accurately release the payload, its algorithm includes several key steps that take into account wind strength, flight altitude and drone speed.

First, the drone receives the coordinates of the target from the ground control station (GCS). After that, the drone adjusts its trajectory so that it flies directly over the target. At this point, wind strength and other parameters are taken into account to calculate the exact drop point.

The key point is the calculation of the time the load falls t_{fall}, which is determined by the flight height:

$$t_{\text{fall}} \approx \sqrt{\frac{2H}{g}}. \quad (11)$$

This calculation allows you to estimate how long the payload will be in the air, which is important to take into account the effect of wind.

Having determined the time of the fall, it is possible to calculate the horizontal displacement of the payload under the influence of the wind:

$$x_{\text{wind}} = \omega\cdot t_{\text{fall}}\cdot\cos(\alpha). \quad (12)$$

This offset is added to the initial drop point to ensure that the payload lands directly on the target.

It is important to note that before dropping the payload, the possibility of manual intervention is checked, which allows the operator to adjust the actions of the drone if necessary. After all, this approach allows you to achieve high accuracy of dropping the payload even in conditions of changing wind speed and other factors affecting the trajectory of the fall.

As a result, the drone automatically adjusts its position during the flight to ensure an accurate hit on the target, taking into account all the calculated parameters, as well as external conditions.

This adjustment helps to achieve a high degree of accuracy even in situations with variable wind speed and other factors affecting the trajectory of the fall.

A. Experimental results

A compact FPV drone capable of carrying 250 gram ammunition was used to implement the accurate cargo drop algorithm. The drone is light and maneuverable, which allows it to operate effectively at heights from 60 to 100 meters.

Payload Drop System: A simple mechanical system that allows you to securely hold and drop 250 gram rounds of ammunition. The reset system is controlled by a servomotor, which is activated when the required coordinates are reached.

Autopilot: Uses the Pixhawk open source autopilot, which allows you to modify the firmware for specific requirements. The autopilot provides accurate navigation, flight stability and interacts with other systems.

GPS: A compact high-precision GPS module connected to the autopilot determines the exact coordinates of the reset point.

Airspeed Sensor: A small differential sensor is used to measure wind speed during flight. This data is necessary to calculate the trajectory and adjust the position of the drone during the delivery of the payload.

After the simulation tests were completed, a series of real flights were performed in the software environment to test the proposed cargo delivery algorithm. The flights were performed at altitudes from 60 to 100 meters under various wind conditions as shown in Table I.

TABLE I. SIMULATION TEST RESULTS

No	Height (m)	Wind speed (m/s)	Drone speed (m/s)	Distance to target (m)
1	61	2.8	10	3.1
2	65	3.0	12	3
3	70	2.5	9	3.3
4	80	3.2	11	4.1
5	94	3.3	10	4.8
6	102	3.5	13	5.4

Analysis of the results showed that the drone is able to maintain a certain height and adjust its position for accurate unloading of goods even in variable wind conditions. The average reset accuracy was more than 75% at a threshold radius of 5 m, which proves the effectiveness of the proposed approach.

V. CONCLUSIONS

According to the results of the tests, it was determined that the proposed method of releasing the payload from a compact FPV drone is effective and can be used for accurate cargo delivery at a height of 60 to 100 meters. The algorithm, which takes into account flight parameters and wind strength, ensures high accuracy of hitting the target. The test results proved that the developed system can be successfully used in conditions where high accuracy of cargo delivery is required.

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В. М. Синєглазов Д. В. Таранов І. О. Юденко. Алгоритм точного скидання вантажу FPV-дроном з урахуванням сили вітру та автоматичної корекції положення

Робота присвячена розробці автоматичної системи скидання вантажу з FPV дрона. Виконано аналіз підходів до побудови такого типу систем. Доведено, що дана задача в повному обсязі не вирішена, що вимагає розробку нових підходів. З метою підвищення точності запропоновано використовувати математичні моделі, які описують процес скидання вантажу. Наведено математичні моделі, які зв'язують такі змінні, як висота, швидкість вітру, швидкість дрона, маса вантажу, площа поверхні вантажу, кут напряму вітру відносно дрона, щільність повітря. Використання отриманих математичних моделей дозволяє розрахувати координати точки скидання. Розроблений підхід було перевірено в реальних умовах. Отримані результати показали значне покращення точності скидання вантажу при наявності постійно діючого вітру.

Ключові слова: безпілотні літальні апарати; автоматична система скидання вантажу; корекція положення; доставка вантажу; станція наземного контролю.

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