Autonomous payload drop system using mini Unmanned Aerial Vehicles

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Abstract- This paper describes a novel mechanism for the airdrop of a small payload from a mini - Unmanned Aerial Vehicle (UAV). The primary objectives were to drop a payload from the UAV in such a way that it falls within the threshold radius around the target location. The payload drop triggered is executed after taking into account various factors including the speed, altitude and heading of the UAV, the wind speed, drag force experienced by the payload, and the target coordinates. The firmware of the open source autopilot, Pixhawk, was modified as per the requirements. An accuracy of around 70% was achieved when threshold radius was kept at 7 meters around the target location and the payload was dropped from altitudes ranging from 100 – 200m.
Keywords – Payload drop algorithm, projectile from UAV, autopilot firmware.

I. INTRODUCTION

UAV, an acronym for Unmanned Aerial Vehicle, is in essence an aircraft with no human pilot on board. The primary function of an Unmanned Aerial Vehicle is ISTAR which stands for information, surveillance, target acquisition and reconnaissance. In recent years, the application base of UAVs has expanded exponentially. They are being utilized in various sectors including military, defense and border patrolling, journalism, scientific researches, disaster relief, agriculture and many more [1].

A new era has begun with the attempts to employ UAVs in tasks other than just surveillance like payload delivery at specified coordinates. The object to be dropped can range from medicines, food for disaster relief programs to potential weapons, bombs in a war etc., thus leading to optimal utilization of UAVs in every sector [1-3]. This paper is thus intended to provide a working mechanism of airdrop along with flight test results.

The rest of the paper is organized as follows: Algorithm for conducting the payload drop is described in section II. Flight test results are shown in section III and finally, conclusion and references in IV and V respectively.

II. PROPOSED ALGORITHM

Calculation of payload Release Point –

The trajectory of the payload will be that of a projectile once released from the aircraft.

To evaluate the GPS coordinates of the Release Point, range of the projectile is needed to be calculated first.
Let us assume that the instant of calculating the range of the projectile,
Aircraft velocity (relative to the ground) = u,
Aircraft altitude (above ground level) = H,
and Wind speed (relative to the ground) = w

The autopilot firmware employs the inbuilt barometer for estimating the altitude, the external air speed measurement sensor for estimating wind speed, and the inbuilt IMU for estimating the aircraft velocity.

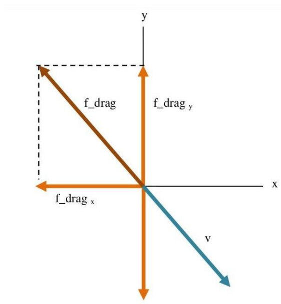


Figure 1: A projectile in flight with velocity v and grad

The drag force due to wind is taken to be proportional to the square of the velocity with respect to the payload [4-5].

The program to calculate the range of the projectile is written in C++ and is based upon the following algorithm:

Step 1: Record the following parameters at the given instant from the corresponding sensors:
Aircraft altitude (above ground level),
Aircraft velocity relative to the ground,
Wind speed relative to the aircraft,

The mass of the payload, its surface area, drag coefficient and air density are constant parameters stored in the FCS before-hand.

Step 2: Calculate the constant q in terms of the above parameters. ‘q’ is given by,

$$q = ½(PCA)$$

where, P = density of air
C = drag coefficient
A = surface area of the payload

Step 3: Choose time interval $\Delta t = 0.02$sec. Set maximum number of iterations (N) = 3000.

Step 4: Iterate steps 4a through 4e while number of iterations < N.

Step 4a: Calculate the new components of acceleration in the horizontal and vertical directions,

$$acc_x = -(q/m)v_x^2 ; \qquad acc_y = g - (q/m)v_y^2 ;$$

Step 4b: Calculate the new components of velocity in the horizontal and vertical directions,

$$v_x` = v_x + acc_x \Delta t ; \qquad v_y` = v_y + acc_y \Delta t ;$$

Step 4c: Calculate horizontal and vertical distance of projectile from the aircraft at the end of interval,

$$x` = x + v_x\Delta t + ½(acc_x)(\Delta t)^2 ; \qquad y` = y + v_y\Delta t + ½(acc_y)(\Delta t)^2 ;$$

Step 4d: Update the value of range, altitude and total time

$$x = x` ; \quad y = y` ;$$
$$t = t + \Delta t$$

Step 4e: Check if y == H, then range = x. Exit from the loop. Else continue.

Step 10: End

The above algorithm calculates the range R of the projectile if the payload is released at that particular instant.

After estimating the value of range R, we need to calculate the GPS coordinates of the release point (RP_{lat} , RP_{lon}). It is calculated as follows:

$\tan\theta$ = (target long – current long)/(target lat – target long)

RP_{lat} = target lat – R * sin θ
RP_{long} = target long – R * cos θ

Therefore, the predicted release point is (RP_{lat} , RP_{lon}).

We now proceed to explain the entire payload release algorithm

Payload release algorithm –

An algorithm was developed for calculating the release coordinates before executing the payload drop. The algorithm was programmed into the Flight Control System (FCS) onboard the UAV. The payload can be released by triggering a servo connected to an auxilliary PWM channel of the onboard FCS. The developed algorithm accounts for following factors in order to execute an accurate drop: aircraft velocity, aircraft altitude, wind velocity, aircraft current location coordinates, and target coordinates. Weight of the payload and its approximate drag coefficients have been hard coded into the software.

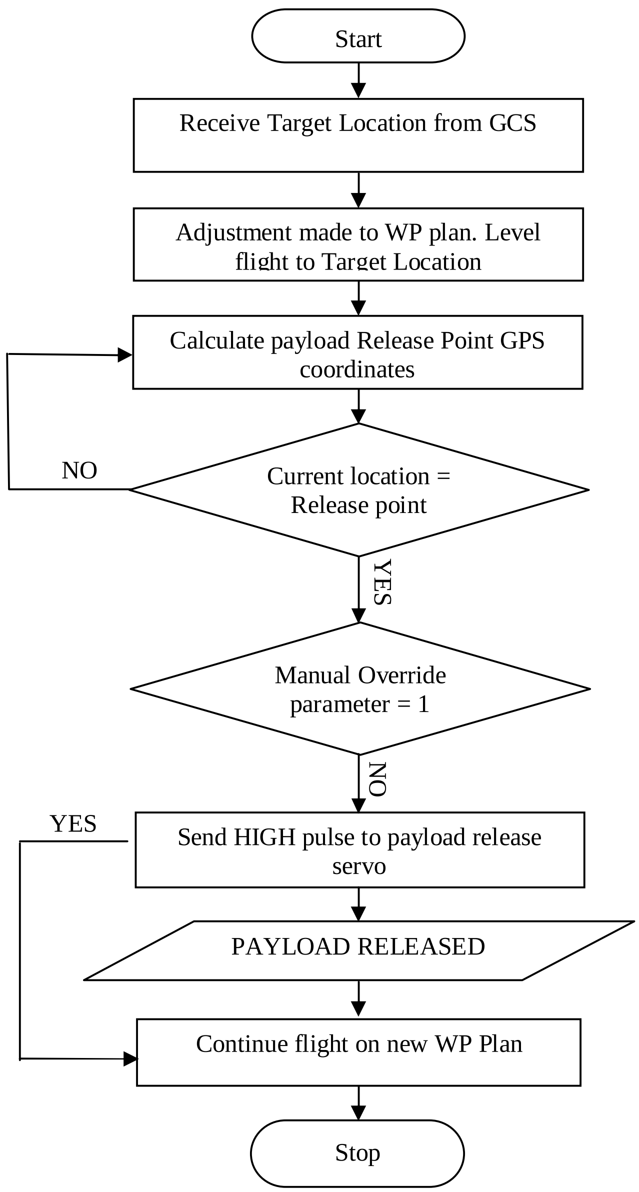


Figure 2: Flowchart for payload drop algorithm

The proposed algorithm waits for the Ground control station to communicate the target location coordinates to the on board FCS via the telemetry link. Upon receiving the target location, the FCS makes minor modification to the aircraft's trajectory by adjusting the way-points such that the trajectory is now in a straight line passing over the target location. The FCS then evaluates the release point by assuming constant wind velocity and aircraft's altitude and velocity from the current point to the estimated release point. This evaluation is done in a loop until the release point is reached and the drop mechanism is triggered.

As a safety procedure, the FCS checks for an override parameter before finally triggering the payload release. The override parameter can be set or reset manually from the Ground control station.

The above algorithm may fail if the calculated range of the projectile is greater than the distance between the aircraft current location and the target location. This can happen if the aircraft velocity is too high.

III. Experiment and Result

A. Hardware Description –

AIRFRAME

The entire testing was carried out on a foam based COTS airframe. It is high winged airframe with a wingspan of 2.5m and the tail configured to an H. The electric propulsion motor is installed in a pusher configuration. Air titan is an EPO foam built frame which makes it light weight as well as strong. Also, EPO foam can be easily repaired. The wings of the frame come pre strengthened with carbon fiber spars embedded near the leading edge. The frame demonstrates rolling takeoff and landing. After thoroughly examining the space inside the fuselage at the C.G. of the frame, the unavailability of space for installing the payload system was felt and hence the entire payload drop system was accommodated outside the fuselage under the belly. However to achieve this the ground clearance of the frame was increased using the modified nose gear.

The payload drop system consists of two wooden cuffs with 2 degree of motions along with a thick iron strip. The payload to be dropped (here bottle) is fitted inside the space provided by wooden cuffs and the cuffs are closed or opened depending on the position of the iron strip. A high torque metal gear servo motor was required which could easily control the lock positioning. It was found that HiTec HS-645MG servo motor provided the much required torque and hence the lock system could be controlled with ease

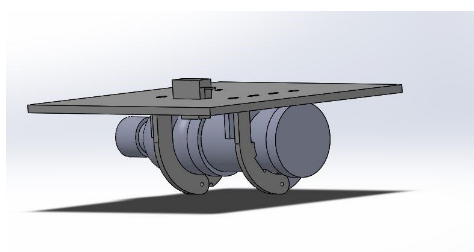


Figure 3: CAD model of payload drop mechanism

AVIONICS

The avionics used in the system can be classified into following sub-sections

1. Propulsion
2. Payload
3. Communication
4. Autopilot and other flight control systems

The paper will introduce each avionics sub-section with a detailed description.

Propulsion: A brushless Electric out-runner motor of 500 kV with 1.5 kW power rating is used as the propulsion system of the frame. Lithium-polymer batteries were used to power both avionics and propulsion system since the energy density of these batteries is greater than lithium-ion batteries.

Payload: Payload could be defined as the extra material apart from propulsion motor, batteries and avionics peripherals which could be carried by the unmanned Aerial Vehicle. In this case the payload is the water bottles of weight 250g which will be dropped during the flight of the vehicle.

Autopilot: A number of autopilots were considered. Since it was required to modify the firmware of the autopilot according to the requirements, Pixhawk, which is an open source autopilot was chosen. Moreover it also provided the liberty to form new parameters e.g. the bull's eye or the target GPS coordinates, the threshold radius etc. the values of which could be provided by the user at real time during the execution of the airdrop.

Telemetry: A pair of 3DR telemetry radio with 433 MHz diploe antenna was used to obtain the telemetry data of the UAV like altitude, distance to home, pitch, roll, yaw etc. One of the telemetry unit was mounted on the UAV and connected to the Pixhawk, was paired to the one present at the ground control station, connected to Mission Planner and thus setting up the telemetry connection.

GPS: GPS module connected to Pixhawk provided the GPS location of the UAV. A module with very small error and negligible Electromagnetic Interference from the surrounding was chosen since the GPS location of the release of the Payload was required to be as accurate as possible.

Airspeed Sensor: A digital differential airspeed sensor was used to measure the air pressure during the flight of the UAV. Air pressure was required so as to estimate the force of drag acting on the object dropped and thus influencing the release coordinates of the bottle.

B. Flight test results –

The system was first tested using Software-in –the-loop (SITL) simulation. After the execution of safe flights along with appreciable results on SITL it was decided to test the system manually on-field. A series of manual flights were conducted to validate the algorithm proposed in the paper. The Airdrop task was attempted during various different wind conditions, however the accuracy obtained was approximately close even in variant conditions, thus generalizing the algorithm.

Table 1: Tabular representation of flight test results

S.NO	Altitude(m)	Wind Speed (m/s)	Aircraft velocity (m/s)	Distance from target(m)
1	101	3.3	12	5
2	103	3.5	14	3
3	107	3.1	11	8
4	102	3.9	13	4
5	104	4.1	11	5
6	112	3.5	15	7
7	116	3.7	15	9
8	118	4.2	13	8
9	111	4.3	14	4
10	116	3.8	14	8
11	122	3.9	12	9
12	126	4.2	11	11
13	124	4.3	15	10
14	120	4.1	13	9
15	123	4.4	14	13
16	155	3.8	14	15
17	159	4.4	15	14
18	152	4.1	15	16
19	155	3.9	11	17
20	161	4.5	14	16

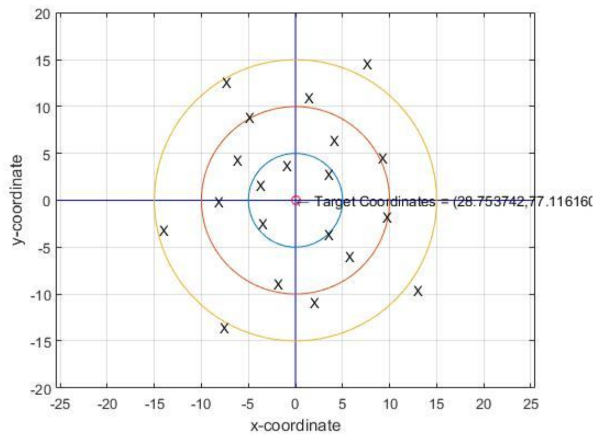
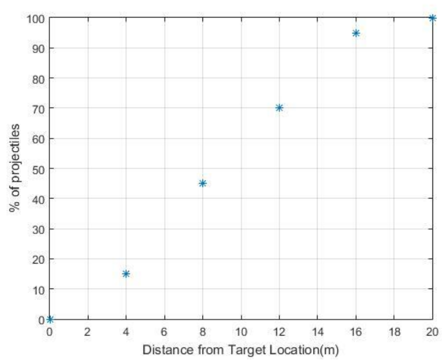


Figure 4: Payload landing points with respect to Target Location

The flight test data was analyzed to find the ratio of projectiles within a threshold radius from the target location. Percentage of projectiles falling within the threshold radius was plotted. Threshold radii considered: 4m, 8m, 12m, 16m and 20m from the target location. The plot is shown in figure 5.



X-axis: Threshold radius from the target
Y-axis: Percentage of projectiles

Figure 5: Percent of projectiles landing within threshold radius

IV.CONCLUSION

In this paper, we present a novel system for the airdrop of a small payload from a UAV. The algorithm was successfully flight tested in over 20 flights. The results depicted an accuracy of over 70 percent when the threshold distance is about 12 meters from the target location, and over 95 percent for a threshold distance of 16 meters. The results prove that the proposed method is a viable solution for autonomously dropping payload in a specified region. Hence, this method can be successfully implemented on a mini UAV for dropping up to 250g of payload with satisfactory accuracy. The accuracy of the method can certainly be improved by taking into account the direction of wind. The number of iterations can be increased and time interval can be decreased for range calculations. Thus, UAVs can be successfully used for implementing payload drop[6]. The above research proves that there is ample ground for future research in this field.

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