DETERMINATION OF RELATIVE POSITION FOR DRONE LANDING USING IMAGE PROCESSING

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Abstract— Autonomous unmanned aerial vehicle like drones are one of the most important tool for material delivery in man made disasters or natural calamity relief operations. For the proper delivery of material, determination of relative position of the drone is an important task. The relative orientation is measured in terms of six Degree of Freedom (6DOF) vector. The six Degree of Freedom vector can be determined by using a sensor system consisting of a passive reflective pattern on the target location, imaging this reflective pattern using two Charge Coupled Device (CCD) cameras mounted on the drone, and then illuminating the target pattern using an array of laser diodes and other image processing units. This paper contains a brief description of the sensor system and the algorithm for determination of relative state vector using five spot passive reflective target patterns for landing of autonomous unmanned drone. The algorithm starts with measurement of azimuth and elevation angles from the camera image. Then the ranges to each spot in the target pattern can be measured. Finally the rotational angles yaw, roll and pitch are determined using QUEST algorithm.

Index Terms— Drone, 6 degrees of freedom (6 DOF), QUEST algorithm, Attitude determination, Range, Azimuth, Elevation.

I. INTRODUCTION

Autonomous multi-rotor unmanned aerial vehicles like drone are one of the most promising and powerful emerging technologies to improve disaster response and relief operations [1]. Drones naturally complement traditional manned relief operations by helping to ensure that operations can be conducted in a safer, faster, economical and efficient manner. Armed drones have been increasingly finding far more positive application in the disaster relief sector [2].

When a disaster occurs, drones may be an innovative approach to provide relief workers with better situational awareness, locate survivors amidst the rubble, perform structural analysis of damaged infrastructure, deliver essential supplies and equipment, evacuate casualties, and help extinguish fires among many other potential applications.

Material delivery is one of the important applications of drones during disaster management. This facility can be used for the delivery of medicines, vaccines and medical/surgical materials and equipment like cotton, suture materials, forceps/scissors, surgical blades etc. in the emergency conditions and calamities such as landslide, floods, and so on. The drone will be located at a nodal location and autonomously fly to the pre-determined desired location, deliver the payload and return to the nodal location via a pre-determined path.

A Quad-Copter or drone is a helicopter with four rotors. If all rotors turn in the same direction, the craft would spin just like the regular helicopter without tail rotor. The aerodynamic torque of the first rotors pair cancelled out with the torque created by the second pair which rotates in the opposite direction and so if all four rotors apply equal thrust the quad-copter will stay in the same direction. A quad-copter has four controllable degrees of freedom: Yaw, Roll, Pitch, and Altitude. Each degree of freedom can be controlled by adjusting the thrusts of each rotor as shown in figure1.

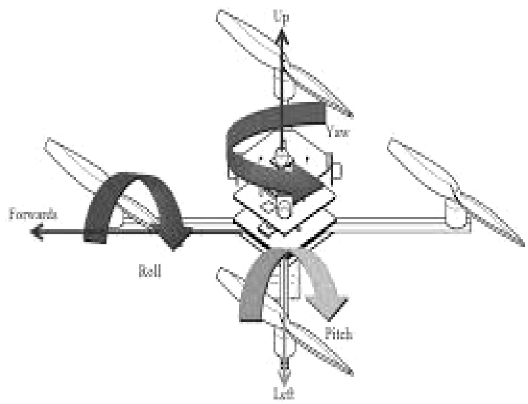

Fig-1 Quad-rotor maneuver

The Global Positioning System (GPS) is a satellite-based navigation system made up of a network of 24 satellites placed in orbit by U.S. Department of Defense. This system is available for civilian use. It can be used to navigate the drone to deliver the payload to a predetermined desired location. But the accuracy of GPS is approximately 15 meters. Due to this limitation drone cannot land on the exact pre-determined location. At the destination it shall land in the landing area that will be located either on the rooftop or in the compound in predetermined location. This is solved by using a sensor system explained in this paper.

The paper is organized as follows. Firstly, a brief description of proposed method and experimental setup for the attitude determination between two space vehicles using five spots target pattern is given. Following this, the algorithm for determination of azimuth and elevation angles, range and rotation angles like yaw, roll and pitch is developed. Finally, the results and conclusions are presented by processing images collected using the experimental setup.

II. PROPOSED METHOD

As an initial condition, it is assumed that the relative range and attitude of drone is within an acceptable level from a global positioning system (GPS). The sensor system is mounted on the drone and it generates laser beam in two different wavelengths to illuminate the passive reflector pattern mounted on the target location as shown in figure 2. The laser diode array contains two sets of diodes. One set will emit in band wavelength and the other set produce out of band wavelength. The target reflector pattern is a five spots pattern having a layer of reflective material and an optical filter that passes only in band wavelength as shown in figure 3.

Hence the reflected beam from the target pattern contains only in band frequency [3,4]. The reflective light from the target pattern is split into two portions. One portion passes though a filter that passes only the in band wavelength to the CCD camera. The second portion passes through another filter that passes only out of band wavelength to the CCD camera. Hence two mages are captured simultaneously in two different wavelengths using two CCD cameras. But only one image contains the traces of the target pattern.

The four spots of the five spots target pattern are in one plane and one spot is out of plane as shown in figure 4. This arrangement of the target model helps to determine the relative attitude of the drone. Since small change in the relative attitude reflects in the position of out of plane spot in the captured image [5]. The size of spots and the height of attitude pin determine the maximum range measured.

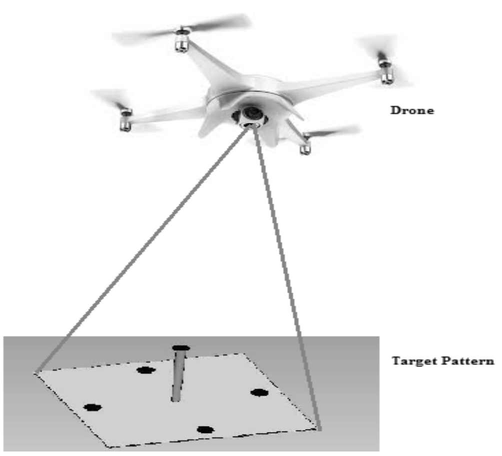

Fig 2. Illustration of drone and target pattern

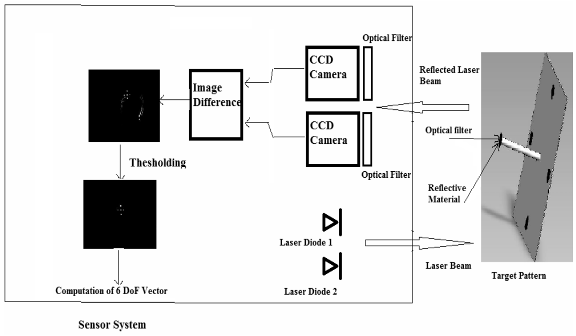

Fig-3 Sensor System

The first CCD camera images an out of band image which contains every reflective object except the target pattern. The second CCD camera images in band wavelength image containing the target pattern. Thus the pixel wise difference between the two images produces a third image which is free from unwanted reflections [6,7]. Further threshold produce only the target pattern required. This is used for further processing to determine the relative attitude.

III. ALGORITHM

Algorithm for determination of attitude of the five point target pattern consists of mainly four steps. Determination of elevation and azimuth angle is the first step. Then consider the five spots target as two set of three spot target pattern and determine the range to every spot. Next calculate the quaternion angles using QUEST algorithm. Then finally, convert the values of quaternion angles in to Euler angles roll, yaw and pitch.

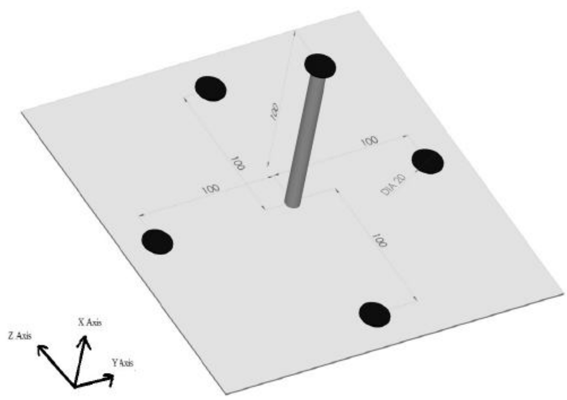

Fig 4 Target pattern

A. Determination of Azimuth and Elevation Angles

The calculation of azimuth and elevation begin with identification of the intensity centroid of each spots. The intensity centroid is the y-z coordinates where most of the intensity values are converges. This is the average of all the pixel coordinates in the spot weighted by their pixel intensity values. The coordinates of the spots determines the azimuth and elevation using (1) and (2).

$$Azimuth = \tan^{-1}\left(\frac{-Y_c}{FocalLength}\right) \quad (1)$$

$$Elevation = \tan^{-1}\left(\frac{-X_c}{\sqrt{Y_c^{\,2} + FocalLength^2}}\right) \quad (2)$$

Here the focal length in pixel of the CCD camera is the scaling factor converts the pixels in to angles. The centroid of each spots is calculated based on the origin as the center of the image.

B. Determination of Range

The five point target pattern split in to two set of three points as shown in figure 4. It is considered as the horizontal three spots 1, 2 and 3 as one set and vertical three spots 4, 5 and 1 as another set. Then solution for range is obtained by averaging the two three spot range solution.

The inverse perspective algorithm can be used to determine the range solution from the azimuth and elevation angles. The azimuth and elevation angles to each spot are used to calculate direction of each spots in terms of the unit vectors. The cosine of the angle $\cos\theta_{12}$, $\cos\theta_{23}$ and $\cos\theta_{13}$ between each pair of unit vectors is determined by calculating the dot product of the vectors. Then the law of cosines is applied to derive three non-linear equations with the ranges to each spot as unknowns. These non linear equations are solved by using Newton-Raphson method which is an iterative procedure beginning with initial guess.

$$l_{12}^{\,2} = R_1^{\,2} + R_2^{\,2} - 2R_1R_2\cos\theta_{12} \quad (3)$$

$$l_{23}^{\,2} = R_2^{\,2} + R_3^{\,2} - 2R_2R_3\cos\theta_{23} \quad (4)$$

$$l_{13}^{\,2} = R_1^{\,2} + R_3^{\,2} - 2R_1R_3\cos\theta_{13} \quad (5)$$

Where

l_{ij} = distance from spot i to spot j

R_i = range from camera to spot i

C. QUEST Algorithm

The QUEST (Quaternion Estimation) algorithm determines an optimal estimation of relative attitude in terms of quaternion angles using the weighted least square method.

Let u_i be the i^th^ vector in the target coordinate system and v_i be the i^th^ vector in the chaser coordinate system. Then the direction cosine matrix A can convert the vectors in the target coordinate system in to chaser coordinate system as equation (6).

$$u_i = Av_i \quad (6)$$

However in the practical condition due to interference of noise the equation (6) is not true always. Thus the attitude matrix A is calculated using least square method. In least square technique the attitude is measured by minimizing the sum of squared errors. The quadratic cost function can be defined as in equation (7).

$$J(A) = \frac{1}{2}\sum_{i=1}^{n} a_i \left\| u_i - Av_i \right\|^2 \quad (7)$$

This can be solved by using the eigenvector method. The cost function J(A) in equation (7) must be minimized to get minimum error estimation. In other words the function g(A) in equation (8) must be maximized.

$$g(A) = 1 - J(A) \quad (8)$$

Consider the constants as below.

$$\sigma = \sum_{i=1}^{n} a_i u_i^T v_i \quad (9)$$

$$S = \sum_{i=1}^{n} a_i (u_i v_i^T + v_i u_i^T) \quad (10)$$

$$w = \sum_{i=1}^{n} a_i (u_i \times v_i) \quad (11)$$

$$K = \begin{bmatrix} S - \sigma I & w \\ w^T & \sigma \end{bmatrix} \quad (12)$$

The function g(A) can be written in terms of quaternion angle as in equation (13).

$$g(A) = q^T K q = \lambda \quad (13)$$

In the above equation, the q is the optimum quaternion matrix and λ is the eigenvalues of the matrix K. From the above equation this is clear that the optimum quaternion vector is the eigen vector corresponding to largest eigen value of matrix K.

D. Determination of Euler Angles

From the QUEST algorithm the quaternion angles are obtained. They can be converted into Euler angles yaw, roll and pitch using the conversion formula as shown below.

$$Roll = \tan^{-1}\left(\frac{2q_3q_2 + 2q_1q_4}{q_3^{\,2} - q_4^{\,2} + q_1^{\,2} - q_2^{\,2}}\right) \quad (14)$$

$$Pitch = \sin^{-1}(2q_3q_4 - 2q_1q_2) \quad (15)$$

$$Yaw = \tan^{-1}\left(\frac{2q_4q_2 + 2q_1q_3}{q_4^2 - q_3^2 + q_1^2 - q_2^2}\right) \quad (16)$$

IV. RESULTS AND CONCLUSIONS

Sensor system and algorithm required for determination of relative orientation of drone for successful landing at predetermined location was developed using five spot target pattern. Algorithm was tested using a target pattern of 200mm diameter spots with 200mm base width. The height of the attitude pin is 100mm. The images are captures from 500mm to 10000mm apart to test the algorithm. It is found that the geometry and pattern of the target has a key role in the range and attitude angles measurements.

The attitude pin is mounted out of plane with other four spots helps to measure small variations in the angular movements. The accuracy of the calculation of the range and attitude angles depends on the size and orientation of the target spots. Larger sized spots are used for long ranges and smaller sized spots for small ranges. It is found that the height of the attitude pin has a key role in the sensitivity of measurements.

The images for testing the performance of the algorithm are captured in various range and angles. The proposed algorithm is simulated using the software MATLAB. Some of the output images are given below. For evaluating the performance of range measurement all the images are captured at aligned position with target.

Figure 5 shows image captured at a distance 750mm from the target. Figure 6 shows the image captured at 1500mm apart. The figure 7 shows an error plot for range. Using this sensor system the range can be measured with in 15 mm accuracy.

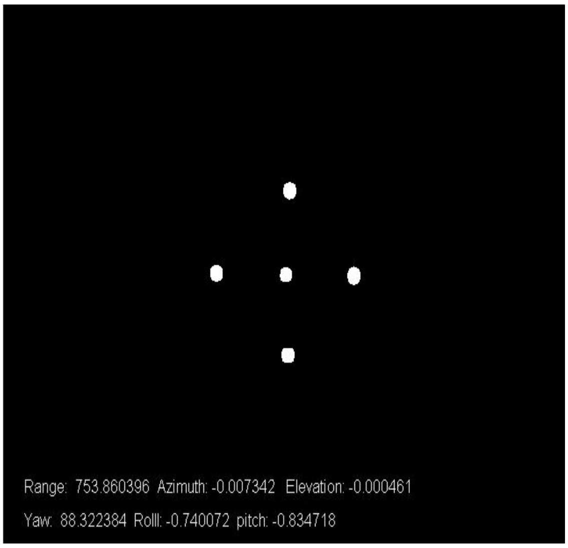

Fig 5 Output image at 750mm range

Fig 6 Output image at 1500mm range

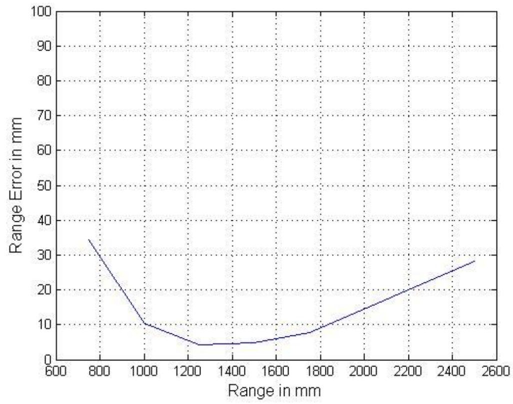

Fig 7 Range Error Plot

Similarly the experiment is continued for different azimuth and elevation angles. Figure 8 shows the output image captured at 1500mm apart at an elevation angle -0.12 radians. The figure 9 shows the output of the image captured at 1500mm at an azimuth angle -0.12 radians. Figure 10 shows the error plot for attitude angle. This is plot error in attitude against the range. The attitude error is within the range of 04 degree.

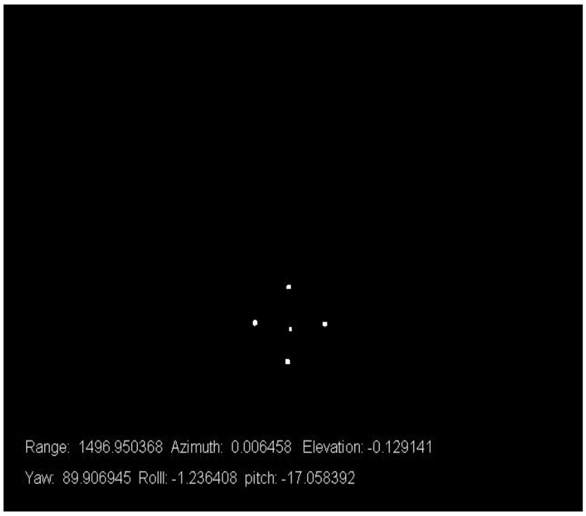

Fig 8 Output image at 1500mm range and elevation angle -0.12 radians

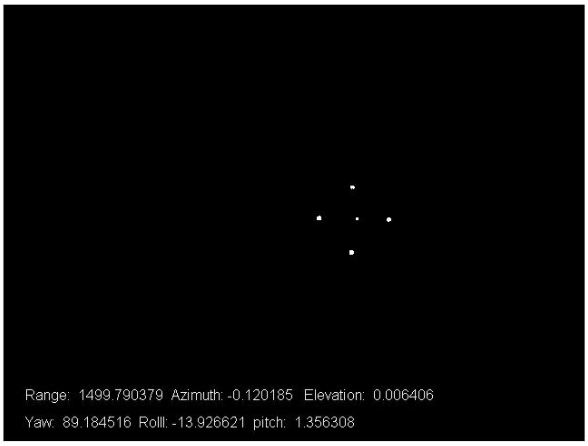

Fig 9 Image captured at 1500mm apart at an azimuth angle -0.12 radians

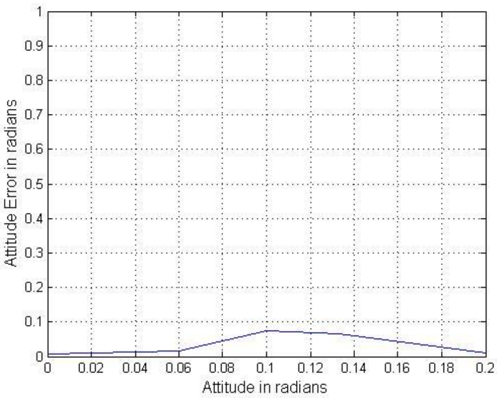

Fig 10 Attitude Error Plot

The results show that the proposed algorithm works better for the determination of range and attitude angles. Instead of five point target a combinational pattern of more than five spot can be used for better and accurate range and attitude angle measurements.

REFERENCES

[1] Jin; Yoon Suk Lee; Sang Su Han ; Sang Ho Kim ; Gun Hyuk Lee ; Ho Jun Ji ; Hye Ji Choi ; Kwang Nam Choi, “Autonomous flight system using marker recognition on drone”, IEEE Frontiers of Computer Vision (FCV), 2015 21st Korea-Japan Joint Workshop on 28-30 Jan. 2015, Page:1-4.

[2] Tullio Tanzi; Ludovic Apvrille; Jean-Luc Dugelay; Yves Roudier, “UAVs for Humanitarian missions; Autonomy and reliability”, Global Humanitarian Technology Conference (GHTC), 2014 IEEE.

[3] Howard R.T., Marshall Space Flight Center, NASA, Huntsville, AL; Bryan T.C.; Brewster L.L.; Lee J.E., “Proximity Operations and Docking Sensor Development”, Aerospace conference, 2009 IEEE 7-14 March 2009, Page:1-10.

[4] Richard T. HAward and Thomas C. Bryan, “The Next Generation Advanced Video Guidance Sensor: Flight Heritage and Current Development”, Space, Propulsion & Energy Sciences International Forum: SPESIF-2009; 24 - 26 Feb. 2009; Huntsville, AL; United States.

[5] Piotr jsiobedzki, Stephen Se, Tong Pan, Manickam Umasuthan and Michael Greenspan, ”Autonomous Satellite Rendezvous and Docking Using LIDAR and Model Based Vision”, Proceedings of SPIE Volum 5796.

[6] Howard R.T., NASA Marshall Space Flight Center, Huntsville, AL; Heaton A.F.; Pinson R.M.; Carrington C.K., “ Orbital Express Advanced Video Guidance Sensor ”, Aerospace Conference, 2008 IEEE ,1-8 March 2008, Page(s): 1 – 10.

[7] Richard T. Howard, Albert S. Johnston, Thomston C. Bryan and Michael L. Book, “ Advanced Video Guidence Sensor (AVGS) Development Testing”, proceedings of SPIE, The International Society for Optical Engineering, February 2004.

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