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OSCILLATION DETECTION OF A QUADROTOR SYSTEM CARRYING SUSPENDED PAYLOAD USING IMAGE PROCESSING TECHNIQUE

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Abstract: This paper proposes using an image processing technique to detect the oscillation deflection of a quadrotor system carrying a suspended payload. A wireless smart camera is attached underneath the quadrotor to capture the payload oscillation in transit from one place to another. The image processing technique was used to measure the oscillation and response based on the output signal captured by the smart camera. A Parrot BEPOP quadrotor drone was used for the experiment and the image processing technique was realised using MATLAB software. Experiments were carried out to detect and analyse the payload oscillation response under different payload masses. The experiment results demonstrate the effectiveness of the image processing technique in detecting the payload oscillation under different payload masses.

Keywords: Sustainability, image processing, payload swing suppression, quadrotor, vibration.

Introduction

A quadrotor is one type of unmanned aerial vehicle (UAV) that can carry a payload and can be used as a form of aerial logistics transport. It is a group of aircraft that can operate without the presence of the pilot. Quadrotor systems consist of sensor payloads, aircraft components and a ground control stations. This quadrotor system can be controlled by equipment from the ground or onboard electronic equipment. Quadrotor UAVs have been employed in a variety of applications, including infrastructure inspection (Chen *et al.,* 2017; Biswas & Sharma, 2019), surveillance (Ma'Sum *et al.*, 2013; Zhang *et al.*, 2019), environmental monitoring (Koziar *et al.*, 2019) and as a remote fire extinguishing system (Ilah N. Alshbatat, 2018).

Various types of quadrotors, such as large quadrotors (Lakshmi Narayanan & Ibe, 2015), medium quadrotor and small quadrotor-micro aerial vehicle (MAVs) (Loianno & Kumar, 2018) are already being used in numerous industries.

This paper focused on the use of quadrotors in the crucial role of carrying loads to inaccessible or dangerous areas because its simple mechanical structures can perform hovering and vertical take-off and landing (VTOL) (Asl & Yoon, 2017; Ichikawa *et al.*, 2018). There are two ways to carry the payload in transit, such as using a gripper and or a cable (Mellinger *et al.*, 2011; Zhou *et al.*, 2016; Pizetta *et al.*, 2019). The first technique studied in this research paper used graspers, which carried the payload closer to the centre of gravity, increasing rotational inertia and reducing the quadrotor's altitude dynamic and response.

While the second method preserved the quadrotor's manoeuvrability, it resulted in an additional degree of freedom due to the payload's oscillation (Pizetta *et al.,* 2016; Cruz & Fierro, 2017). This paper also considered the second technique; however, this is much more complicated due to the quadrotor's motion that causes or adds to the payload oscillation. The oscillation generates force, which causes a disturbance that can affect the movement of the main body of the UAV (Goodarzi *et al.,* 2015; Hashemi & Heidari, 2020).

The use of cable to hold or attach the payload can increase payload oscillation (Maghsoudi *et al*., 2017; Cruz & Fierro, 2017). It is important to detect the payload swing in order to suppress it by using control techniques (Fang *et al.,* 2018; Ichikawa *et al.,* 2018; Liang *et al.,* 2019; Liu *et al.,* 2019; Yu *et al.,* 2019).

Machine vision systems with image processing techniques facilitate faster, more efficient and comparatively high identification of key parameters (Uluisik *et al.,* 2018). A vision system is used to detect and analyse the physical system of the movement payload's UAVs model (Ghommam *et al.,* 2016; Pizetta *et al.,* 2019).

Thus, it is crucial to determine swinging oscillation, minimise the vibration without decelerating or sacrificing speed, overcoming the errors, increasing the robustness of the system and rejecting or negating the factors that cause a disturbance (Cruz & Fierro, 2017). A vision-based autonomous quadrotor has been used to estimate and detect a moving platform's motion (Falanga *et al.,* 2017). They focused on an on-board vision to approximate the calculation of the position of the moving platform by converting the image into the binary black-and-white images by thresholding.

Furthermore, the idea to analyse vision algorithms and methodologies has been proposed to promote the creation and use of autonomous miniature aerial vehicles (MAV) (Minh & Ha, 2010). MAVs exploit the vision sensor to estimate the respective position of the target using a two-camera system.

Based on this project, the blob tracking algorithm tracks the movement of blobs and analyses the data from the experimental test. It identified the two-dimensional (2D) image by tracking the multi-color blobs on the ground and under the quadrotor MAV. Ghommam *et al.* also used the vision-based motion estimation and target tracking algorithm for a moving target with an unknown velocity and at varying times.

The vision-aided inertial navigation systems (VINS) are proposed as a tool to help the quadrotors navigate and collect monocular and stereo camera data. Besides, using it to gain information regarding the angular velocity of the quadrotors using the onboard inertial measurement unit (IMU) and global positioning system (GPS) from the quadrotor itself. Other researchers have also implemented vision-based systems on the two UAV quadrotors to increase the limitation of heavy payload. They have also made use of a Visual Inertial Odometry (VIO) system the only difference being the author made use of multiple quadrotors with a single camera on-board. It required the leader's tracking estimation and the follower's ability to track the leader while carrying the suspended payload and the trajectory motion capture measurements (Gassner *et al.,* 2017).

In this paper, various experimental tests will be carried out to explore the dynamic effect of the payload when handling the VTOL. In order to detect and measure the suspended payload, this paper makes use of an image processing method using the software MATLAB. The payload oscillations and the speed of the quadrotors are analysed with different payload masses.

Methodology

The quadrotor with a suspended payload is prone to an excessive payload oscillation during transportation. Hence, this project focuses on capturing the induced oscillation using image processing techniques. Figure 1 shows the quadrotor attached with the payload mass of 35 g using the inextensible cable. A Bepop Parrot 2.0 quadrotor weighing 500 g was used in this experiment. A wireless smart camera installed underneath the quadrotor was used to capture the induced payload oscillations when the drone was in transit with the payload.

The quadrotor can be initialised and managed via the FreeFlight Pro application. This application has a function that reboots or resets the flight, especially if the drone crashes or malfunctions. Aside from that, it can calibrate and flat-trim the quadrotor before performing a vertical take-off and landing (VTOL). If there is an error on one of the motor's propellers, this application will notify the user. Figure 2 illustrates the FreeFlight Pro application, where the green area on the quadrotor picture shows the motor's propellers, indicating the four motors are working properly. In contrast, a red color will be displayed, where the propellers require troubleshooting. After calibrating and flat trimming, the quadrotor, the quadrotor and be issued commands using the MATLAB software to perform a VTOL.

MATLAB was chosen for this application because it runs quickly on most computers with advanced image processing tools and is a well-known program often used by engineers and researchers (Hernández *et al.*, 2018; Ferrón-Carrillo *et al.,* 2020; Murphy *et al.,* 2020; Ijemaru *et al.,* 2021). The image processing algorithm plays a crucial role in determining the measurement of the oscillation angle for the suspended payload due to converting the three-dimensional (3D) image to a 2D image as spatial coordinates (Kiran *et al.,* 2018). This project made use of three types of the images Red-Green-Blue (RGB) images, Grayscale images and Binary images.

The simplest type is a binary image. Each pixel is assigned a value of 0 or 1 which corresponds to black or white. Each pixel requires only one bit. Black and white graphics are produced by binary code.

The second type of image the grayscale image is a one-color image with each pixel representing a different shade of grayscale. Each pixel is 8-bit, with a brightness value ranging from 0 to 255.

The last image type is the RGB Image, where each pixel in the image is represented by one of three colors: Red, green or blue. Each colour has a value ranging from 0 to

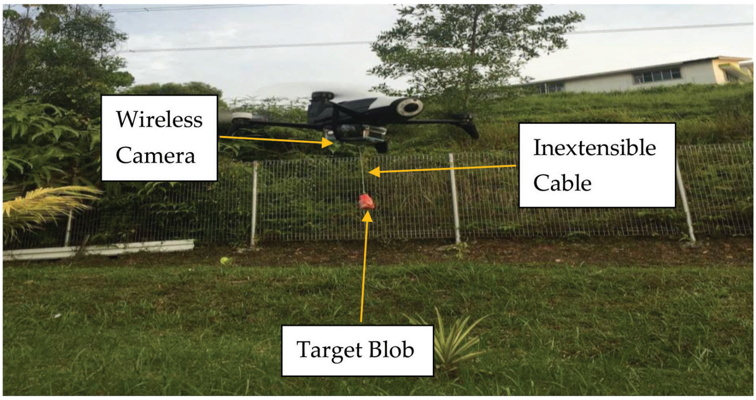
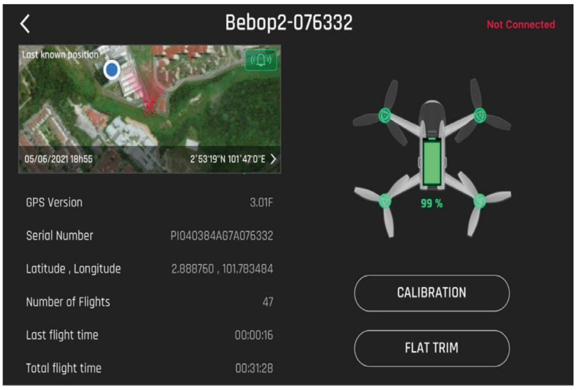


Figure 1: Quadrotor carrying suspended load



GPS Version	3.01F
Serial Number	PI040384AG7A076332
Latitude , Longitude	2.888760 , 101.783484
Number of Flights	47
Last flight time	00:00:16
Total flight time	00:31:28

Figure 2: The FreeFlight Pro application

255, resulting in a total of 16,581,375 possible hues (2553 = 16,581,375) (Goel *et al.,* 2017; Abdulrahman & Varol, 2020).

For the first step, the image processor used a median filter to filter out the noise in the captured video because binary images have fewer memory and processing needs. It used a median filter to filter out the noise and remove all small objects with less than 300 px. The median filter removes unwanted noise from an image, while keeping the image's originality. The filtered image is then converted to a binary image so that it can only work on the region of interest (1 for yes and 0 for no) (Goel *et al.,* 2017). Vision systems based on binary images are faster and less expensive than those based on color or gray-level images. For example, analyzing an image at 256 levels (grayscale) will use up to eight times more RAM than analyzing an image of the same size at two levels (Hernández *et al.,* 2018).

Next, the recorded video from the wireless camera is sent to MATLAB for image processing analysis. The initial step in every image processing task is to create a picture that can be used to detect colors. Read the input image in RGB format, the most common format for representing colored images. If the image's resolution is M x N, the RGB format will be a 3D matrix of size M x N x 3, with each dimension representing the image's red, green and blue color components (Goel *et al.,* 2017). When an RGB image is converted to a grayscale image, the grayscale format is a 2D image that contains the intensity value of each pixel in the image. By turning a 3D image into a 2D image and reducing the number of bits necessary to represent each pixel of an image, a grayscale image usually improves processing speed, ease of visualization and code complexity.

Figure 3 shows both an RGB and binary image. The payload used for the experiment is red for detection in the image processing algorithm. The algorithm will only detect and extract the red channel from the video. It will subtract other colours except for the red colour from interfering with the measurement of the swinging angle throughout the analysis process.

This algorithm runs video in a 2D image which can return the measurement for the target to each 8-connected component in the binary image. The thresholding procedure creates this binary image from the filtered image. During the thresholding process, each pixel in the image is assigned a value of 1 or 0 based on whether the pixel value is greater than the set threshold value or not. If the pixel value is more than the set threshold value, it is assigned "1" (white), otherwise "0" (black) (Goel *et al.,* 2017). Figure 4 illustrates the RGB and binary images as processed using MATLAB.

The 3D image has already been transformed into a 2D array. Any random pixel in the object background interface is now picked and manipulated in either a clockwise or anti-clockwise direction to obtain other pixels. The

RGB image

Binary image

Figure 3: The RGB image and Binary image

image's boundaries are produced in this manner. (Goel *et al.,* 2017). The analysis can be made even more precise using the "regions props" function in the MATLAB program (Kiran *et al.,* 2018).

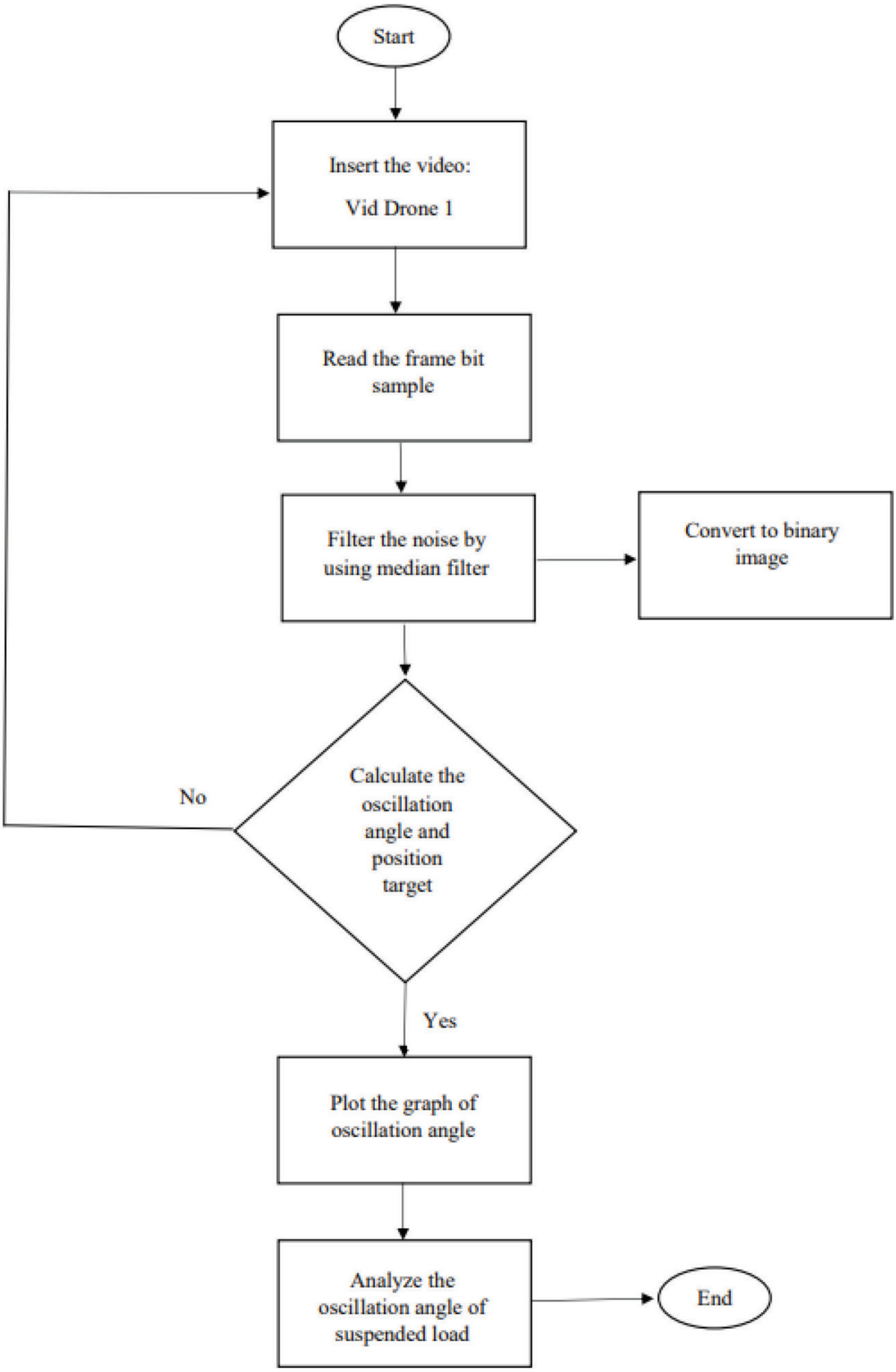


Figure 4: Flowchart of the process

An imaginary rectangle represents the identified item with parallel sides to the axes. It can operate the bounding box and centroid to indicate the region's mass by detecting their coordinate in the x and y axes.

The function can also calculate the target's position and the oscillation angle by reading the image centroid and stats bounding box in the video. Figure 4 shows the flow chart for implementing the algorithm. The oscillation angle versus the time graph will be plotted throughout the analysing process. This graph records the target's angle and movement on the x-axis and y-axis.

Implementation and Results

Three payload masses of 10 g, 35 g and 70 g were used for the experiment to analyse the effect of induced payload oscillations with different payload masses. The cable length used in the experiment was 0.3 m. The quadrotor movement was set at 30 seconds. Three experimental cases with different payload masses were considered such as:

(i) Case 1: Lightweight Payload – 10 g + 60 g camera's weight

(ii) Case 2: Mediumweight Payload – 35 g + 60 g camera's weight

(iii) Case 3: Heavyweight Payload – 70 g + 60 g camera's weight

For image processing, the image captured by the camera will be read at a frame rate of 20 frames per second (fps). The high-quality video might be between 16 and 24 fps. By using only 20 fps was enough to detect the payload. Additionally, the total data sample used in this algorithm was 328 bits. It used a median filter to filter out the noise and remove all small objects with fewer pixels than 300 px.

The Mean Square Error (MSE) represents the overall swing where a lower MSE is desirable, indicating a small oscillation. Figures 5 to 7 show the payload oscillation responses for cases 1 to 3, respectively. Figure 8 illustrates the chart of MSE performance for all cases. Based on the chart, case 3 the heavyweight payload recorded the smallest value of the MSE as compared with cases 2 (medium weight) and 1 (light weight) payload. The percentage of MSE values for case 1 (lightweight payload) over case 2 (mediumweight payload) recorded 17.85%. In contrast, the percentage of MSE values for case 1 (lightweight payload) over case 3 (heavyweight payload) recorded 76.61%.

Based on the percentage comparison, the decrease in payload mass induced more payload oscillation. The lightweight payload's MSE

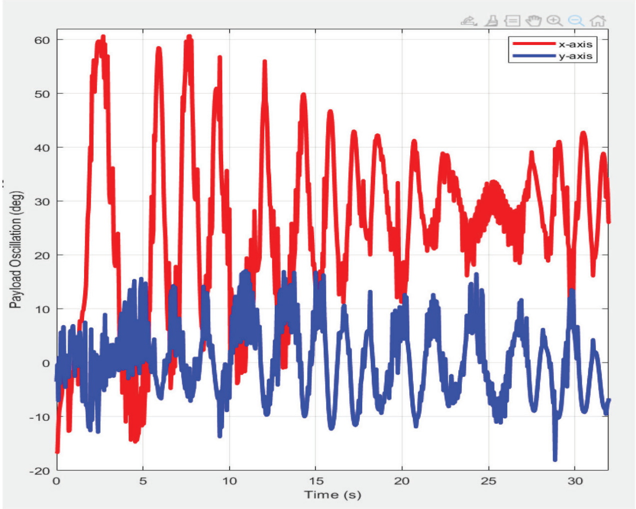


Figure 5: Oscillation angle for 10 g payload (Case 1)

values in case 1 were the highest compared with both case 2 and case 3. It is worth mentioning that, when designing a controller for swing suppression, the effect of payload weight needs to be considered as a parameter to achieve good swing suppression.

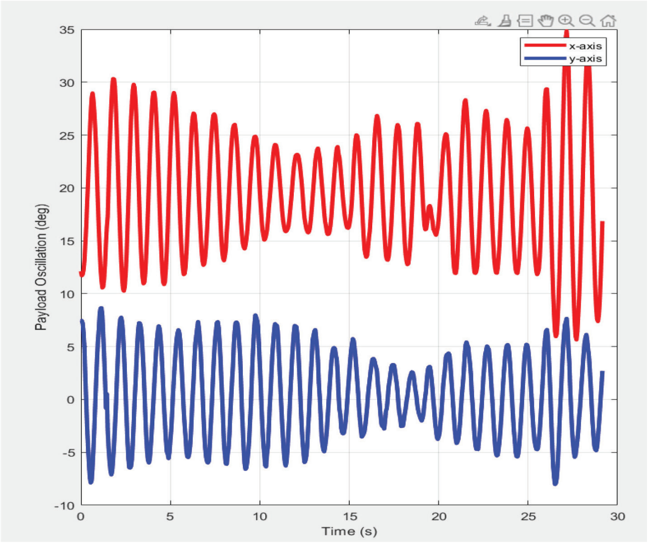


Figure 6: Oscillation angle for 35 g payload (Case 2)

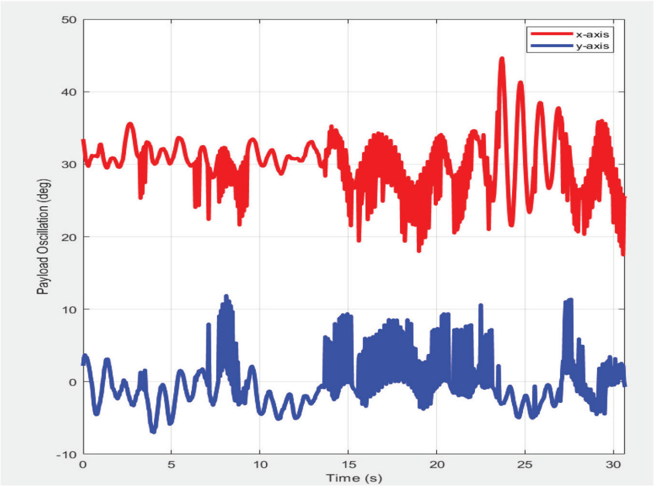


Figure 7: Oscillation angle for 70 g payload (Case 3)

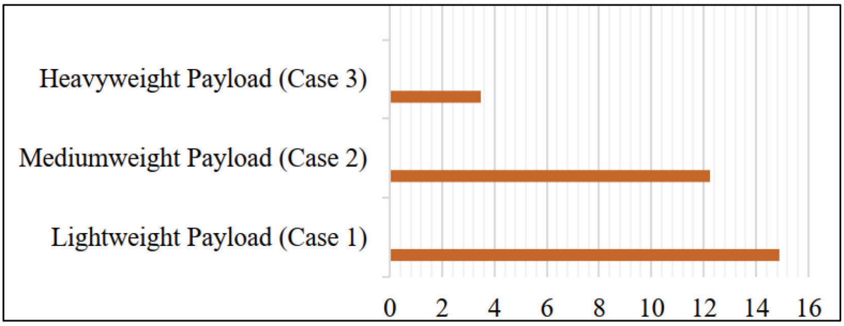


Figure 8: MSE performances for all cases

Conclusion

In conclusion, the image processing technique has been successfully implemented to detect the quadrotor system's payload oscillations. Experimental results showed that the heavyweight payload achieved the lowest MSE compared to the medium and lightweight payload for the oscillation angle during performing VTOL. In future work, an open-loop controller design will be tested to check its effectiveness in suppressing payload oscillation during the quadrotor transportation.

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