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Indoor UAV Positioning Using Stereo Vision Sensor

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Abstract

The UAV system has becoming increasingly popular in the application such as surveillance, reconnaissance, mapping and many more. Different from guided vehicles, which rely on the pilot to navigate the system, UAV relies on autonomous control to provide this functionality. Hence, precise feedback on the position of the UAV is very important. Unlike outdoor positioning, there are no standard, low cost indoor positioning systems available. Hence, we proposed to utilize a stereo vision sensor as an indoor positioning system for our UAVs. The system utilizes two video cameras for stereo vision capture and set of fast algorithms so that position information can be obtained in real-time. Experiment conducted shows that the system could provide a reliable accuracy in real-time.

Keywords: UAV, Indoor Localization, Stereo Vision.

1. Introduction

In recent years, research on unmanned aerial vehicles (UAVs) has been becoming increasingly popular, and their potential applications in civil and commercial roles are receiving considerable attention by the research community as well as industry. A reliable UAV system must have good tracking characteristic for its flight path. Different from guided vehicles, which rely on the pilot to navigate the system, UAV relies on autonomous control to provide this functionality. Robustness in the controller will be an important aspect in the UAV, considering the wide operation regime of the UAV and the nature of disturbance, which often experienced by the UAV in operation. The UAV must be able to fly according to the desired flight path and maintain its altitude at the specific height precisely. To do this a precise feedback on the position of the UAV is very important.

Getting position information in an outdoor environment can be done easily using a GPS as has been reported in many previous works. Unfortunately, there is no easy way to obtain position information of a UAV in an indoor or in satellite occluded area environment. Thus, several researches has been done proposing different way of localizing a UAV in this type of environment such as using laser ranger, ultrasonic sensors, infrared sensors and visual sensors [1-5].

In [1] a strategy using a laser range scanner to map the UAV position to the surrounding area is proposed. The author further proposed a guidance strategy using wall-following logic for the UAV. The quad rotor UAV with a laser range-finder in a GPS-denied environment is demonstrated in [2]. They reported that the limited range and field of view of laser range-finder can cause the vehicle to lose track of its own position in certain configurations and some parts of environment. Then, in [3], a mirror is used to deflect laser range finder beams in order to improve the distance measurement to the obstacles in surrounding and the distance from the ground. However, the system is still limited by the sensor range making it less suitable for accurate positioning.

Recently, the navigation system based on schematic maps of the environment and ultrasonic sensors is proposed in [4]. It

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is found that the resulting localization and navigation for UAV indoor with ultrasonic sensor and schematic map not very accurate. A simplified optical flow algorithm using a long-range lens and a high power LED is applied in [5] to find the position changing. An author applied an extended Kalman's filter to estimate the quad rotor UAV's translational velocity based on IMU and an optical flow sensor. The optical flow sensor could solve the changes in the quad rotor by adjusting the intensity of LED through PWM signal. This system is very reliable but it requires several optical flow sensors to be equipped on board of the UAV to work properly.

The work reported in [6] applied a monocular camera for vision-based navigation with the Simultaneous Localization and Mapping (SLAM) algorithm. This algorithm is splitting the tracking and mapping task into two separate threads, which can build a 3D point cloud of the surroundings area. The lack of depth information from the monocular camera will cause some unobservable area at the map scale. A used of wireless video camera and reflective infrared marker sensor for quad rotor navigation is investigated in [7]. A vision data of the airborne system sent wirelessly into on board system to generate environment mapping and to define the path with obstacle avoidance. The system presented as complex system architecture for guidance control in GPS denied environments. In [8], the Microsoft Kinect sensor is utilized instead of the normal visual sensor for UAV navigation. Kinect sensor allow for visual as well as the depth sensing. Unfortunately, the work is done only for altitude positioning.

For all of the works mentioned above, visual sensor is equipped on board of the UAV. Thus, the limited number of camera can be equipped on the UAV and the possibility of loss of data during transmission might reduce the overall accuracy of the system. Hence, in this work, we proposed a reliable and easy to deploy stereo vision based positioning system that we utilized for our UAV positioning that is suitable indoor. We proposed to deploy the visual sensors at a fixed, off-board position so that the UAV can be localized in the sensor field of view. The advantage of using a stereo vision camera over a mono vision is that a single stereo vision capture system can provide accurate depth information (distance of object) without any additional distance measurement sensor.

2. Proposed System Setup

For our indoor UAV localization system, we chose to utilize visual sensors device to detect the position of the UAV. Visual sensors have a very long and accurate sensing accuracy compared to other lower resolution sensors such as the laser range sensor or optical flow sensor. In addition visual sensors or the cameras are widely available today at low cost. The visual sensors are connected directly to the image processing platform, which is a portable computer or laptop. This way, possible loss of data in transmission can be reduced.

The image processing platform task is to analyse and calculate the position of the UAV for each video frame and transmit the data to the UAV as positioning feedback. Hence, we have to design a suitable algorithm for the UAV detection and position calculation so that image analysis and data feedback can be done in real-time. Positioning data can be transmitted to the UAV wirelessly using a radio frequency signals. For this project, we assume that the 10Hz of frequency of positioning data to be sufficient for real-time autonomous control of the UAV. Fig.1 illustrates the proposed indoor positioning system set up.

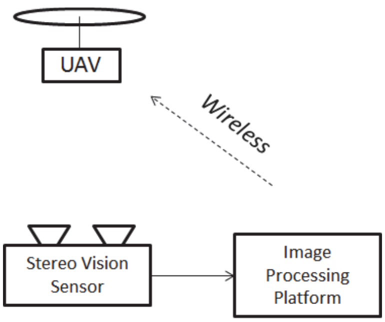

Fig. 1. The proposed indoor positioning system.

3. Positioning Using Stereo Vision

Stereo vision has been used for distance measurement in several works such as in [9] and [10]. Distance data is very useful to estimate the z (depth) coordinate of the UAV and to estimate the effective frame width for x and y coordinates estimation. For our positioning algorithms, firstly, a stereo vision image capture is done. Then, preprocessing, UAV detection and UAV segmentation are performed on both left and right images. Finally, the disparity value of the stereo image and the UAV estimated coordinate will be calculated. The flow of the algorithm is as illustrated in the Figure 2 below.

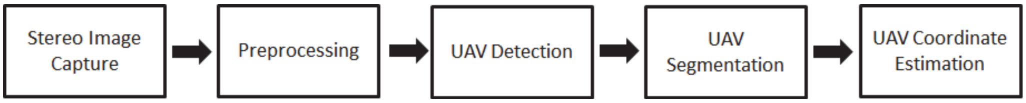

Fig. 2. The flow of the proposed stereo vision position estimation algorithm.

3.1. Stereo Image Capture

Stereo image capture is done by using two video cameras which are aligned in parallel in fixed position. Both cameras are calibrated so that they have matching image properties such as the size, color space and lighting well as corrected for lens distortion. The UAV coordinate can be evaluated when it enters the overlapping view of the two cameras. Figure 3 below illustrates the stereo vision field where the gray area indicates the overlapping view of the camera.

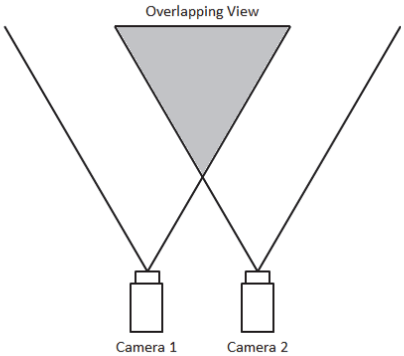

Fig. 3. Stereo image capture

3.2. Preprocessing

Preprocessing is a set of algorithms applied on the images to enhance their quality and improve the computational efficiency. It is an important and common in any computer vision system. In the stereo vision system, a good selection of preprocessing stages could greatly improve the speed and accuracy of the system.

Firstly, the image is converted from the RGB (Red, Green and Blue) color space to the grayscale color space. RGB color space consist of 3 channels which means that it requires 3 times more computation and memory space compared to grayscale which only consist of one channel. Hence, by grayscaling the image, we theoretically improve the speed of the system by 3 folds. Then, median filtering is applied onto the images to clean the images from noise. Median filter is selected since it is fast and able to produce sufficient smoothing.

3.3. UAV Detection

Different most of the other stereo vision works [9-10], the stereo matching process that we utilizes is only applied to the region of interest in the image which is detected using an object detection algorithm. This approach is much faster compared to the stereo matching using features similarity in the two images. In this approach matching is directly done on a known parameter that is the center of detected object.

In our proposed system, the UAV is considered as foreign moving object that enters the view of the stereo vision system. Since the cameras of the system are always fixed to one position, the detection of the UAV is can be done using the pixel to pixel background subtraction and thresholding.

The background subtraction is done by taking the difference of every pixel, I_T in the image to its respective reference pixels in the background model, I_{BG}. The difference value is then thresholded with a value, T_R to determine if the pixel belongs to the object of interest or not. If the pixel does not belong to the UAV, it will be used to update the background model.

$$I_T = object\ if, \quad |I_T - I_{BG}| > T_R \tag{1}$$

Background model is initialized by assuming that the first frame in the video is the background. The background model is updated by averaging the new intensity with the background model intensity value. An on-line cumulative average is computed to be a new background as:

$$\mu_T = \alpha I + (1 - \alpha) \mu_{T-1} \tag{2}$$

where μ_T is the model intensity, I is the intensity and α is update weight. The value for α is set to be 0.5.

3.4. UAV Segmentation

The binary image resulting from the background subtraction and thresholding stage is then processed for object of interest segmentation. Firstly, a quick morphology is applied on the binary image to improve the subtraction result. A sequence of erode and dilate operation are involve in the morphology where the effect is to remove smaller detected regions usually due to noise and to enlarge the areas of object of interests and to close any holes within them.

We then applied a connected component analysis on the image to segment the object of interests on the image. Connected component analysis locates separated regions in the binary image and labels them as different objects. A one pass connected component analysis is applied to improve the speed of the system. From the connected component analysis results, blob extraction is done by drawing the bounding box around the every object of interests. Figure 4 shows the image processing stages on captured stereo image.

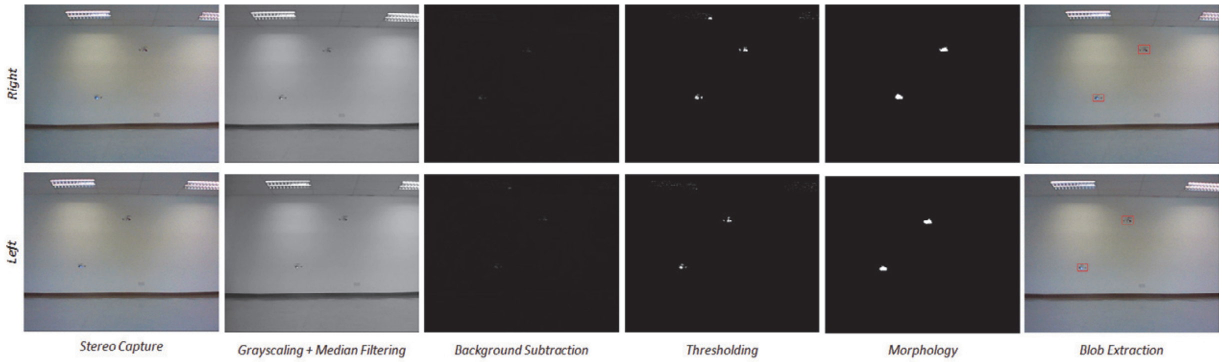

Fig. 4. Morphology and connected component analysis (CCA) and blob tracking

3.5. UAV Coordinate Estimation

Up to this point, all the processing was done in parallel on two images captured from the two cameras. The coordinate estimation use the information extracted from the UAV position in both images. The disparity value of the UAV in the two images, d. can be used the get the relative distance between the UAV and the cameras. From the distance information, the x, y and z coordinates can be obtained. Since the camera is aligned in parallel, we can simply take the pixel difference between the two width center lines of the object of interest as the disparity value.

The distance, D of the object can be calculated using the following equation:

$$D = \beta d^{-1} \tag{3}$$

where β is a fix parameter given by:

$$\beta = b f \tag{4}$$

where b is the distance between two cameras and f is the focal length of the camera.

z coordinate is the measure of distance between the UAV and the camera which is the value of D in meter. Meanwhile, x coordinate is the product of the average value of the UAV blob horizontal center in the left and right images with the effective width per pixel of the camera view at the distance of the UAV measured in meter. The vertical center line in the image is assumed to be the origin (x=0) of the measurement. y coordinate is the product of the value of the UAV blob vertical center with the effective height per pixel of the camera view at the distance of the UAV measured in meter. The value of y is given with respect to the ground which can be obtained depending on the cameras position.

4. Result and Discussion

The algorithm was implemented using the C++ and OpenCV library [11]. The video cameras with frame resolution of 640x320 pixels are utilized. The implemented algorithm running on a laptop with an Intel i5 2.5Ghz processor and 4.0GB RAM is able to produce an output at a frequency of 14Hz which satisfied the required feedback frequency of 10Hz. 10Hz is the maximum update frequency of the GPS sensor installed on the our UAV and is sufficient for the micro size UAV positioning.

Then experiment is done to estimate the indoor position of UAVs. The estimated x, y and z values of the UAV at several positions are collected and the results are as shown in the Table 1. It can be seen that the system can give accurate reading where the mean of the estimated position values are close to the actual values. The standard deviation between the readings can goes up to around a meter which might cause some problem for a very sensitive system. However, since we are targeting for a moderate sensitivity UAV system which position is updated at a frequency of less than 10Hz, the standard deviation can be considered acceptable. Compared to the GPS system which has the accuracy of ±3 meters and update rate of maximum 10Hz, our proposed positioning system is more reliable.

Table 1. Result of the indoor positioning system. x, y and z are the actual x, y and z position of the UAV. μ is the mean of 10 measured values. σ is the standard deviation of the 10 measured values.

Test	x (m)	μ x (m)	σ x	y (m)	μ y (m)	σ y	z (m)	μ z (m)	σ z
1	1.00	1.07	0.52	1.00	0.96	0.26	4.00	4.02	0.73
2	-1.50	-1.54	0.43	1.50	1.46	0.63	6.00	5.91	0.69
3	0.00	-0.12	0.28	2.00	2.07	0.56	7.00	7.13	0.81
4	2.00	2.08	0.63	2.50	2.60	0.74	8.00	7.89	0.76
5	-2.00	-1.96	0.45	1.00	0.94	0.37	9.00	9.03	0.64

5. Conclusion

The UAV system has becoming increasingly popular in the application such as surveillance, reconnaissance, mapping and many more. Precise feedback on the position of the UAV is very important. Unlike outdoor positioning, there are no standard, low cost indoor positioning systems available. Hence, we proposed to utilize a stereo vision sensor as an indoor positioning system for our UAVs. The system utilizes two video cameras for stereo vision capture and set of fast algorithms so that position information can be obtained in real-time. Experiment conducted shows that the system could provide a reliable accuracy in real-time. Our future work is to implement the system for autonomous UAV positioning feedback for various indoor applications such as multi UAV coordination.

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