Automatic Quadcopter Control Avoiding Obstacle Using Camera with Integrated Ultrasonic Sensor

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Abstract. Automatic navigation on the drone is being developed these days, a wide variety of types of drones and its automatic functions. Drones used in this study was an aircraft with four propellers or quadcopter. In this experiment, image processing used to recognize the position of an object and ultrasonic sensor used to detect obstacle distance. The method used to trace an obstacle in image processing was the Lucas-Kanade-Tomasi Tracker, which had been widely used due to its high accuracy. Ultrasonic sensor used to complement the image processing success rate to be fully detected object. The obstacle avoidance system was to observe at the program decisions from some obstacle conditions read by the camera and ultrasonic sensors. Visual feedback control based PID controllers are used as a control of drones movement. The conclusion of the obstacle avoidance system was to observe at the program decisions from some obstacle conditions read by the camera and ultrasonic sensors.

1. Introduction

Using a computer vision is another alternative, and some of these kind of works have been done. Barron et al. [8] provides a survey of optical flow computation algorithms. Gosiewski et al.[9] using an optical flow based on a lucas-kanade method for reading collisions. Sagar and Visser [10] using an optical flow method that combined with a background substractor to knowing the distance between the UAV and the collision. Computing optical flow and performing three dimensional reconstruction are very similar mathematically. Using this method, data from the camera will be reconstructed to form the coordinates of obstacle presence. The image coordinates are connected to the Robot Operating System (ROS), so the drone can navigate automatically avoid obstacles. But there are some drawbacks using such a method. One of which is the difficulty of getting the appropriate programming to achieve goals. A high degree of programming difficulty becomes a major drawback. Therefore here the author tries to use this method with the program as easy as possible.

One other challenge is the condition when the camera cannot distinguish between obstacles or not. Under current conditions the drone cannot be stopped because it is automatic so it cause accidents and damage to the drone. Therefore here the author wants to provide additional features with the use of ultrasonic sensors to help the drones to know the existence of obstacles with a higher level of accuracy. The authors more preferred to uses a computer vision method as the main thing. Like Ohya et al. [12] said that a primary focus of machine intelligence and advanced robotics is to capture human faculties in a computer and since humans use vision for obstacle avoidance while navigating. The ultrasonic sensor is used as a backup, if an error has occurs. Here the author aims to create an
automatic navigation system on drones to pass through obstacles using a camera that integrated with ultrasonic sensor. The limitations of the coupled problem consist of how to implement the Image Processing method using a single camera on the drone, transferring the object readings data by ultrasonic sensors, as well as the use of PID-based control ROS as a drone flying control.

2. The Proposed Method

The method studied in this paper uses image processing and ultrasonic sensors. Image processing method contains feature detection and optical flow. The theory behind those techniques is worked out in the following subsections.

2.1. Image Processing

The Image Processing method will produce the output of a path planning for quadcopter movement. The process consists of several stages, such as Pre-processing, Grouping, and Decision making. This stage consists of filtering, feature detection, and optical flow.

The feature detection method will define and track the important points of an image, such as the corner and edge. The Shi and Tomasi feature detection method outperforms the other three methods based on both, the detection range and the ratio of frames containing a detected target. Based on that experiment the feature detection method used in this paper is Shi-Tomasi method.

$$R = \min(\lambda_1\lambda_2)$$

The Shi-Tomasi method uses a minimum value of R that acts as a threshold value for the quality level of a corner and edge. The eigenvalues $\lambda_1$ and $\lambda_2$ represent the bidirectional axis value of the ellipse to determine the corner [12].

Next, the optical flow method is used in object tracking through feature comparison of two frames. A feature found in the first frame compared to the same features found in the second frame. The vector is obtained by the location of an object on a particular specific pixel (feature) from one point in the frame, to another point in a different frame is what is known as the optical flow of the object. Here the author uses the Lukas-Kanade method as a guide for optical flow.

$$h \approx \frac{\sum_{x} F'(x)[g(x) - F(x)]}{\sum_{x} F'(x)^2}$$

The h value for the gradient of the two frame images is the vector of the optical flow of the area. The Lucas-Kanade method makes it possible to produce unusual movements of certain environments from our destination points [13]. The downside of this method is if there is a large undetected movement in the search area. To solve the problem, this method is compensated by developing LK algorithm into pyramid shape [18]. This process involves a pictures with different resolutions, starting at the highest position on the pyramid (low resolution) and moving gradually to the lowest position of the pyramid with higher resolution (high definition image).

From Pre-processing, we are grouped into the Grouping stage, where the existing features will be grouped by finding the average value of each feature and the frame will be split into four different quadrants. Decision Making is the controller of the drone movement to go to the quadrant without obstacles.

2.2. PID Controller

Ultrasonic sensors are used as an additional feature on the drone to help the drone determine the presence of obstacles or not. The principle is to detect the time that the ultrasonic wave is required from the transmitter to the receiver. To detect an obstacle from ultrasonic sensor, it depends on many factors, such as the orientation, reflectively, curvature, etc., of the surface of the obstacle toward the sensor and on the threshold used for the detection of the received echoes [15].
2.3. Decision Making

Specifications of the camera with image processing and ultrasonic sensors, integrated into a decision-making system based on information obtained from both sensors. The decision making algorithm uses two sensors as a reference movement. The essence of avoiding obstacle is how quickly the sensor recognizes that there is an obstacle in front of the drone. In the flowchart figure 1 below, there is a program decision-making flow that states the linkage and relationship between image processing and ultrasonic sensors in some conditions.

The decision-making algorithm method begins with obstacle detection by the camera and the ultrasonic sensor calculates the distance in front of the drone, and we set the minimum distance of the drone near the obstacle to be 50 cm. The program is divided into several conditions in avoiding obstacles, can be seen in Figure 1. If the image processing detects an obstacle, the program identifies whether the distance is 50 cm or less, if more then the image processing information will be used as a reference for the obstacle-avoiding drone, but if the distance is less than 50 cm, then the reference distance from ultrasonic is used as a reference drone to avoid. In other situations, if image processing can not detect an obstacle, it will be divided into two conditions, if the distance read by the ultrasonic sensor is still above 50 cm, then the obstacle detection process is still in progress. But if the obstacle is still not detected, but the distance on the ultrasonic sensor is below 50 cm, then the drone uses this information to dodge.

Figure 1. Flowchart Decision Making Algorithm

Figure 2. Flowchart of drone work process.
The whole avoiding obstacle work system can be seen in figure 2, with data processing and ultrasonic sensors running simultaneously. After the decision making algorithm is processed, the information reference is obtained and used as the control drone reference. After the drone moves, then the process will come back from beginning.

3. Evaluation and Experimental Result

Before test the quadcopter, the authors have to know the characterization of each sensor that used in this paper. The process of ultrasonic sensor characterization done by the author to get the precision value of the sensor. The result show that

\[ S (cm) = 0.0176 \times t(s) - 0.1625 \]

The percentage of obstacle detection success using the Lucas-Kanade-Tomasi method has a success rate above 85% with the highest yield at 100 centimeters.

![Figure 3. Percentage of Success Obstacle Graph](image)

The result of the plot of the line with the quadratic equation had a decreasing trendline proportional to the greater distance. This was because the ability of Lucas-Kanade-Tomasi was algorithm decrease to trace the features of an obstacle, as the resolution of the obstacle decreases proportionally to the obstacle away from the camera. We get the equation from trendline this chart is

\[ y = -0.0007x^2 + 0.0929x + 90 \]

![Figure 4. Feature detection with 500 point (left) and 50 point (right).](image)
threshold value of the feature. The reduction in the number of features indicates the location of the obstacle is more specific than if the number of features more, because if the number of features reproduced, then the algorithm will look for more features than in the obstacle, so the background can identify there is a feature.

![Figure 5. Average value point in different quadrant and different distance.](image)

Further data obtained results will be used for testing to find the optimal distance of obstacle readings using the optical flow method. This test is performed to determine the distance from the obstacle object to the optimal camera for the program to get information on the obstacle presence of the image. In the program as you can see in figure 4, the author divides the image into 4 quadrants with each having the same size. The existence of an average value determines where the obstacle is in a particular quadrant.

4. **Conclusion and Future Work**

The conclusions, we can see the avoiding obstacle system integration between image processing with complementary ultrasonic sensors. Image processing in detecting obstacle with 85% success rate at 50-200 cm distance, where there is a relation between distance and image processing capability in recognizing obstacle. From these results it can also be seen that the resolution of the camera affects the results of obstacle tracking, because the far more obstacle, the obstacle resolution will be reduced so that the lucas-kanade-tomasi algorithm reduced effectiveness.

This drone framework is designed to be as simple as possible, in order to meet the purpose of the author as well as many people who can use this author's proposal easily. This aspect has great flexibility properties, because it can be used not only on quadcopter, but other flying robots or ground robots. For that the authors hope this paper can be implemented to the upcoming human life, where all the difficult work can be done by robots that are automatic.

From this paper the authors expect a lot of development that can be done, such as the need for an algebraic program to read two different obstacles but are at the same distance. The main developmental hope of the author is, the drone can avoid the obstacles that are dynamic. By calculating the approximate movements of the object, the drone can avoid such moving obstacles, but higher complexity programming is required. This is still a shortcoming of this paper, so it is expected that many future can develop this paper to solve the problem.

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