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Object Detection Technique for Small Unmanned Aerial Vehicle

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Abstract. Obstacle detection and avoidance is desirable for UAVs especially lightweight micro aerial vehicles and is challenging problem since it has payload constraints, therefore only limited sensor can be attached the vehicle. Usually the sensors incorporated in the system is either type vision based (monocular or stereo camera) or Laser based. However, each of the sensor has its own advantage and disadvantage, thus we built the obstacle detection and avoidance system based multi sensor (monocular sensor and LIDAR) integration. On top of that, we also combine SURF algorithm with Harris corner detector to determine the approximate size of the obstacles. In the initial experiment conducted, we successfully detect and determine the size of the obstacles with 3 different obstacles. The differences of length between real obstacles and our algorithm are considered acceptable which is about -0.4 to 3.6.

1. Introduction

An Unmanned Aerial Vehicle (UAV) as the name implies, it is an aircraft without a pilot on-board or attached to it. It can fly autonomously by pre-programmed the UAV's system or controlled manually by the pilot on the ground. Hypothetically, UAVs have a great potential to replace manned aircraft in many tasks or missions (e.g. surveillance, search and rescue mission, attack mission, collecting data, and etc.). For example, in 1946 to 1948, United States Air Force and Navy used unmanned B-17 and F6Fs to fly into nuclear clouds within minute after bomb detonation to collect radioactive samples [1]. The concern to operate UAVs in a low altitude either indoor or outdoor are indeed very demanding due to the growing number of small and micro air vehicles.However, to achieve robust level on self-governing system is very challenging and it is important needs for modern-day UAVs.

Obstacle detection and avoidance system highly depend on sensors that being employed on the UAVs, type of the most research and considered popular choice for the system will be a Vision based and Laser based. The selection of detection and avoidance systems are very well connected to the UAVs itself. Besides, selecting a proper sensor to be placed on board of the UAVs plays a critical role for the system, and each of the techniques has its own advantages and disadvantages.

For example, vision based method has rich information regarding bearing angle of the detected obstacles, while distance from the vehicle to obstacles are poorly recognized. On the other hand, Laser based method is able to find accurately the distance of the obstacles to the UAVs, but weak in determine the bearing angle. In order to encounter these disadvantages, different type sensors can be fused or combined together to make the system operate into a reliable detection and avoidance system.

Integration of different sensors (e.g Laser and Optical) allows the extraction of information which cannot be acquired by a single sensor [2]. It will upgrade and increase the capability of the system to estimate the attitude of the obstacles.The concepts of multisensor fusion on one system can be traced back to the humans and animals, they naturally perfomed the sensors fusion to do lots of things (e.g identication of threats, assessment of surrounding enviroments,etc). For example, precise evaluation of

some substances by animals can be done by combining different senses such as sight, touch, smell and taste [3].

Nowadays, commercial UAVs are already equiped with single camera (monocular vision) on-board and can be pre-programed to use features based detection techniques. Hence, to take advantage of this matter, the research project are focusing on monocular vision features based taken from computer vision technique. Plus, considering the size, weight, power consumption and capability to extract useful information, camera is the most competitive tool for UAV [4].Therefore, this dissertation mainly aims at developing a real-time obstacles detection and avoidance system based on multi-sensor integration (combination of optical and laser sensors) to achieve autonomous operation for UAVs. Plus, the aims is also to estimates or approximates the size congfiguration of the obstacles for safe avoidance purposes.

2. Related works

Obstacles detection and avoidance system is desirable for small and lightweight UAV and is challenging problem since the payload constraints, it only allows monocular cameras to act as a sensor to detect the obstacles. Eventhough, monocular cameras cannot measure the depth of scenes in an image, various cues can be computed to help with the hitch. In [5,6]uses expansion cues to detect a frontal obstacles by using only single camera. He used Speeded Up Robust Features (SURF) features matches in combination with template matching image to compare relative obstacles sizes. Abdulla Al-Kaff et al [7] estimates the size ratios of the approaching obstacles from the sequences image frames. He used SIFT [8] featuresdetected points and contructs a convex shape from these points, after that, he observed size changes of the convex shape when obstacles are approaching.In [9], a MOPS are used to detect the outline or edges of the obstacles. Then, they apply SIFT features to the image of the obstacles to detect the internal outline. Cooper Bills et al [10], proposed a method to fly the UAV in indoor enviroments by using perspective cues.However their experiments, are strictly applied to corridor and stairs regions. Detection of obstacles based on texture variatons has been demonstrated by G.C.H.E de Croon [11]. By using the facts that when observers approach an object, there are two effects happen which are the image size of the object increases in the image and the detailed texture in view becomes more and more visible.

On the other hand, there is also method used by monocular vision known as optical flow. It is a natural solutions to navigation and obstacle avoidance problem, as motivated by insect and birdflights [12]. Green and Oh [13] has built MAV platform than can enabled a quick transition from cruise flight into hovering mode to avoid collision by using this method. However, they stated that optical flow has limitations when it comes to approaching an obstacles directly (frontal obstacle), because the detection very poor. Simon zigg et all [14] use the method to navigate the UAV through indoor corridors. Zufferey et all [15], use optical flow on their microflyer weighing only 30 g to be fly in small indoor environment.

In [16], sensor fusion of ultrasonic (US) and infrared (IR) sensors is developed to obtain reliable range data for obstacle detection purposes. Results from the project showed that sensor fusion provided accurate range estimation by reducing noises and errors that were present in individual sensors measurements. In [17], they used a combination of Ka-band radar and optical cameras as their detection system. Tomic et all [18] use full capability of laser based sensor and vision based sensor. He integrate a wide LIDAR sensor and stereo vision camera in it UAV.Shadib et all [19] employed optical sensors and U.S sensor for their autonomous mobile robot. They determine the distance to obstacles by measuring the time difference between the transmission of ultrasonic wave and the reception of reflected wave.

3. Methodology

An obstacle detection technique is described as based on the combination of features based detection by monocular camera and laser sensors.Features based detection is one concept in computer vision field to extract the interesting or distinct features on an image such as edges, corners and blobs. It is generally used for finding an object (e.g matching features in one image to another) and tracking.

Two of widely know features based detection technique which are SURF created by Herbet Bay [20,21,22] and Harris corner by Chris Harris [23] will be employed in this project.

3.1. Obstacle detection

The presented obstacle detection method are based on combination output from different sensors which is camera and Laser sensor. It allows the measurement of length of the obstacles from far for the purpose of earlier decision making in avoidance and also safe avoidance. It is desired for obstacle detection and avoidance system to have good approximation on the length of the obstacles rather than using a tolerance.This is true when a UAV has to fly through tight spaces and enviroment that filled with obstacles. In pursuance of that matter, we will describe the process in the following chapter.

3.1.1 Laser sensor detection

Laser sensors can be used to measure a distance to obstacles with very high accuracy. On top of that, the range of detection very high as compared to U.S sensor and I.R sensor. However, most of worthy distance laser sensors available also known as LIDAR (e.g Hokuyo,SICK,etc) is heavy and big in size. Thus, it is not suitable for application in small UAVs. In this project, we adopted small and compat LIDAR for the system, which use only single ray of beam to find the distance. This sensor performs initial detection by first capture the appropriate distance to obstacles and instruct the camera to capture the reference image frame. Secondly, inform the camera sensors to capture target image frame after avoidance distance has been detected (see figure 1).
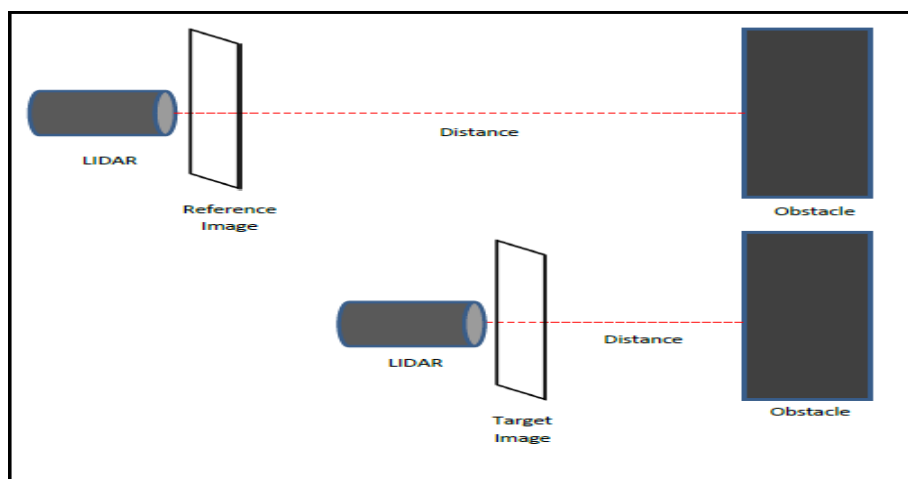

Figure 1:Image frame illustration

3.1.2 SURF detection

Since the system equipped with LIDAR sensor to measure the distance to obstacles and instead of detecting the incoming obstacles by using size expansion, we used the SURF algorithm to help recognize and identify the obstacle size, particularly on length of obstacles.SURF algorithm also can be considered as a Blob detector because the scale produce by this algorithm will direcly propotional to the size of detected blob or in another words size of particular object in an image. Therefore, we took advantage of this characteristic to distinguish the detected obstacles from background of the image. This is neccesary to allow for the calculation of obstacle's length. However, we must determine the rightful scale changes between obstacles that are being captured in reference image frame (RIF) and the one in target image frame (TIF) as shown in figure 2.

Figure 2: SURF keypoints features

We have conducted several experiments to determine the appropriate scale changes by varying the distance between RIF and TIF. For this experiment, TIF distance has been fixed to 4ft.This is due to the fact that, if the TIF distance keep increasing, then obstacle size or blob will be small in the image as compared to the surrounding. As a result, the SURF algorithm will produce a lot of keypoints to the background rather than to the obstacles itself. On the other hand, if the TIF distance is small enough, the avoidance planning by the UAV towards the obstacles will be a problem. These scale changes are the scales that are able to separate or distinguish the obstacles from background of an image.

Table 1: Scale changes

RIF (ft)	RIF-TIF (ft)	Scale changes
5	1	0.8
6	2	0.9333
7	3	1.2
8	4	1.8667
9	5	2
10	6	2.8
11	7	3.3333
12	8	3.4667
13	9	3.6

In adjusting the distance of RIF, amount of matching feature keypoints between frames should be take into account. The higher amount of matching feature keypoints detected, the higher chances of length of obstacles approximation will be near to true value.

3.1.3 Location maxima keypoints

SURF algorithm generate feature keypoints with sets of 2 data which are scale of the features and location of the features with regard to an image. After the obstacle features keypoints have been subtracted from the background of an image, we need to find the maxima (minimum/maximum) location in X-direction of the features keypoints located on the obstacle. Any features keypoints that lies within the boundary of maxima location will be removed.

3.1.4 Binary image conversion

The image frame in TIF is converted to binary from greyscale image. Binary image contain only 2 pixels value which are 0= white and 1=black, while greyscale pixels value is from 0 to 255. To perfomed this conversion we use luminace level of 0.5, which means any greyscale image pixels higher than 127.5 will replace into white otherwise black. Having performed this conversion, edge of the obstacle can be localized or transformed into many steps corner (see figure 3). We take this advantage to know the edge coordinate in the image by applying Harris corner detector.

Figure 3: Corner step edge

3.1.5 Finding discontinuities

If Harris corner detector is apply to the binary image, it produce a lot of corner points in the background as well as in the obstacle. Thus, some method to extract corner points only at the edge of the obstacle are needed because corner point coordinates can be used latter to find pixels and real dimension relation. Small window or patch is created to find the discontinuities of the Harris corner points in the image. The patch is of size 30 x 40 pixels and it search the discontinuities at step size of 1 pixels on both side (left and right) of the image. If the discontinuities is found, then we assume the point of discontinuities in the image is edge coordinates of the obstacle (see figure 4).
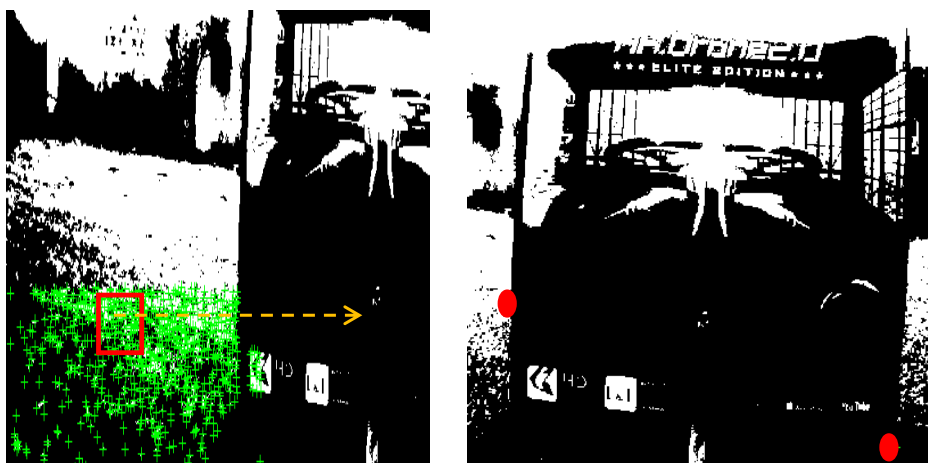

Figure 4: Moveable patch window

3.1.6 Finding the length

As previously stated, pixels to real dimension relation is used to find the real dimension (length) of the obstacles. Besides, a simple triogonometry function is also incorporated in the calculation.

$$PD = RCL - LCL \qquad (1)$$

$$IL = (TIF \times tan31°) \times 2 \qquad (2)$$

$$\frac{P}{ft} = \frac{IL}{1280} (3)$$

$$TL = PD \times P/ft \qquad (4)$$

3.2 System configuration

The platform used in the experimentation is the A.r drone 2.0 elite edition, a low-cost MAV built by the company Parrot. This vehicle was selected because it is low-cost commercial UAV available in market, stable flying and proper size configuration. The cameraattached to A.r drone has 1280x720 resolution and horizontal field of view is 62 degree. On the other hand, LIDAR-Lite from Garmin will act as laser sensor distance in this project. It has low weight of 22 g, hence, making it suitable as the additional sensor for UAV application. In addition, the range that the LIDAR-Lite can cover is very impressive which is about 40 m. In this research, the main tool or software that we used for analysis and calculation is Matlab 2016a. The software contain a computer vision system toolbox which makes it possible to use as tool development for our obstacle detection and avoidance system. All our algorithm processed on ground laptop which is quad core Intel i7 running windows operating system.

4. Experiment results and discussion

Experiments are perfomed by moving the UAV from RIF position to TIF position and record the image frame captured. There are 3 obstacles used to be detect by the algorithm in the experiment and each has different sizes. However, for our initial experiment and algorithm validation, we only carry out the experiment with UAV at RIF position equal to 10 ft and stop at TIF position equal to 4ft. In our future experiment, we will test the algoritm at different RIF position to simulate the scale changes as indicated in previous table 1. The algorithm process which produce the approximation length dimension of the obstacles are to be validated with real length of each of the obstacles. From the experiment, the algorithm is able to detect and determine the length of 3 obstacles used in the experiment. It shown that the accuracy of algorithm is exceptional because the length generated by the algorithm (True length) as compared to real length is only by within -0.4 to 3.6 cm. In obstacles 3, the difference is slightly greater than the rest because during the experiment, the captured image frame by the camera at TIF position may got tilted a little to the left or right which is not exactly perpendicular to obstacle. As a consequence, egde coordinate of the obstacle 3 detected by Harris corner detector will be underestimated and so, the length approximated is much less than the real length.

Table 2: Results

Obstacles	Real length (cm)	True length (cm)	Difference
1	58	59.8	1.8
2	39	38.6	-0.4
3	55	51.4	3.6

5. Result and Discussion

In this research project, multi sensor integration for obstacle detection and avoidance system has been proposed. We have combine monocular sensor with LIDAR sensor to help increase the robustness and accuracy of the system. By, using this system with combination of SURF algorithm and Harris corner detector, we are able to determine the approximate size of the obstacles. Experiment have been performed with 3 different sizes of obstacles and the results shows that our algorithm closely approximate the length of the obstacles.

In our future work, the algorithm will be implement in real time environment including the development of avoidance algorithm once we have the output from detection algorithm. We also eager to investigate the detection and avoidance decision mechanism when multiple obstacles are introduced. In the next experiment, all of RIF position and variety of obstacles will be tested to futher validate the algorithm.

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