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Obstacle Detection Technique Using Multi Sensor Integration for Small Unmanned Aerial Vehicle

Muhammad Faiz Bin Ramli[1], Syariful Syafiq Shamsudin[2], Ari Legowo[3]
[1,2]Deparment of Aeronautical Engineering, Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn, Johor, Malaysia
[3]Department of Mechanical Engineering, Kulliyyah of Engineering, International Islamic University, Malaysia
*Corresponding author, e-mail: legowo@iium.edu.my

Abstract

Achieving a robust obstacle detection system for small UAV is very challenging. Due to size and weight constraints, very limited detection sensors can be equipped in the system. Prior works focused on a single sensing device which is either camera or range sensors based. However, these sensors have their own advantages and disadvantages in detecting the appearance of the obstacles. In this paper, combination of both sensors based is proposed for a small UAV obstacle detection system. A small Lidar sensor is used as the initial detector and queue for image capturing by the camera. Next, SURF algorithm is applied to find the obstacle sizes estimation by searching the connecting feature points in the image frame. Finally, safe avoidance path for UAV is determined through the exterior feature points from the estimated width of the obstacle. The proposed method was evaluated by conducting experiments in real time with indoor environment. In the experiment conducted, we successfully detect and determine a safe avoidance path for the UAV on 6 different sizes and textures of the obstacles including textureless obstacles.

Keywords: *Lidar, Feature keypoints, Connecting keypoints. Safe avoidance path, Textureless obstacles*

1. Introduction

Inrecent years, the application of Unmanned Aerial Vehicle (UAV) has experienced tremendous growth in civilian application and not merely restricted to military environment. It is mostly due to autonomous capability and size advantage of the UAV. Hypothetically, UAVs have a great potential to perform numerous task such as mapping [1], inspection [2], [3], search and rescue [4-6], and others. Most of the tasks require UAV to achieve a higher level of autonomy and this autonomous operation could be very challenging for small sized UAV because weight and size constraints.

Typically, the obstacle detection system depends on the type of sensors installed in the system which is either vision based or range sensor based. Selecting proper sensors to be placed on board of the UAV plays a critical role for the system operation where each of the aforementioned techniques has its own advantages and disadvantages. For example, vision based method can provide rich information regarding the bearing information of the detected obstacles, however, distance from the UAV to obstacles are poorly recognized and conversely applied to range sensor based.

There is lot of research about obstacle detection method. In [7], perspective cue by the camera is used to fly within an indoor environment. However, it restricted to detecting corridor and stairs case only. Feature matching method is accomplished in [8], but pre-data on obstacle features is needed inside database before flying. Expansion cue by scale [9] is applied to detect the appearance of obstacles. However, it only applies to tree body sizes and requires a good visible texture. Similar to that, [10] convex shape is constructed from the expansion feature points and observed the sizes changes when obstacles are near. They created safe avoidance path by assuming tolerance extension from the detected feature points which is not robust enough considering the obstacles has random texture and features. Plus, textureless obstacles

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are still a problem. In [11], texture variations method is investigated. The technique required the obstacles to have enough texture for detection.

On the other hand, a bio-inspired method called as the optical flow can also detect the presence of obstacles [12-15]. However, it has a weak ability on identifying frontal obstacles due to frontal flow vector from frame to frame is zero. For range sensor based [16-18], the sensor used is heavy and expensive to be practically used in small commercial UAV. Prior works also have focused on multi-sensor integration. In [19], similar sensors based is combined to only enhance the range output without knowing the bearing of the obstacles. Integration between vision and range sensor based is investigated in [20],[21], but, it is only suitable for a larger size UAV. Plus, the sensors equipped are again very costly and heavy. Thus, it is not suitable for placement in small UAV.

UAV needs a robust obstacle detection system that can determine a trusted safe path for avoidance regardless of texture appearance, obstacles sizes and motion of the obstacles. On top of that, the system must perceive a robust distance value to obstacles, so that, warning for collision and decision for avoidance can be made. Although it may be possible for a larger UAV, it is still difficult for small UAV to achieve. Therefore, in this paper, we present a method to meet these needs by integrating multi-sensors which are camera sensor and Lidar-based sensors into the system. We use Lidar as initial detection in term of detecting distances and queue for activating the camera. To approximate the obstacle size and safe avoiding path, we are using connecting features key points and non-obstacles features points by Speeded up Robust Features (SURF) algorithm.

2. System Configuration

The platform used in the experimentation is the A.r drone 2.0 elite-edition, a low-cost UAV built by the company Parrot. This UAV was selected because it is a low-cost small commercial UAV available in the market and also has stable flying properties. Camera sensors used is the built-in UAV camera with1280x720 resolution and horizontal field of view is 62 degree. However, we use a lower resolution (640x360) to increase the computation speed of the algorithm. For range sensors, Lidar lite v3 is selected (see Table 1). Arduino Uno board is used to read and connect Lidar lite to the system (see Figure 1). In this research, the primary tool or software that we used for analysis and calculation is Matlab 2015b. The software contains a computer vision system toolbox which makes it possible to use as tool development for our obstacle detection and avoidance system. All the algorithm processed on a ground laptop which is quad-core Intel i7 running Windows operating system. Communication and data transfer between UAV including Lidar lite and ground laptop are done by XBee radio module.

Table 1. Lidar sensor specification

Specification	Measurement
Weight	22 g
Size	20 x 48 x 40 mm
Range	40 m
Beam divergence	8 radian

Figure 1. UAV configuration

3. Obstacle Detection

In this chapter, we describe an obstacle detection technique based on the combination of features based detection by monocular camera sensor and Lidar sensor distance output. In order to approximate the obstacles size configuration, stable obstacles features from scaling, translation and rotation motion are needed. Therefore, the invariant feature based detection technique that is known as SURF [22-24] will be employed in this project. Also, it is much faster in computation when compare with other invariant feature based method [25]. The algorithm is able to produce scale size value according to the detected features in the image. Therefore, we can estimate the incoming obstacle by looking at scale value on each image frames.

Lidar lite is selected because the measured range is very high as compared to other sensors like Infrared and Ultrasonic sensors. Also, it is considered low-cost and small in sizes when compare with other wide scanning Lidar (e.g Hokuyo, SICK, etc). Thus it is very suitable for small size UAV application. It determines the distance by measure the time delay of laser light between transmission and reception.

3.1 Distance Detection

Lidar sensor performs initial detection process by first determine the appropriate distance to obstacle and instruct the camera to capture the first frame of image namely as Detected image frame (Dif). For Dif distance, we have specified the distance to be 244cm from the obstacle. Secondly, inform the camera sensor to capture the next image frame which is Avoidance image frame (Aif) after avoidance distance has been detected (see Figure 2).

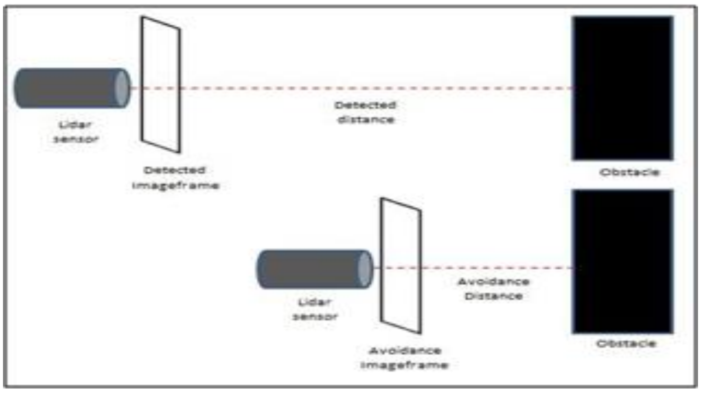

Figure 2. Image frame illustration

3.2 Feature Points Detection

Instead of detecting the incoming obstacles by using scale expansion characteristic [9], [10], we used the SURF scale expansion characteristic to help approximate the physical size of the obstacle and determine the safe avoidance path.

The algorithm will give feature points detected on each Dif and Aif. After that, feature points that are matched from both image frames will be identified. However, the rightful scale changes between matched feature points in Dif and Aif need to be determined to remove any feature points noises or outliers in the image frame. It is required so that the obstacle physical body size approximation percentage will be much higher and also to provide safe avoidance path for UAV. Ideally, the distance changes between Dif and Aif should be small so that avoidance path can be determined earlier. In this project, 30cm distance change is used, and it is considered the best smallest distance because we have to take into account all the algorithm processes timing. Hence, several experiments have been conducted to measure the 30cm scale changes between Dif and Aif matched feature points. The result shows that 0-0.49 scale changes are the most dominant. However, we also include the 0.5-0.99 in the algorithm to be conservative (See Figure 3). It is needed to safely reduce the chances of losing any feature points on the obstacle. Feature points that are matched (mf) on both image frames are filtered by removing any feature points that have scale changes value higher than 1.0.

$$mf = \{mfs_{,}\ mfl\}\ ,mfs_{Aif} - mfs_{Dif} < 1.0 \qquad (1)$$

where *mfs* and *mfl* are the matched feature points scale and location in pixels respectively. Henceforth, the term feature points will interchangeably used for match feature points.

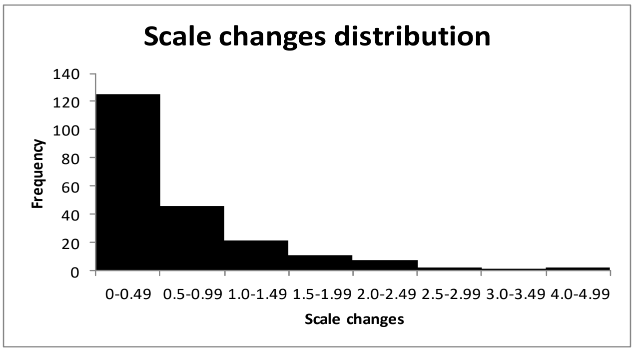

Figure 3. Scale changes distribution

3.3 Projected Uav dimension

The dimension of UAV is projected onto the image frame captured to keep track the feature points of the obstacle (see Figure 4). Since the algorithm depends on the texture, we use the projected dimension as a baseline to determine either the obstacle has texture or not by looking at the number of feature points inside the projected dimension. If the features points do not appear inside the projected dimension box below than detected distance of 122cm, then, the obstacles are assumed to be textureless. Therefore, other algorithm is needed to determine the Safe avoidance path. Theoretically, the size or any dimension of the real obstacles on the image frame will become larger in term of pixels if the distance is small and conversely, it will become smaller when far. Figure 5 shows the relation between width dimensions of the obstacles in pixels against distance.

Figure 4. UAV projected width dimension

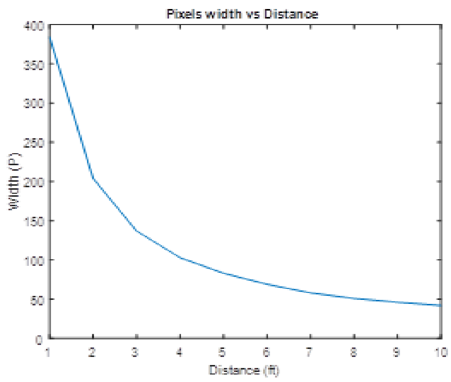

Figure 5. Pixels width and distance relation

3.4 Distant feature points filtering

After unwanted feature points on the image frame have been removed, there are still a number of feature points need to be filtered. Feature points in the image frame calculated by the SURF algorithm consist of a background and obstacle mixture. If these background feature points are not filtered properly, they will mislead the estimation of obstacle sizes and avoidance path for the UAV. In that case, background feature points filtrations are required.

In this project, feature points that are in distant from the center area feature points (yellow box) can be eliminated. This is accomplished by looking at Feature points distance ratio (Fdr) which derived from Interior feature points width (Ifw) and Exterior feature points width (Efw). Feature points having distance ratio (Fdr) that is lower than 0.6 are assumed to be noise and not part of the obstacle (see Figure 6). Feature points location for inside and outside the projected dimension are given variable as *mflI* and *mflE* respectively.

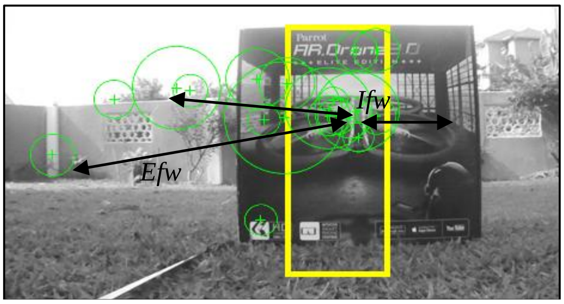

Figure 6. Distant feature keypoints filtering

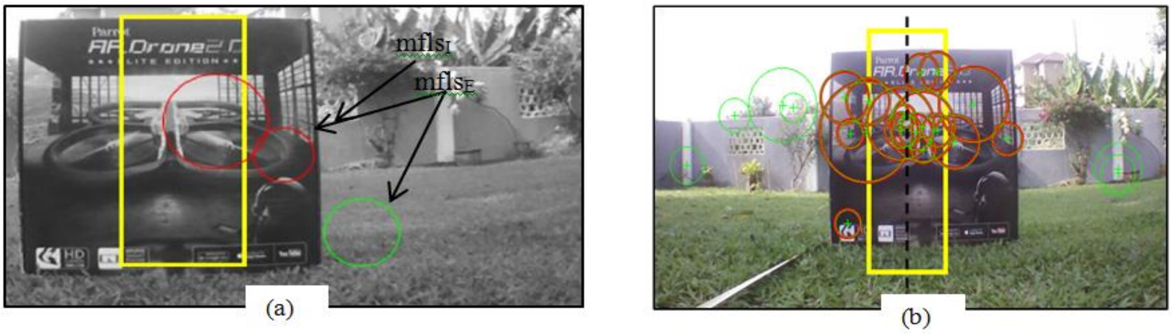

Figure 7. (a) Shows selection of feature points that are connected. (b) Estimation of obstacle sizes from the connected feature points

$$Ifw = max(mfl_I) - min(mfl_I) \quad (2)$$

$$Efw = max(mfl_E) - min(mfl_E) \quad (3)$$

$$Fdr = \frac{Ifw}{Efw} \quad (4)$$

3.5 Approximation of obstacle sizes

It is difficult to estimate the physical body size of the approaching obstacle because feature points detected by the algorithm are scattered around obstacle. Plus, not all features on the obstacles will be efficiently detected. We use connected feature points in the image frame as a method to approximate the real physical size of the obstacle. This is done by looking at the difference between feature points location on scale value (Green circle) inside (*mflsI*) and outside (*mflsE*) the projected dimension. To ease the computation, we divide the image frame equally to its right and left. Any exterior feature points that are connected to the feature points inside the projected dimension in term of width x-direction, it is assumed to be part of the obstacles.

$$\text{Right} \begin{cases} mfls_I = max(mfl_I + 6mfs_I) \\ \text{Section } \; mfls_E = mfl_E - 6mfs_E \end{cases} \quad (5)$$

$$\text{Left Section} \begin{cases} mfls_E - mfls_I < 0 \\ mfls_I = \min(mfl_I - 6mfs_I) \\ mfls_E = mfl_E + 6mfs_E \\ mfls_I - mfls_E < 0 \end{cases} \quad (6)$$

3.6 Safe avoidance path

Once obstacle size has been estimated, we need to find what the avoidance path that is safe for UAV. Instead of solely depend on a fix tolerance from the detected feature points to create the avoidance path for the UAV, our safe avoidance path creation depends on feature points which lie on the exterior of the estimated obstacle (see Figure 8).

The width dimension from the estimated obstacle will be extended to the exterior feature points. To be conservative towards any detected obstacles, we extend until to the center location of exterior feature points (FklE). These are the points before matching between frames (Aif and Dif). The reason for selecting this feature points rather than matched feature points is because it holds more location of the feature points in the image frame. This way, we are able to estimate the safe avoidance path without directly using same fix tolerance on each detected obstacle. In the case of textureless obstacles, the safe avoidance path is developed from median location of feature points on both sides of the image frame.

Red line represents the position of the UAV in the environment, while yellow line represents the unsafe region during that particular distance from the UAV to the obstacle. Hence, to avoid safely from the obstacle, the red line (UAV) should move outside or beyond the yellow line extrema.

$$\text{Avoidance path} = \begin{cases} \max(mfls_E - mfls_I) + Fkl_E \\ \min(mfls_I - mfls_E) - Fkl_E \end{cases} \quad (7)$$

Algorithm : Obstacle Detection

```
Input: Distances and Image frames
Output : Safe avoidance path
While Airborne do
  measure, d
    if d < 244cm then
      get Dif and detectKeyPoints fk_Dif
    end
    While Airborne do
      measure, d
      if d<Dif – 30cm then
        get Aif and detectKeyPoints fk_Aif
        mf(mfs_Aif – mfs_Dif < 1.0)
        if Pd(mf=0) then
          Dif = Aif
          fk_Dif = fk_Aif
          Continue;
        end
        mf(Fdr > 0.6)
        mfls_E – mfls_I < 0
        mfls_I – mfls_E < 0
        max(mfls_E – mfls_I) + fkl_E
        min(mfls_I – mfls_E) - fkl_E
      end
      if d <122cm then
        median(fkl_E)
      end
    end
end
```

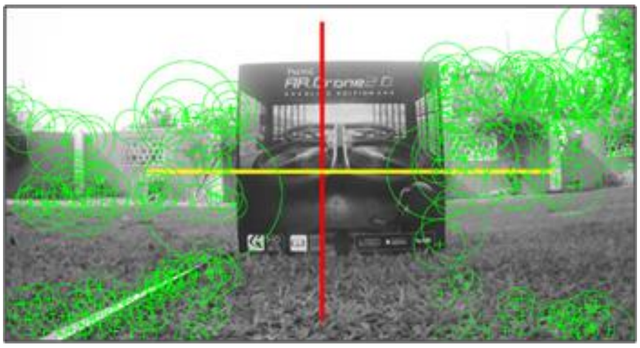

Figure 8. Safe avoidance path

4. Experiment Results and Discussion

Experiments are performed in real-time condition and indoor environment by moving the UAV towards the obstacles starting from the selected initial position which is 305cm. we randomly picked 6 obstacles to be used in the experiments, and each has different sizes and textures. 3 of them are textureless obstacles. The sizes for obstacles that have texture on them are ranging from 39cm to 11.5cm, while for textureless obstacles is from 67cm to 11.5cm. The meaning of size in this context is the width of the obstacles because our algorithm only detects the safe avoidance path from a horizontal plane. These different configurations are needed to validate the robustness of the algorithm towards any obstacles having different sizes and textures.

The experiments are run ten times on each of the obstacles, as stated above if the algorithm produces the yellow line within the obstacles width, it is considered failed, while, if the yellow line extends beyond the obstacles, it is a success. From the experiment on both texture and textureless obstacles (see table 2 and 3), show that the algorithm able to detect and provide safe avoidance path for the UAV from colliding with tested obstacles used in the experiment with high percentage.

Table 2. Texture obstacles

Obstacles	Failure	Avoidance distance (cm)	Computational time (ms)
1	1	210	93
2	-	205	87
3	1	196.2	91

Table 3. Textureless obstacles

Obstacles	Failure	Avoidance distance (cm)	Computational time (ms)
4	-	120.4	9.0
5	-	119	9.2
6	1	151.8	80.1

However, there are few failures in obstacle 1, 3 and 6 due to the unstable reading of distance by Lidar sensor and causing miscommunication with the algorithm in Matlab. Thus, it will cause an error for Safe avoidance path computation. In future experiments, a capacitor will be implemented in the Lidar sensor circuit to maintain a level voltage. Other than that, the algorithm performance is considered excellent and dependable.

Avoidance distance means distance at which UAV will execute avoidance action away from the obstacles. Tables above show an average of avoidance distance for every same obstacles. There are different avoidance distances. It is because feature points produced by the algorithm are random and highly depends on the attitude of the camera sensor. The avoidance distance detected by the algorithm is greater as compared to previous work in this field that uses only single camera with feature based detection [9][10]. It is around 90 to 120 cm. For avoidance distance in textureless obstacle, it is stated as in section 3.3.

However, avoidance distance for obstacles 5 is higher than fixed textureless distance. The reason for this is because obstacle 5 is small as compared to UAV projected dimension (see section 3.3) that is used to determine either it is a texture or textureless obstacles. In this case, obstacle 5 is considered as having texture on it due to surrounding feature points inside the projected dimension. Nevertheless, the algorithm can still provide Safe avoidance path from the obstacles which makes it a robust algorithm. It also explain why the computational time for obstacle 5 is relatively similar with obstacle 1, 2 and 3.

Computational time of our algorithm is ranging from 87 to 93ms for textured obstacles, while around 9ms for textureless obstacles. This is considered acceptable for UAV to initiate the control system for avoidance maneuver without jeopardizing the safety because the UAV is far enough from the obstacle.

Relatively, the algorithm able to provide avoidance path for UAV from a great distance and thus enhance the safety of UAV. Plus, the safe avoidance path is determined and calculated from the exterior feature points itself, makes it more robust and reliable rather than fix tolerance method. Besides, the algorithm is also able to provide a solution for textureless detection problem which is a crucial constraint for most of the vision-based detection method.

5. Conclusion and future work

In this research project, multi-sensor integration obstacle detection system for small UAV has been proposed. We combine monocular vision sensor with Lidar sensor to help increase the robustness and accuracy of the system. By using our obstacle detection algorithm, it enables the determination of safe avoidance path for UAV when encountering obstacles in the path. The algorithm also provides a solution for textureless obstacles in term of detecting and safe avoidance path.

Our method estimates the physical size of obstacles by using connecting feature points derived from SURF algorithm. For the determination of avoidance path, we calculate it through the exterior feature points from the estimated width of obstacle on the image frame. Consequently, it is more robust and reliable for the detection of any obstacles configuration (size and texture) as oppose to fix tolerance approach.

Experiments are conducted on 3 textured and 3 textureless obstacles to see the effectiveness of the algorithm for detecting and providing the safe avoidance for the UAV. The results are positive and very convincing with only a few failures recorded. The avoidance distance is within 196.2cm to 210cm. It depends on the size and texture of the detected obstacles, if greater, then, the avoidance distance will be much higher. Computational time for the textured obstacle is around 88ms while 9.1ms for textureless obstacles.

In future work, we would like to bring the optical flow method into our obstacle detection algorithm to further increase the robustness from the side and sudden appearance of obstacles. We also eager to investigate the detection and avoidance decision mechanism when multiple obstacles are introduced.

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