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Vision Based Obstacle Detection mechanism of a Fixed Wing UAV

S.N. Omkar[1], Sanjay Tripathi[2], Gaurav Kumar[3], Itika Gupta[4]

Abstract

In this paper we have developed a vision based navigation and obstacle detection mechanism for unmanned aerial vehicles (UAVs) which can be used effectively in GPS denied regions as well as in regions where remote controlled UAV navigation is impossible thus making the UAV more versatile and fully autonomous. We used a fixed single onboard video camera on the UAV that extracts images of the environment of a UAV. These images are then processed and detect an obstacle in the path if any. This method is effective in detecting dark as well as light coloured obstacles in the vicinity of the UAV. We developed two algorithms. The first one is to detect the horizon and land in the images extracted from the camera and to detect an obstacle in its path. The second one is specifically to detect a light coloured obstacle in the environment thus making our method more precise. The time taken for processing of the images and generating a result is very small thus this algorithm is also fit to be used in real time applications. These Algorithms are more effective than previously developed in this field because this algorithm does the detection of any obstacle without knowing the size of it beforehand. This algorithm is also capable of detecting light coloured obstacles in the sky which otherwise might be missed by an UAV or even a human pilot sometimes. Thus it makes the navigation more precise.

Keywords

Unmanned Aerial Vehicles (UAVs), Image Processing, Dark Coloured Obstacle detection, Light Coloured Obstacle Detection, Runway Detection, Erosion and Dilation

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S. N. Omkar, Department of Aerospace Engineering, Indian Institute of Science Bangalore, India.

Sanjay Tripathi, Department of Computer Engineering, National Institute of Technology Surathkal, (Karnataka), India.

Gaurav Kumar, Department of Computer Engineering, National Institute of Technology Surathkal, (Karnataka), India.

Itika Gupta, Department of Electrical Engineering, National Institute of Technology Hamirpur, (Himachal Pradesh), India.

1. Introduction

Unnamed Aerial Vehicles (UAVs) have been under development since the beginning days of flight but in recent years, Autonomous operation of UAV has been progressively developed. Specifically vision-based navigation, guidance and control have been most focused research topics for automation of UAVs.

In recent years, the utility of UAV has greatly increased in severe applications such as surveillance, law enforcement and aerial mapping. Furthermore, UAVs are quickly becoming an integral part of both military and commercial operations, UAVs have enabled many missions so far impossible with current technology. Disaster areas could be quickly searched from high altitude after which the same vehicles could fly down and into flooded or partially collapsed buildings, looking for survivors and other time sensitive situations.

For these applications, accurate UAV navigation is very critical for safe operation of vehicle. For some military missions, UAVs have to operate in congested environments that include obstacles. For such type of missions, obstacle avoidance is an anticipated requirement. Therefore this paper focuses on vision-based navigation for UAVs to detect and avoid obstacles in the path.

In this paper we are using the basics of MATLAB [11], image processing. We have gone thoroughly the different studies being carried out in this field and we have developed two algorithms to overcome the problem of navigation of a UAV with obstacles in path.

For fist algorithm, we are extracting and processing images from a single on board camera on the UAV and by using these images we detect horizon and land that needs to be followed by the UAV. This method is cheap, versatile and can be effectively used to navigate the UAV in difficult environments.

Here we are using images by a camera because camera is acclaimed for its unique advantage to deliver multi-layered information in the format of images. Contrary to navigational sensors such as GPS and INS which provide information about only vehicle's own motion, vision can provide additional information relative to the environment, like distance between obstacle and vehicle and alignment of vehicle with horizon.

In the second part we detected a dark coloured obstacle in the sky that needs to be avoided. To make this algorithm more universal we later modified it for detecting a light coloured obstacle too which can otherwise be misleading and the UAV can crash into it.

In the field of mobile robotics, a lot of research in the field of vision-based obstacle detection has mainly been done in robotics for the 2-D cases. With motion constraints in certain directions, a robot has the ability to stop its motion before making a decision on the path based obstructions detected by the camera. This critical feature does not require the controls system to act in real-time and the vehicle is able to travel along the circumference of an obstacle. On the other hand, an airplane is required to make decisions of the environment ahead in real-time to avoid obstacles while maintaining forward velocity required for flight [1].

2. Literature Review

For UAVs, Positioning, location and navigation are distinct processes.
In 1971, Krakiwsky and Wells [2] proposed that positioning is about determining coordinates in a fixed coordinate system. But Coordinates by themselves is a very little information to tell the average person where they are.

In 1995 Krakiwsky [3] proposed that location is the process of putting coordinates into a frame of reference that is more useful. Typically, a map with topographical features, navigational aids, roads, street addresses, etc. is used to determine location.

In 1989 Harris [4] proposed that navigation regards the provision of directional information on how to travel from the vehicle's present position to a given destination or a set of waypoints.

In 1992 Hagen and Heyerdahl [5] proposed an approach for estimating an aircraft's position and orientation using visual measurements for landmarks located on a known topographic map using an EKF.

Another approach for estimating aircraft position from image sequences was proposed by Lerner in 2004 [6]. In this approach, aircraft position and orientation was estimated from combining optical flow measurements, acquired from two successive images, with DTM.

In 1992, Roberts and Bhanu [7] proposed an approach for object detection and avoidance for aerial vehicles. The proposed approach fused inertial measurements with information that originated from image sequences to calculate range measurements for estimating the object distance.

3. Design and Calculation

A. Finding the horizon

To detect the obstacle on the path of the UAV, first the horizon line needs to be detected by the UAV. We presume that the UAV is navigating by following horizon line in the images that it captures. Thus to help in navigation we need to analyse the images extracted from the on board camera and detect the horizon in them. The horizon is the line on the image where the transition of pixels is taking place from dark to light coloured pixels. In the binary form of the image the land is detected by black pixels and the sky by white pixels. Thus it becomes easier to detect the horizon in it and plot a line across the horizon for navigation purpose.

The point of change of pixel can be found on either sides of the frame by analysing the pixel at different values on the y axis keeping the x co-ordinate constant. These two points can be joined with each other thus marking the horizon in the image. This is an easy method to detect the horizon in case of a flat land.

We can modify this method to make our horizon detection more effective in case we have to detect the horizon in a mountain area [10]. Then we detect the change of pixels in each co-ordinate of the x axis by analysing pixel values of y co-ordinates in each of them and join all these points to get the horizon. This gives us the exact horizon in the mountain region making our navigation better.

B. Finding the dark coloured obstacle

Initially we assume we have a dark coloured object in the region of interest and it needs to be detected. Thus we first modify our image by turning into binary format and detect the horizon. Then to detect the obstacle we analyse the position of the black pixels present in the region of interest that are not a part of the usual land in the image.

This helps us firstly in finding the direction of obstacle i.e. whether it is present on the left or right side of the UAV giving us an indication of which direction to navigate the UAV into so as to avoid hitting the obstacle detected.

To find the exact angle by which we need to move our UAV, we find the angle of the first black pixel of the obstacle from the centre. This angle calculated is the angle that is taken as a reference to guide the UAV to deviate from to avoid the obstacle.

C. Calculation of angle of deviation from Centre

The distance of the total region of interest from the centre is known. The angle of the end of region of interest from the centre is also known. We can find the distance of the obstacle from the centre .Thus using basic trigonometry we can find the angle of the obstacle from the centre (α).This angle gives us the angle with which we need to deviate from to avoid the obstacle.

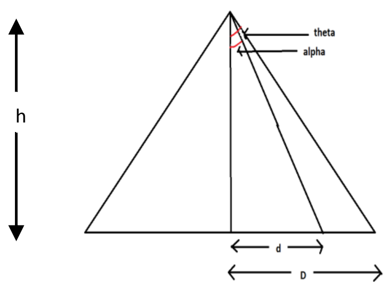


Fig.1- Calculation of angle of deviation

$\tan(\theta) = D/h$ (1)
$\tan(\alpha) = d/h$ (2)

From (1) and (2)
$\tan(\alpha) = d*\tan(\theta)/D$ (3)
$(\alpha) = \tan^{-1}(d*\tan(\theta)/D)$
$(\delta) = (\theta) - (\alpha)$

Where the increment (δ) depends on the wing size of the UAV
d = distance of the edge of the obstacle from the centre.
D = distance of the edge of the captured frame from the centre.
h = distance of the UAV from the obstacle.

D. Finding the light coloured obstacle

Finding a dark coloured obstacle that has higher values of pixels from the rest of the sky is easier to detect. But there can be instances where you have a light coloured obstacle in the path of the UAV that has a pixel value lesser than the rest of the sky. To enable the UAV to detect such obstacles can be a challenge.

In the algorithm that we have developed to detect such objects we first take the gray scale format of the extracted image from the UAV's onboard camera. We find the highest gray value in the image by calculating the value of the highest peak in the histogram of the image. This gives us a mean value.

Using this mean value and finding the difference between pixel values in the image and the mean value calculated we can detect the light coloured obstacle easily. After detection we can change the value of obstacle to the highest gray value and the rest of the image to the lowest gray value.

On conversion on this modified image into binary format makes the light coloured obstacle appear like a normal dark obstacle thus helping us in calculating its angle and distance from the centre to guide the UAV in avoiding the obstacle.

E. Finding the runway

In order to facilitate vision based autonomous landing of a UAV, we first need to detect a runway in the frames captured by the onboard camera of the UAV for it to land on. Runway detection on the land can be of various kinds. The runways can either be lighter or darker than the rest of the environment.

The edges of the runways lines can be detected and the detected lines can be plotted to help the UAV differentiate between them and the rest of the edges [9]. Our algorithm can detect the runway lines in an image thereby helping in guiding the UAV towards landing.

4. Cases of Position of Obstacle

Obstacles can be at different regions in the field of view of UAV. Following are the different cases of position of an obstacle:

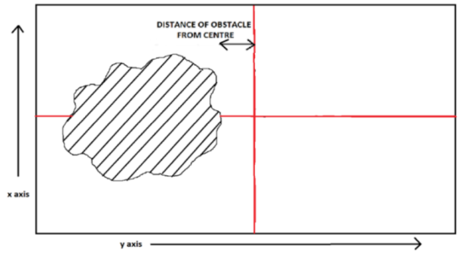


Fig. 2- Position of Obstacle-I

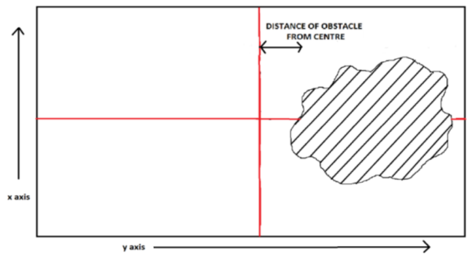


Fig. 3- Position of Obstacle-II

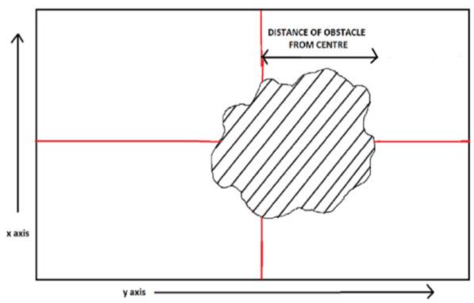


Fig. 4- Position of Obstacle-III

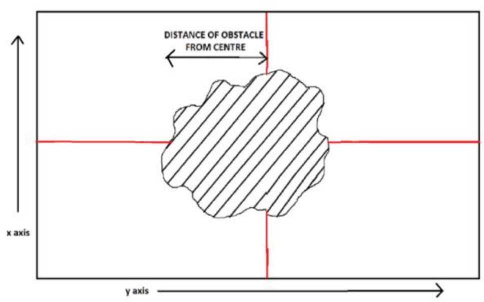


Fig. 5- Position of Obstacle-IV

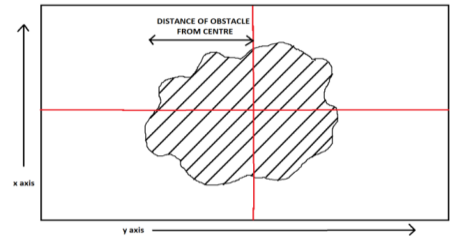


Fig. 6- Position of Obstacle-V

A. Case 1:

In Fig. 2, the angle as per our presumption will be negative in this case when the obstacle is on the left. The distance can be calculated relatively as we know the distance of our region of interest from the centre.

B. Case 2:

In Fig. 3, the only difference is that in this case angle will be positive. Further processing will be done of which side i.e. Left of right has more white pixels so the UAV will turn in that direction to avoid the obstacle.

C. CASE 3:

In Fig. 4, this and the next case the condition is that the obstacle is over lapping with the UAV. Thus for all such cases of overlapping we have taken the angle to be positive. In these cases further processing will be done of which side i.e. Left of right has more white pixels so the UAV will turn in that direction to avoid the obstacle.

D. CASE 4:

In Fig. 5, this case is also similar to the previous case with the only difference being that of the side of the presence of the obstacle.

E. CASE 5:

In Fig. 6, this is a typical case in which the obstacle is right in the centre and the UAV can move on either side to avoid it. Thus the distance of the obstacle from the centre is calculated on one of the side and accordingly the UAV navigates without hitting it.

5. Algorithms

A. To detect the horizon and the obstacle in the path of UAV

- Extract images from the on board camera by taking snapshots from the video frame by frame.

- Feed the initial velocity of UAV and the angle of camera on the UAV.
- Convert the RGB image into a binary image and find the size of the image matrix formed.
- Check if the image extracted is light in colour and convert it to its complimentary form if it is.
- Select a disk shaped structure and open image with areas greater than the area of disk.
- Find the left most and right most point of the horizon and draw a line across the two points to mark the horizon.
- Find the midpoint of the horizon and draw a rectangle around it that is our area of interest in the image.
- Calculate the number of black pixels in the region of interest. These are the obstacle in the path of the UAV.
- Find the distance of obstacle from centre and its angle from the centre.
- Locate the position of obstacle from the centre and display it to help the UAV deviate from its path to avoid the obstacle.
- The UAV will be directed to deviate from the obstacle at an angle slightly greater than the angle of the obstacle from the centre.

B. To detect a light coloured obstacle in the path of UAV:

- Extract images from the on board camera by taking snapshots from the video frame by frame.
- Copy the original frame to a blank frame and Convert it to gray scale.
- Calculate the size of the gray scale image matrix that is obtained.
- Construct a histogram of the gray scale image above the horizon line and use its highest peak to detect the mean value of the pixels [8] obtained in the gray scale image
- Use the obtained mean value and find the difference between the mean value and the value of a pixel of the gray scale image after a difference of five pixels.
- A difference of five pixels is taken to decrease the processing time and make the algorithm more practical.
- If the difference is between the ranges of 0-10 the pixel is assigned the lowest gray value of 0 and if the difference is not in the given range thenthe pixel is assigned the highest gray value of 255.
- The modified gray scale image is then converted to a binary image.
- Processing is done on the given image by eroding and dilating it. Erosion is a basic morphological operation performed on an image which generally decreases the sizes of objects and removes small anomalies by subtracting objects with a radius smaller than the structuring element. Dilation generally increases the sizes of objects, filling in holes and broken areas, and connecting areas that are separated by spaces smaller than the size of the structuring element.
- The obtained image displays the light coloured obstacle in the image.
- This image can then be used for finding the position, distance and angle of the obstacle from the centre using the previous algorithm.

6. Experimental Analysis

By using the fundamentals of image processing and programming in MATLAB [5] we were able to develop a method to use vision based navigation to detect an obstacle in the path of the UAV. This algorithm works efficiently for dark as well as light coloured obstacles.

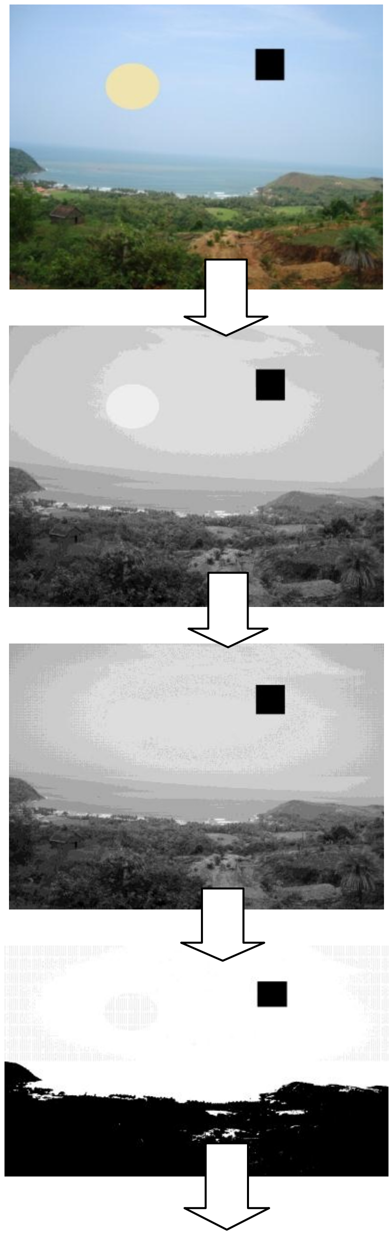
This method provides an easy and cost effective way to make UAVs fully autonomous by the use of simply a single on board camera and a few sensors.
The algorithm that we have developed helps in navigating UAV autonomously thus it can be efficiently used in difficult environments where GPS is absent and where humans cannot reach.

The algorithm developed is fit to be used for real time navigation of UAV using a camera as on processing the algorithm of MATLB we found that the time taken for the detection of horizon and an obstacle in the path of the UAV is as follows:

Table.1- Observed obstacle detection time

Obstacle type	**Detection Time(seconds)**
Dark Coloured Obstacle	0.16
Light Coloured Obstacle	2.6748

Thus the processing of the image can be carried out quickly and the UAV can be correctly navigated.
In the following pictures taken during our experiment circular object is light coloured obstacle and rectangular one is dark coloured obstacle.



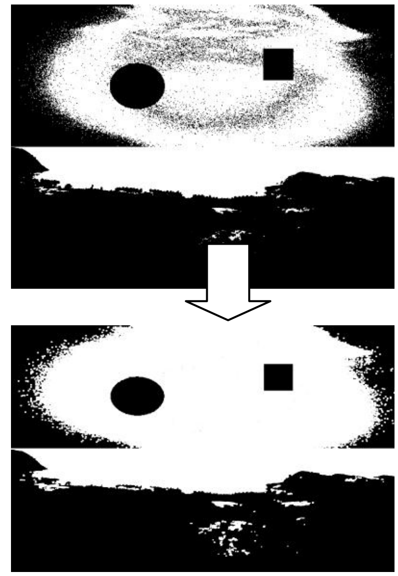


Fig.7- Simultaneous Light and Dark coloured obstacle detection

7. Conclusion and Future Work

Our vision based obstacle detection mechanism is more versatile than the previous methods developed in vision based navigation, for example in the paper on obstacle detection through sky segmentation [2] it's not generalised for light coloured or unknown size obstacles. Our algorithm is a generalised algorithm that detects anonymous obstacles whose size is unknown to us. This algorithm is also capable of detecting light coloured obstacles in the environment that would otherwise be ignored by a UAV and sometimes even by a human pilot. This method makes the navigation of UAV more versatile as it can be used even in absence of a GPS system in difficult environments.

By developing this mechanism various options have been opened for us for the future. This system can be modified greatly for making a UAV completely autonomous that can fly in all kinds of environments .By the use of a single on board camera and a few necessary sensors we can develop a UAV that is cheap, versatile and fit to be flown in any kind of environment. Hence, this project has a wide scope for future work and enhancements.

In future we aim improving our algorithm by reducing noise in the images and making this algorithm work efficiently even in foggy environments when the objects of the image are not very sharply defined. This will help us in making this algorithm work correctly even if the images are not very clear due to environmental disturbances.

In order to enable the UAV to fly in urban environments with enormous and large number of buildings, we aim at modifying this algorithm to detect multiple obstacles in its vicinity and finding a path fit to move without hitting them. Along with detecting multiple obstacles we also aim at working on moving obstacles in the environment of the UAV.
We also aim at extending this work to develop a robust algorithm for landing of the UAV on a runway thus making it a full-fledged vision based navigation system for UAV from its movement in space, obstacle detection and avoidance and landing on a runway.

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Dr. S.N.Omkar is currently working as a Principal Research Scientist at the Department of Aerospace Engineering, Indian Institute of Science, Bangalore. His research involves both computational and experimental approaches.

Sanjay Tripathi completed his Under Graduation from National Institute of Technology Surathkal, India with B.Tech in Computer Science. Currently he is working as a Software developer at Citrix at Bangalore since June 2011.

Gaurav Kumar completed his Under Graduation from National Institute of Technology Surathkal, India with B.Tech in Computer Science. Currently he is working as a Analyst developer at Nomura Services India pvt. Ltd at Mumbai since June 2011.

Itika Gupta completed her Under Graduation from National Institute of Technology Hamirpur, India with B.Tech in Electrical Engg. Currently She is working as Analyst at Quicksand Design Studio,Mumbai.