Detection of Airport Runway Edges using Line Detection Techniques

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Abstract— **Airport runway detection is a vital aspect for both military and commercial applications. An algorithm to extract runway edges based on edge detection and line detection techniques is discussed. The runway images are initially enhanced by dilation, thresholding and edge detection. Based on some unique characteristics like the runway being gray with two white lines indicating the runway boundaries, long and continuous edges of the runway are considered to be straight lines. The straight lines are detected using Convolution operators pertaining to vertical, 45° or -45° lines. Hough Transform is then applied to fit only the pair of lines corresponding to the runway boundaries in certain orientations. The test results prove that combination of Convolution and Hough transform is very competent in detecting runway edges accurately.**

Keywords- Runway detection, edge detection, Straight line detection, Hough Transform

I. INTRODUCTION

The detection of airport runway is significant for both military and commercial applications. Pilots should be able to see the runway even under adverse weather conditions. Dense fog conditions in particular, may pose a great threat to the pilots while landing. Although several techniques have been proposed for assisting a pilot to land an aircraft, it is indispensable to follow a modus operandi which will be less time consuming and accurate in detecting the exact runway edges during approach [1]. An airport is characterized by runways being planar, rectangular in shape with certain length and width. This distinctive shape is very useful in discriminating any runway from its surroundings. The runway itself is gray with two white lines marking the boundaries of the runway. These two boundary lines are considered to be two straight lines of interest in the image. When this information about the boundaries can be obtained from the imagery in an automatic manner, the task of landing an aircraft in poor visibility conditions is considerably easier [2]. Therefore, runway detection task transforms into a technique to extract straight lines in an image [3]. A detection method is developed for airport runways, considering runway boundaries to be straight lines in the image. The runway image is processed by edge detection and the straight lines are identified using Convolution and Hough Transform.

II. RUNWAY EDGE DETECTION ALGORITHM

Before identifying runway boundaries, it is important to analyze runway characteristics. The characteristics of runway images are:

- Gray value is higher on the runway edges when compared to the scenery around and runway neighborhood.

- The runway border lines appear to be two continuous straight lines inclined at a particular angle.

The first characteristic of the runway favors edge detection technique to be used on the runway image [4]. Once the edges of the objects in the image are detected, the second feature favors straight line detection to be used on the edge detected image. The information flow diagram of the algorithm is shown in Fig.1. It is done in two steps viz., 1. Image Enhancement and Edge Detection and 2. Line Detection . The details of these steps are discussed in the successive sections.

A. Image Enhancement and Edge Detection Techniques

Image Enhancement is the process of improving an image characteristic such that it is more suitable for a particular application. The original image with runways as long continuous edges contains other information too, which are not useful for detecting the exact edges. Before performing straight line detection in the image, it is essential to enhance it so as to reduce the impact of detecting unnecessary lines in the image. Some of the image enhancement and edge detection methods followed are discussed in the following sections.
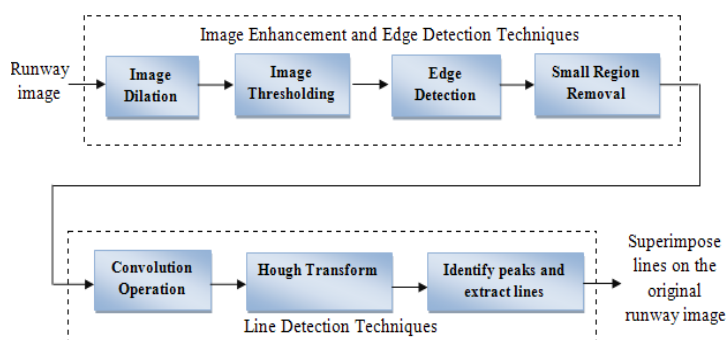

Fig.1: Information flow diagram of runway edge detection algorithm

A1. Image Dilation

Dilation is the basic morphological operation which adds pixels to the boundaries of the objects in an image. The number of pixels added or removed from the objects in an image depends on the size and shape of the structuring element used to process the image. A structuring element is a matrix consisting of only 0's and 1's that can have any arbitrary shape and size. The pixels with value 1 define the neighborhood. Dilation is extensively used to bridge gaps in the objects by adding pixels to the image. As shown in Fig.2, runway markings are highlighted using this technique.
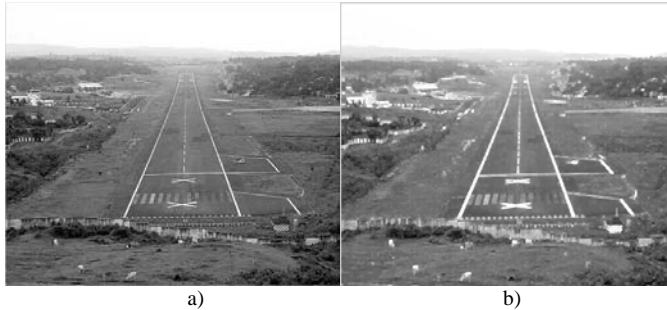

a)   b)

Fig.2 a) Original Image b) Dilated Image

A2. Image Thresholding

Thresholding is the process of mapping pixels to produce a two-level image [5]. Each pixel is compared to a threshold value, and then assigned to either foreground or background of the image. Pixel values greater than threshold are considered to be objects and are labeled 1. Pixel values less than threshold are considered to be background and are labeled 0.

The thresholding results of various methods are tested as shown in Fig.3. Otsu's method appears more appropriate in our scenario, as we are interested only in the
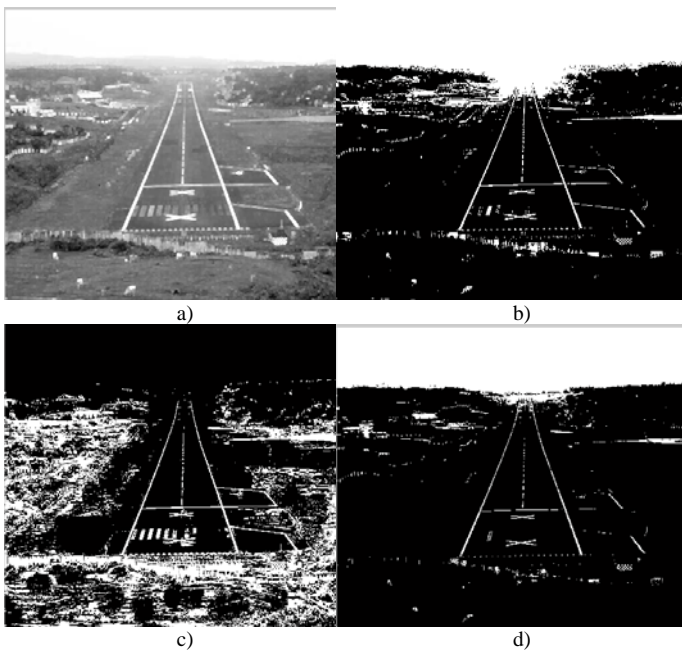
runway edges and not the surroundings. Otsu's method chooses the threshold value in such a way that the intra-class variance of black and white pixels is minimized [6].

A3. Edge Detection

Edges are a set of connected pixels that lie on the boundary between two regions [7,8]. Edge detection techniques which aim to produce *line drawing* are used to identify the edges in an image. They look for places in the image where the intensity changes rapidly. There are two major advantages in performing edge-detection as:

- Edge detection provides noise immunity to certain extent.
- Edge detection reduces the overall complexity of the problem by reducing the amount of data to be utilized, eliminating unwanted information.

Airport runways are generally distinguished from background, yielding edges after edge detection. After several trials with other edge detection operators as shown in Fig.4, Sobel edge operator is selected for this operation because of its optimal solution for low defective edge rate, localization of edges and giving one response for a single edge.

A4. Removal of small regions

Small and unnecessary regions not contributing to runway edges are removed from further consideration based on the expected size of a runway in the image. This is accomplished by morphologically opening binary image to remove blobs or objects with less number of pixels as shown in Fig.5b.

B. Line Detection Techniques

Enhanced image containing only the runway edge information is subjected to Line Detection Techniques to extract the pair of lines representing the runway boundaries.
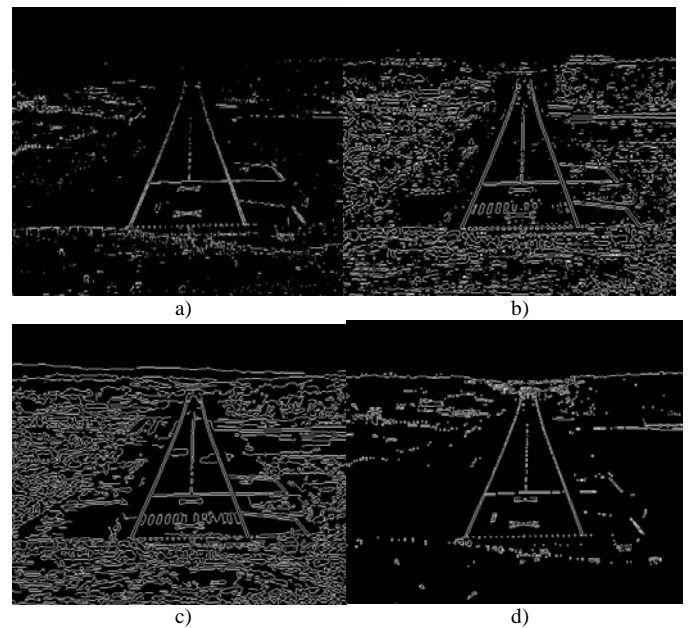

a)   b)

c)   d)

Fig. 3: Comparison of different thresholding methods
a) Gray image b) Local thresholding c) Iterative method d) Otsu's thresholding

a)   b)

c)   d)

Fig.4: Comparison of edge detection operators a) Roberts operator b) Laplacian of Gaussian Operator c) Canny Operator d) Sobel operator
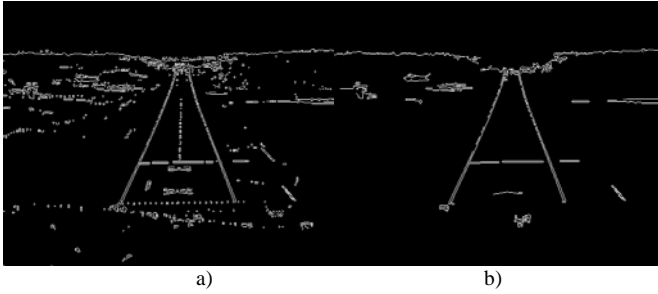
a)   b)

Fig.5: a) Image before small region removal b) after small region removal

B1.   *Straight Line detection using Convolution operators*

Once the runway boundaries are roughly obtained, straight line detection is to be performed, considering the runway edges to be a pair of straight lines in some orientation. The runway boundaries are considered to be oriented vertically, horizontally or approximately around 45° or -45° during approach.

Straight lines in particular orientation are determined by Convolution. Convolution is a neighborhood operation in which each output pixel is the weighted sum of neighboring input pixels. Image convolution can be used to easily detect lines. While landing, only vertical, 45° and 135° masks are sufficient. Fig.6 shows the three convolution masks used to detect vertical, 45° and -45° lines.

B2.   *Line fitting using Hough Transform*

Hough Transform is a robust method used to extract arbitrary shapes, such as lines, circles, ellipses, out of an image [9,10]. It is extensively used to detect straight lines, with the unique ability of detecting even disjoint line segments [11-14]. Hough Transform approach is:

1. Straight lines with coordinates (r1,c1) and (r2,c2) are assumed to be parameterized in the form $\rho = x\cos\theta + y\sin\theta$, where ρ (rho) is the perpendicular distance from image origin and θ (theta) is the angle with a normal to the line from the origin as shown in Fig.7.

2. The Hough transform generates a parameter space matrix whose rows and columns correspond to ρ and θ values respectively. In a Hough space, lines are mapped to a point such that a point represents all possible lines through that point as shown in Fig.8.

3. This way, all contiguous edges are transformed to straight lines that could pass through a particular point in Hough space. Peak values are points in this space which represent the longest lines in the image.

$$\begin{bmatrix} -1 & 2 & -1 \\ -1 & 2 & -1 \\ -1 & 2 & -1 \end{bmatrix} \begin{bmatrix} -1 & -1 & 2 \\ -1 & 2 & -1 \\ 2 & -1 & -1 \end{bmatrix} \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix}$$

Vertical lines   45° lines   135° lines

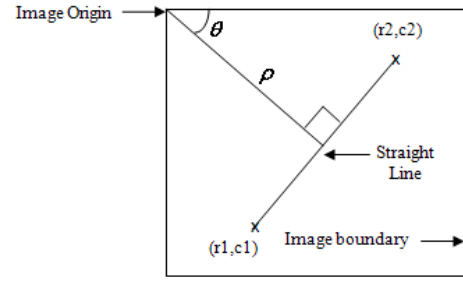Fig.6: Convolution masks for straight line detection

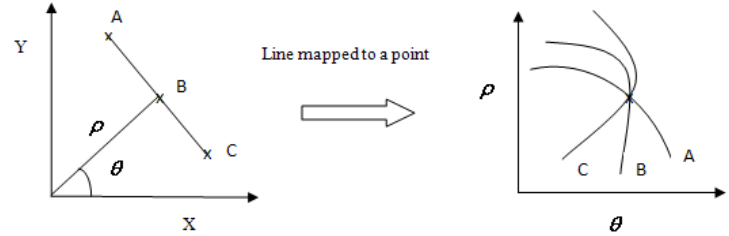Fig.7: Rho and Theta calculation for a line in Hough Transform

Fig.8: Line parameterization and mapping of a line in Hough space

4. In order to extract peaks pertaining to runway boundaries, theta values which satisfy the below criteria are only considered for our line extraction [15,16].
   a) During approach and landing i.e. when the aircraft is approximately aligned to the center of the runway, the runway boundaries would be well within 45° and -45°. Hence, Hough peaks of lines outside this range are eliminated.
   b) Further, the two runway edges appear parallel in the image. Hough space matrix is searched for theta values with opposite peak pairs representing a runway (e.g. +25° and -25°). In order to consider the fact that the aircraft may not be exactly aligned to the center of runway during approach, ±10° deviation is allowed in the pair angles (e.g. +25° and -25°±10°). Each opposite peak pair corresponds to a line pair.

5. To proceed with line segment detection, pair angles [e.g.:- 23 25] were considered. Coordinates of the line segments corresponding to the filtered theta values are obtained and drawn as runway boundaries over the original runway image.

The performance of the algorithm with Convolution and Hough Transform pair was compared to one without Convolution operation i.e. only Hough Transform applied directly after edge detection. The results show that in clear and good contrast runway images as in Fig.9, Convolution does not have a major role i.e. Hough Transform itself is able to detect the edges to some extent without Convolution. Whereas in dim images where the runway edges are not very prominent as seen in Fig.10, Hough Transform is not efficient in detecting the exact edges without the help of straight line detection using Convolution masks.
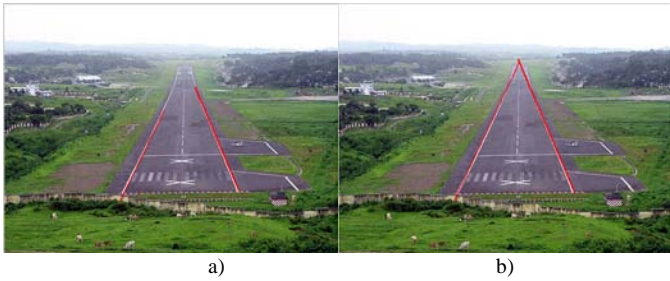
Fig.9: a) Line detection with Hough only b) Line detection with Convolution & Hough pair for a clear image

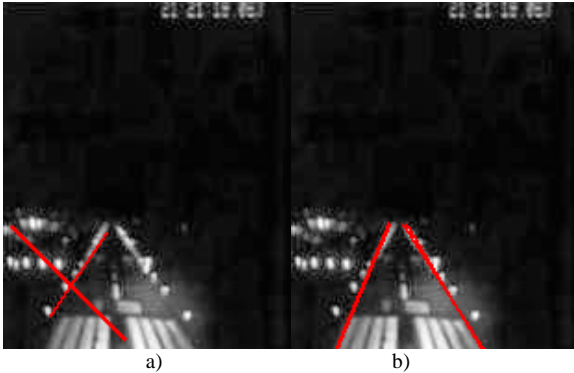Fig.11: Test image 1a) Original image b) Extracted runway edges in red

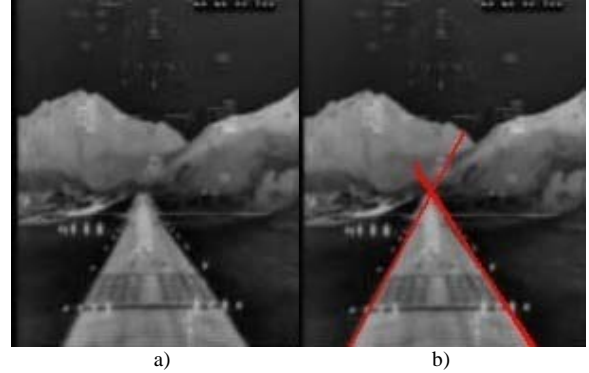Fig.10: a) Line detection with Hough only b) Line detection with Convolution & Hough pair for a dim image

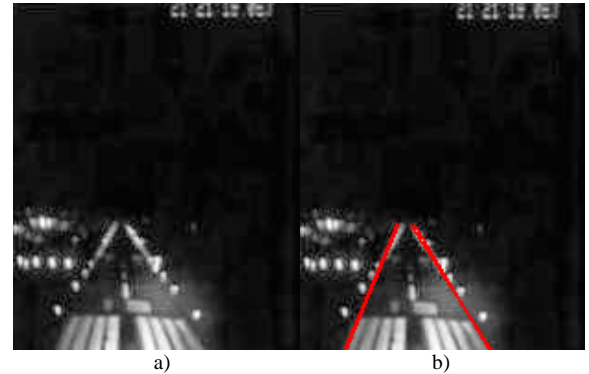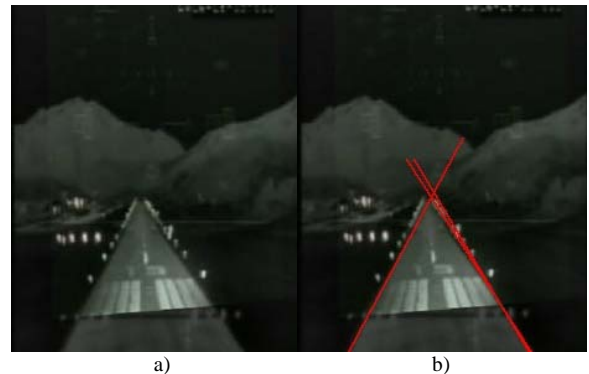Fig.12: Test image 2 a) Original IR image b) Extracted edges in red

III.   RESULTS AND DISCUSSIONS

Input runway image was initially converted to a two dimensional gray level image. The gray image was then dilated with a 3x3 matrix of all ones. Thresholding was then performed on the scaled image by Otsu's method using the matlab function 'graythresh'. The edges were detected using Sobel operator. Smaller regions in the image with total pixel numbers less than 20 were removed using the matlab function 'bwareaopen'. This number was obtained on a trial and error basis. Considering only the landing scenario where the runway boundaries would be well within 45° and -45°, the image was filtered using 'imfilter' with convolution operators pertaining to vertical, 45° and -45°. Hough transform was then applied using the matlab function 'hough'. Theta values in the range 45° to -45°, occurring in pairs were only considered. Assuming that the filtered theta values would correspond to only runway edges, 5 Hough peaks were considered. Line coordinates or the end points of the longest line segments are extracted and drawn as runway edges on the original image.

The algorithm tested on various input images and their corresponding runway edge extracted images are shown in Figs. 11-16. A clear runway image has been detected perfectly in Fig.11. Figs 12 & 13 depict night time images of a runway captured simultaneously using Infrared, and Electro-Optical cameras along with their edge extracted images. Fig.14 is that of a fused image from infrared and color camera. Fig.15 is an image simulated using a desktop simulator with a distance of 1km between runway touchdown point and camera. It can be seen that the algorithm was effective in automatically extracting the boundaries in all the above test images. But Fig.16a shows that the algorithm was unable to extract the

Fig.13: Test image 3 a) Original EO image b) Extracted edges in red

Fig.14: Test image 4 a) Fused image b) Extracted edges in red

edges automatically from a simulated image with the runway at a distance of around 2 km from the aircraft using the above considered threshold values and number of peaks. The runway margin was only a few pixels in length which was considerably very small when compared to all other objects in the image. Due to this reason, the Hough space was unable to detect this as a peak. As a solution, the threshold values can be changed,

but to retain the algorithm completely automatic, a small Region of Interest (ROI) can be selected manually by the pilot as shown in Fig.16b and then fed to the same algorithm. In this way, the algorithm was able to detect the edges as shown in Fig.16c.

IV. CONCLUSION

A robust algorithm for runway edge detection using convolution masks and Hough transform has been studied. The runway images are subjected to image enhancement techniques like dilation, thresholding, edge detection and blob removal. Smaller regions pertaining to runway surroundings and markings are eliminated to focus only on the runway edges. Hence, the amount of information required by the pilot for processing has been reduced drastically, cutting down the computation time. Considering the runway boundaries to be straight lines in the image, convolution masks for straight line detection and Hough transform are applied. Hough transform has been modified to enable only the lines related to the two runway edges to be extracted. The combination of Convolution and Hough transform guarantees the accuracy in exact boundary extraction. The algorithm has been developed only after comparing its performance to various other thresholding techniques,

edge detection operators etc. The entire process is fully automated, without expecting any user input at the time of running the program, even during threshold value selection. The algorithm has been implemented in Matlab® and tested on sufficient number of test images captured at different altitudes with the results being satisfactory.
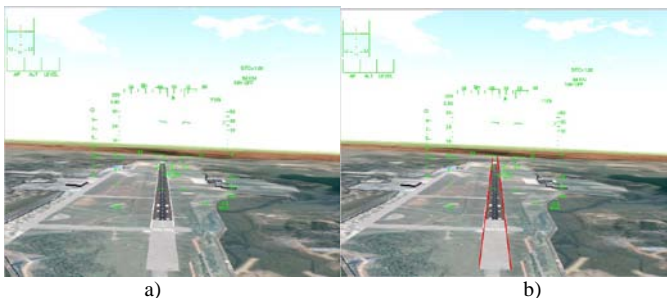
Fig.15: Test image 5. a) Simulated runway image at 1km distance
b) Extracted runway edges in red
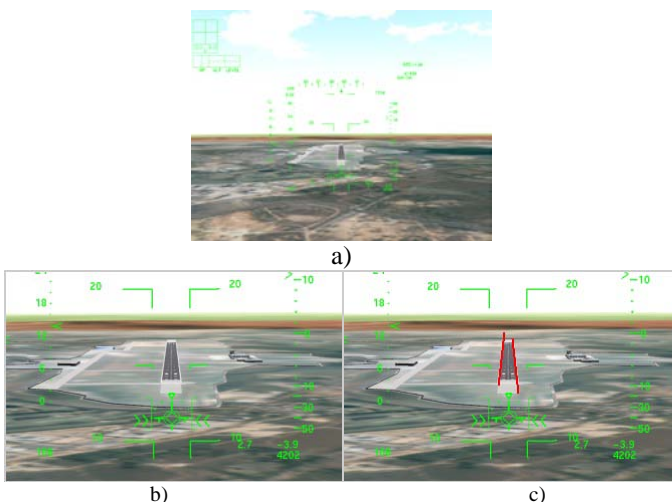
Fig.16: Test image 6. a) Simulated image at 2 km distance
b) ROI extracted image c) Runway edges in red

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