Airport Signs and Markings Recognition for Enhanced Runway Incursion Avoidance

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***Abstract*—Detecting and recognizing runway holding position signs and hold-short lines are of significant safety interest for runway incursion avoidance. It is an important supplement to pilots' education and airport ground radar to enhance safety, particularly at complex major airports. In this project, we leverage the standards of airport signs and markings for the detection and recognition purposes. For sign detection and recognition, an HSV color space based algorithm is developed to detect runway holding positions signs and Optical Character Recognition (OCR) is used to recognized the signs. For line detection, Canny Edge Detection and Hough Transform are used to recognize major line features in the images, and a heuristic algorithm leveraging the layout characteristics of the images is used to determine the presence of hold-short lines among those lines. An accuracy of 95.1% is achieved for runway holding position signs detection and recognition while an accuracy of 89.2% is achieved for runway hold-short line detection.**

Keywords: HSV, OCR, Edge Detection, Hough Transform

I. Motivation and Introduction

A runway incursion is defined as any occurrence in the airport runway environment involving an aircraft, vehicle, person, or object on the ground that creates a collision hazard or results in a loss of required separation with an aircraft taking off, intending to take off, landing, or intending to land. In the United States, an average of three runway incursions occur daily[1]. Multiple factors contribute to runway incursion, including failure to comply with air traffic control (ATC) instructions, lack of airport familiarity and nonconformance with standard operating procedures. A typical runway incursion scenario is shown in figure 1[1].

In this project, we target the last defense of runway incursion - incursion into an active runway, by detecting and recognizing runway holding position signs and runway hold-short lines. The signs and lines that we intend to detect and recognize are shown in figure 2[1]. For runway holding position signs, we have developed a color-based algorithm in the HSV color space and shape-based method to detect runway holding positions signs and used Optical Character Recognition (OCR) to recognize the signs. For runway hold-short lines, the Canny Edge Detection and Hough Transform is applied to recognize major line features. Then the unique heuristic characteristics of those images (relationship between horizon and hold-short lines) are leveraged to identify the most likely position for hold-short lines. The test images used in our project are obtained from a real aircraft ground operation at Palo Alto Municipal Airport (KPAO) by Huafei Wang. GoPro 4 Silver with 1 frame / 5 seconds and resolution 1920×1080 is used.

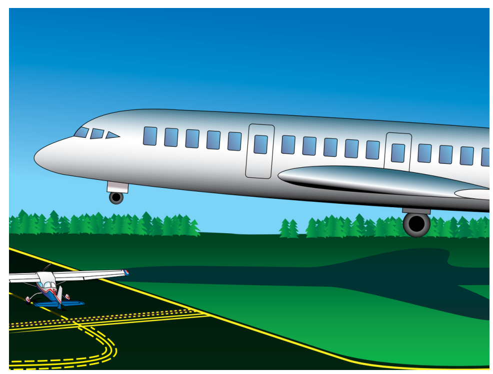

Fig. 1: Typical Runway Incursion Scenario

Fig. 2: Signs and Lines to Detect and Recognize

II. Runway Holding Position Signs Detection and Recognition

Runway holding position signs detection and recognition is divided into two functional modules - sign detection and sign recognition. Since runway holding position signs would only occur in a fraction of the total flight and ground operation of an aircraft, applying sign recognition using OCR w/o sign detection would be both computation-inefficient and energy-inefficient. Therefore, we would apply runway holding position signs detection first to locate the sign and then send the subframe containing only the sign for recognition. If the image frame does not contain the runway holding position sign, it would not be sent for sign recognition, thus saving computation and energy.

A. Work Flow for Runway Holding Position Signs Detection

Regulated by International Civil Aviation Organization (ICAO) and Federal Aviation of Administration (FAA), runway holding position signs have red as background and white as characters[2][3]. A color-based method is developed on these standards. Since the colors in the Red-Green-Blue (RGB) color space not only contain color information, but also intensity information, using RGB color space would not be versatile in different brightness conditions[4]. Therefore, we first convert the RGB color space into Hue-Saturation-Value (HSV) color space, where the brightness information is only stored in the V channel.

$$H = \begin{cases} 60 \times \frac{(G-B)}{max(R,G,B)-min(R,G,B)} \\ \quad if R = max(R,G,B) \\ 60 \times \frac{(B-R)}{max(R,G,B)-min(R,G,B)} + 120 \\ \quad if G = max(R,G,B) \\ 60 \times \frac{(R-G)}{max(R,G,B)-min(R,G,B)} + 240 \\ \quad if B = max(R,G,B) \end{cases}$$

$$S = \frac{(max(R,G,B) - min(R,G,B))}{max(R,G,B)}$$

$$V = max(R,G,B)$$

After the image is represented in the HSV color space, a threshold of $H_{low} = \frac{20}{360}, H_{high} = \frac{335}{360}, S_{low} = 0.3$ is used to detect the red background of the runway holding position signs. To prevent the algorithm from picking up random objects of red color, it is required that at least 1000 pixels are detected as red to be considered a valid sign. Then, a rectangle covering only the sign would be generated cropping the input image for recognition.

B. Work Flow for Runway Holding Position Signs Recognition

Before the OCR is applied the cropped image, Top-Hat Filtering is applied to reconstruct the image because that the cropped image sign is small in dimensions and may contain dirt or blur that may adversely influence the OCR recognition[5]. Then, a Median Filter of window size 3×3 is applied to reduce the noise on the image. After the OCR recognition, the result is further validated by examining whether the recognized sign is a valid runway number. The valid runway number can only be from 00-36 since the number corresponds to the magnetic heading of the runway.

C. Experimental Result

A typical runway holding position sign detection and recognition scenario is shown in the following figures. Figure 3 shows the original input image. Figure 4 shows the detected sign after top-hat filtering and median filtering. Figure 5 displays the runway information on the original image frame. 223 images obtained from the ground operation of an aircraft are tested using this method and the result is shown in Table I. We can see that the detection has high recall yet relatively low precision. It is caused by the algorithm picking up similar objects (color and shape) in the vicinity including light box, aircraft painting and wind sock. The overall accuracy is 95.1%.

Fig. 3: Original Input Image for Sign Recognition

Fig. 4: Detected Sign after Pre-processing for OCR

Fig. 5: Display Sign Recognition Result

TABLE I: Holding Position Sign Detection Result

Accuracy = 95.1%	Sign Present	Sign Not Present	Precision
Sign Detected	8	9	47.1%
Sign Not Detected	2	204	99.0%
Recall	80.0%	95.8%	

III. Runway Hold-Short Line Detection

The work flow for runway hold-short line detection consists of Canny Edge Detector, Hough Transform and leverages the heuristic characteristics of the layout of the horizon, and hold-short line to determine the location of the hold-short lines.

A. Algorithms for Runway Hold-Short Line Detection

Canny Edge Detection is first applied to the image to extract the edges from the input image. Then, Hough

Transform is applied to locate edges that are straight lines and the midpoints of those straight lines are calculated. Those straight lines and midpoints are of significant interest to us because that the two dashed lines in the runway hold-short lines would greatly contribute to those segmented straight lines and midpoints. Another contributor to the segmented straight lines and midpoints are the horizon in the input image. Furthermore, the segmented straight lines and midpoints from the hold-short line and the horizon exhibit a clustering property, with the hold-short line position being 100 pixels below the peak in the y direction while the hold-short line position being approximately the same as the peak in histogram in the x direction. Since hold-short lines often occur in a rectangular window of size 600 by 200 pixels, two windows are searched, one with (PeakX, PeakY-100) as the top right corner (left window), and the other with PeakX, PeakY-100) as the top left corner (right window). The number of midpoints in these two windows are computed respectively, and if the count is larger than our threshold of 5 in any of them, it is determined that hold-short lines are present.

Input images would typically come from consecutive video frames, so the location of hold-short lines from one image to the next one would only change by a relatively small amount. We record PeakX and PeakY values from the previous image. If no hold-short lines were detected in the previous image, these values were both set to 0, and we proceed according to the previously described algorithm. Otherwise, the two windows near the previous PeakX and PeakY position also need to be searched. The number of consecutive images that have hold-short lines detected are also kept. If no hold-short line has yet been detected, then a stricter criterion would be imposed that requires the sum of midpoints in both left and right windows to exceed a certain threshold of 12 to determine that hold-short lines are present.

B. Experimental Result

A typical runway hold-short line detection scenario is shown in the following figures. The original input image is shown in Figure 6. The Canny Edges obtained using the Canny Edge Detector are shown in Figure 7. The segmented straight lines obtained from the Hough Transform are shown in Figure 8. The peak point in both x and y direction histograms is shown in Figure 9. The window drawing from the peak point is shown in Figure 10. Figure 11 displays the warning information regarding the runway hold-short line with the original input image.

223 images obtained from the ground operation of an aircraft are tested using this algorithm and the result is shown in table II. We can see that the detection has high recall yet relatively low precision. It is caused by either the similar markings in the airport environment including taxi lines, movement-nonmovement lines and etc or the random line clustering in the background scene. The advantage of the algorithm is that false positives rarely occur consecutively, so these false warnings to the pilots would quickly disappear even if they appear at some point. The overall accuracy is 89.2%.

Fig. 6: Original Input Image for Line Detection

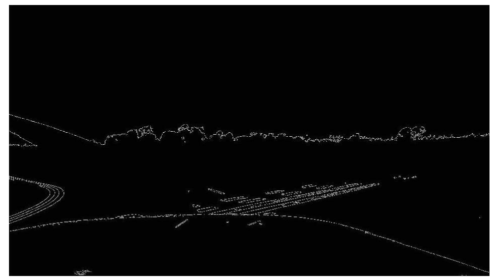

Fig. 7: Canny Edges

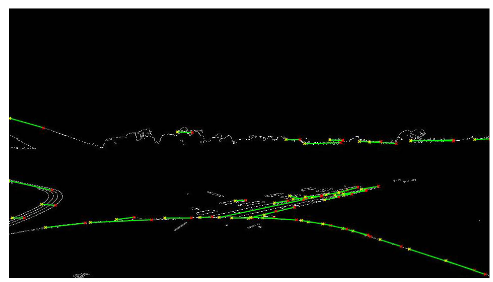

Fig. 8: Hough Straight Lines

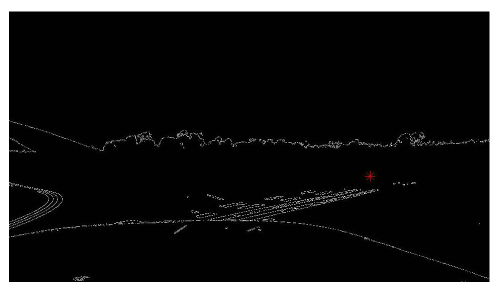

Fig. 9: Peak Point

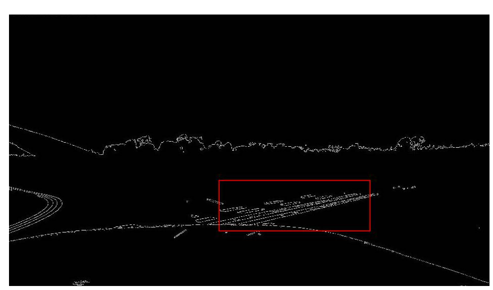

Fig. 10: Window for Midpoint Counting

Fig. 11: Display Line Detection Result

TABLE II: Hold-Short Line Detection Result

Accuracy = 89.2%	Line Present	Line Not Present	Precision
Line Detected	24	22	52.2%
Line Not Detected	2	175	98.9%
Recall	92.3%	88.8%	

The two algorithms detecting and recognizing runway holding positions signs and hold-short lines are combined together and they work seamlessly with each other. The display of two algorithms working together is shown in Figure 12.

Fig. 12: Display Line Detection Result

IV. Conclusion and Future Work

We have developed algorithms to detect and recognize runway holding position signs and runway hold-short lines with high detection recall and overall accuracy. It is important to notice that in our application, recall is of more importance than precision because that even though false positives may be annoying, false negatives could lead to accidents. In addition, our algorithms require no time in training and runs on the order of sub-second on each image.

Our approach can be further extended to detect other airport signs and markings of operation safety interest. We believe this a promising way to promote pilots' situational awareness when operating at complex major airports and enhance runway incursion avoidance. Future directions include: (1) Set up a database for airport signs and markings and combine feature-based methods to existing methods to enhance the robustness against perspective distortion, image blur, night operation and false positives caused by similar objects in the vicinity. (2) Expand the system's capability to detect airport location/direction signs, ILS hold-short lines, movement-nonmovement hold short lines and etc. (3) Implement these methods on a digital signal processor (DSP) to achieve efficient standalone airport signs and markings detection and recognition.

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References

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Appendix

Qinxia Wang:
Design, Implement and Test Runway Hold-Short Line Detection and Recognition

Huafei Wang:
Design, Implement and Test Runway Holding Position Sign Detection and Recognition, Images Collection

Data Source:
Images are obtained from a Cessna 172N at Palo Alto Municipal Airport (KPAO) by Huafei Wang using GoPro 4 Silver with 1 frame / 5 seconds and resolution 1920×1080 setting