A Comparison of Line Detection Methods for Power Line Avoidance in Aircrafts

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Abstract

Power lines constitute a great thread for aircraft flight safety. Digital camera based methods consider these power lines as digital lines and edges which are desired to be detected using line and edge detectors. EDLines, LSD and Hough Transform are the best line detection methods that are known in the literature. In this study, in order to determine the power lines for aircraft safety, methods of EDLines, LSD and Hough Transform are considered. The paper starts by briefly describing the methods, then continues with their performance analysis. Finally, the results are discussed. EDLines method is observed to provide higher accuracy among the three methods. In addition, it produces faster results. Consequently, EDLines method is expected to be widely used in aircraft safety applications.

1. Introduction

Use of helicopters for several urban operations such as search and rescue operations, firefighting, military necessity etc. has increased. Landing and close approaching ability of helicopters is the main reason of common usage. Therefore, the attention of researchers is increasing day by day [1,2,3]. The capability of carrying useful load is limited for helicopters. For this reason, using computer vision systems for some applications such as power line detection, redound a low size, light and power saving computer system.

Helicopter pilots may not detect thin power lines easily when they fly low. Especially some parameters like weather condition, cloud amount, quantity of light make the power line detection problem harder for pilots. Various studies have been made for solving this problem [4,5,6,7,8]. Despite this, according the report issued by the USA armed forces emphasized that power lines underlie many of the helicopter crash [9,10,11].

In urban regions, power line detection gets more difficult because of trees, buildings, shadows which align in the flyway of helicopter and has linear pattern. Therefore, an automated early notification system is of great importance. Helicopters fly at an average speed of 135 knots. The average total reaction time of helicopter and pilot is around 3 seconds in case of an emergency. Approximately, a helicopter covers a distance of 200 meters in 3 seconds. Thus, a reasonable system should be aimed to detect the power lines from at least 200 meters.

In this paper, EDLines, LSD and Hough Transform techniques are tested for detecting power lines to preserve aircrafts flying low in urban areas. Then, three methods' performances are compared.

2. Present Condition

Warning spheres are a popular solution. They have two contrasting colors and weigh about 4 kg, located on power lines. They decrease aircraft crash rate by reason of power lines. However, the aircraft crash rates due to cable hitting proves that this precaution is not sufficient. Computer aided warning systems are a must.

Fig. 1. Warning sphere [8].

3. Imaging and Detection Systems

Imaging technologies cannot be substituted for radar, navigation and object definition based sensor systems. However, imaging technologies can be used for acquiring additional data when unsuitable weather conditions occur. Under those conditions, visual contrast may be too low for the pilot to distinguish background color and object color.

Infrared and laser systems are two sensor based electric power line detect systems. Although, high resolution cameras are used to help pilots, they are not sufficient for automatic target tracing systems. For this reason, infrared camera systems may be used for detecting objects with different temperatures. Nevertheless, they are not very suitable for thin objects (like power lines). Laser systems are also too susceptible to atmospheric effects [12]. Moreover, this type of systems have quite limited reliability in good weathers.

Generally, image processing algorithms give better results when image includes simple background. Yet, image processing algorithms which ensure aircrafts to fly snugly have to assure accurate, rapid and exact results.

Line segmentation algorithms are used widely in image processing, image compression [13], detecting fracture in metal [14], stereo comparison [15], robot navigation [16,17], image segmentation and image restoration, etc. Ideal line segmentation algorithms provide fast, precise and accurate results, especially in real time applications, regardless of the size of image and direction. Also, these algorithms have to ensure working for all kinds of image formats without the need of parameter setting.

Conventional line segmentation algorithms use Canny [18] edge map detector firstly to find edge map. Secondly, Hough transform is implemented over the edge map [19,20]. After this stage, persistent length lines, which involve a certain number of edge points, occur. After this, these lines are segmented again using peak and length sensibility values.

Hough Transform has many variants such as “Randomized Hough Transform”, “Progressive Hough Transform”, “Elliptical Gaussian Kernel Hough Transform” [21]. All of these types are different forms of Hough Transform. A clear edge map is critical for these techniques that the parameters, cannot be determined automatically, have to be adjusted by the user. Also, these methods’ run times are too long.

Etemadi [22] suggests a line segmentation detector that can determine all segmentations of lines without depending on any parameter. Burns and friends [23] propose a detector merging pixels having the same orientation. All of these methods are successful, but if the background of the image is noisy and involving lots of trees, buildings or farms, the probability of false alarm increases.

Desolneux and friends [24] suggest a line segmentation detector which can restrict ‘false alarm’ potentiality without depending on any parameter. This detector, uses Helmholtz principle [25], calculates pixel numbers towards a given direction, and presumes them as line segment the pixel set. Weak point of Desolneux method is its computational complexity depending on generated long lines.

Von Gioi and friends [26, 27] use Helmholtz principle with Burn and his friends’ study to generate straight line segmentation, which generates line segments while limiting the number of errors. The name of that detector is Line Segmentation Detector (LSD) [28]. LSD is a unsupervised line segment detector. Also made in the error control. Although LSD produces good results for some images, mainly produces low-accuracy results in images that is contain a high proportion of white noise.

EDLines [29] is a new line detector which is using edge information in image. Experiments indicate that EDLines is fairly quickly produces high precision results and also is robust to noise. EDLines, three main phases occur: (1) Edge Drawing (ED) [30], (2) Line Detection and (3) Line Validation

3.1. Edge Drawing (ED) Algorithm

The edge detection process is carried out in four stages. First, image smoothing process is made with 5x5 Gaussian kernel. In the second step, the gradient strength and direction are calculated using the Sobel operator for each pixel. After this traditional steps, a new edge detection method is applied for detect to edge points. In the last step, this the edge points are connected.

$$g_x(x,y) = \frac{I(x+1,y)-I(x,y)+I(x+1,y+1)-I(x,y+1)}{2}$$

$$g_y(x,y) = \frac{I(x,y+1)-I(x,y)+I(x+1,y+1)-I(x+1,y)}{2}$$

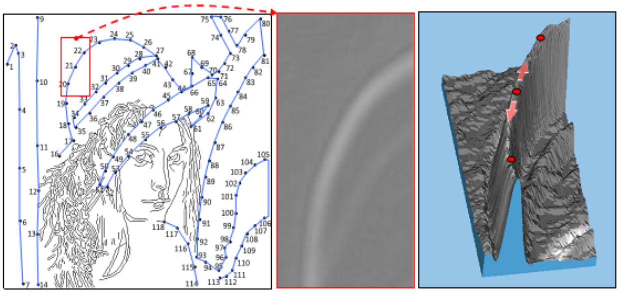
$$g(x,y) = \sqrt{g_x^2(x,y) + g_y^2(x,y)}$$

$$angle(x,y) = tan^{-1}\left(\frac{g_y(x,y)}{g_x(x,y)}\right)$$

Where I(x,y) the intensity of each pixel at the coordinates of (x,y), g(x,y) is gradient strength and angle(x,y) is the slope angle of each line. Using the gradient strength, direction map is calculated for each pixel. If $x < y$, edge passes in the horizontal direction, $x > y$, edge passes in the vertical direction.

3.1.1. Anchor Detection

Using gradient map calculated in the previous step, the name is anchor which is given to the local maximum in the gradient map. As shown in figure 2, edge segments drawing is passing through the anchor point.

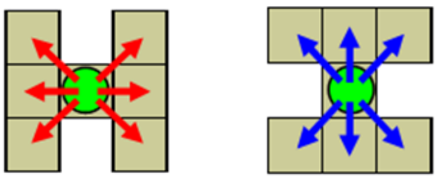


(a) (b) (c)

Fig 2. (a) Lena’s edge map. (b) A patch from the gradient map of Lena’s hat. (c) The 3D illustration of the patch in (b). [29].

3.1.2. Anchor Connection

Edge Drawing start from any anchor point. The direction of progress is determined by the gradient direction. As seen in figure 3(a), if a horizontal edge goes from an anchor point, shall continue to progress the horizontal direction. Similarly, as seen in figure 3(b), if a vertical edge passing an anchor, progress in the vertical direction.



(a) (b)

Fig 3. (a) Horizontal proceeding, (b) Vertical proceeding [29].

If during the progress, image limits are exceeds or coincides to another anchor, progress is stopped and it starts again from the new anchor. This process is continued until all anchor are processed.

3.2. Line Segment Extraction

"Least Squares Line Fittings" method is used to obtain line segments from the edge segments. Each line segment is determined to exceed the 1-pixel error. If pixel error exceeds 1 pixel, algorithm starts to produce a new line segment.

3.3. Line Validation

Helmholtz Principle used to line validation step. "Number of False Alarms (NFA)" is calculated for the each edge segment. "n" is length of edge segment and "k" is number of edge pixel for this edge segment, NFA

$$\mathrm{NFA}(\mathrm{n},\mathrm{k}) = \mathrm{N}^4 \sum_{\mathrm{i}=1}^{\mathrm{n}} \binom{\mathrm{n}}{\mathrm{i}} \mathrm{p}^{\mathrm{i}}(1\text{-}\mathrm{p})^{\mathrm{n}\text{-}\mathrm{i}} \leq \mathcal{E}\,(1) \qquad (25)$$

is defined. Where N^4, the maximum number of lines that can be found in an image of nxn size, p is the probability for each line in an image of nxn size and n defines the number of different angles for each line segment. In this case, there are eight different angles for each pixel (n=8, p = 1/8) for each anchor point.

4. Image Database and Experimental Set-up

Database includes photos of 29 cases of obstacles (i.e. power lines). Each picture is taken by different cameras from different angles under unequal weather conditions and various sizes. The cases are also selected to increase variations. Some photos are shown in figure 4.

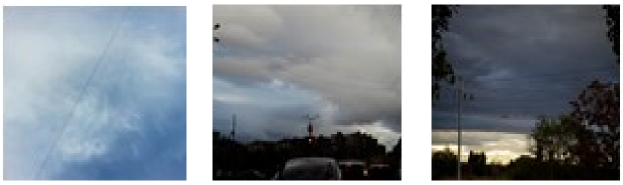


Fig 4. Example power line photos

The quantitative measures for line detection are selected as standard values, such as "accuracy", "precision", "recall", and a combined F-score. According to True Positive (detect - TP), True Negative (detect - TN), False Positive (false alarm - FP) and False Negative (miss - FN) values, these parameters are defined as:

$$accuracy = \frac{TP + TN}{TP + TN + FP + FN}$$

$$precison\ (P) = \frac{TP}{TP + FP}$$

$$recall\ (R) = \frac{TP}{TP + FN}$$

$$F - Score\ (FS) = 2 * \left(\frac{P * R}{P + R}\right)$$

5. Comparison and Experimental Results

EDLines, LSD and Hough Transform algorithms in image database (number of 29) has been applied and the determined the accuracy percentage and average detection times are shown in figures 5 and 6. In these figures, the horizontal axes correspond to the used image and the vertical value corresponds to the performance. In figure 5, EDLines (the blue labelled values) method seems to consistently perform among the top accuracy values. Meanwhile, in figure 6, the same blue labels clearly show that the run-time of EDLines is the shortest among these methods. Some example performance results are shown in figure 7. Again, the leftmost column results (corresponding to EDLines) give the best accuracy with the least false positive and shortest run-time. As a result, in systems where speed and accuracy is important for aircraft systems, EDLines method have been found to provide a more robust performance.

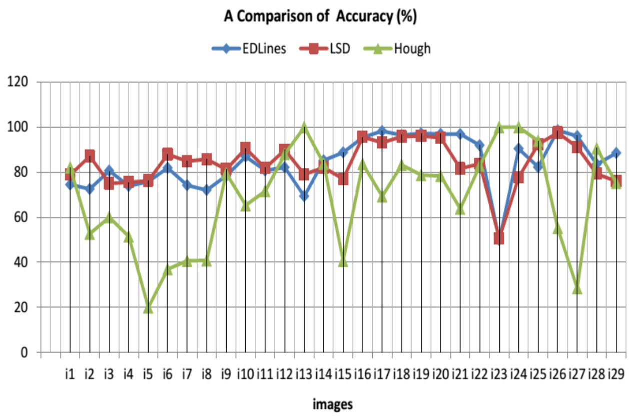


Fig 5. A Comparison of Accuracy (%)

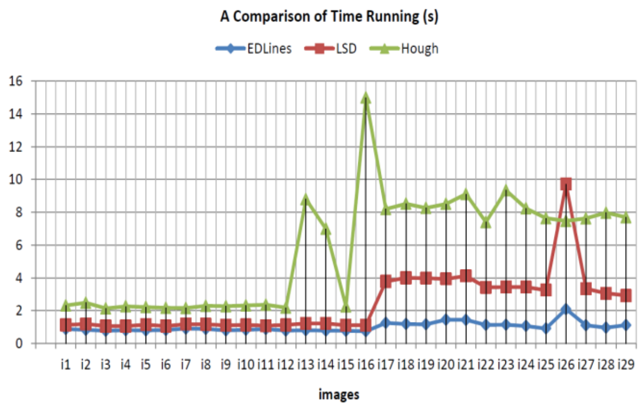
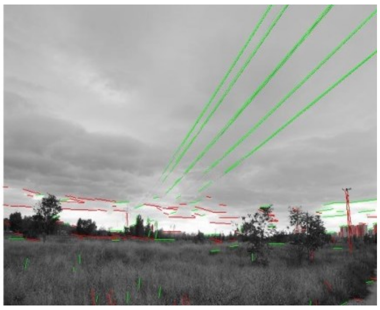
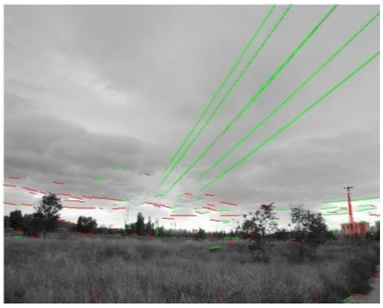
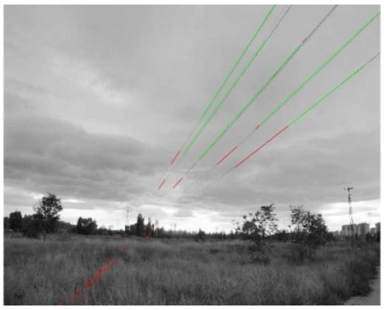


Fig 6. A Comparison of Run Time (second)


EDLines (74.51-0.88-1024x768)

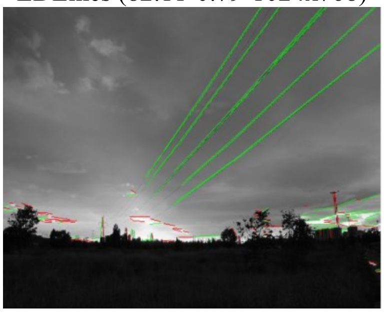

LSD (78.87-1.13-1024x768)

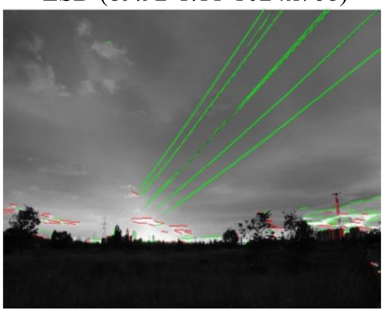

Hough (82.05-2.31-1024x768)


EDLines (82.11-0.79-1024x768)

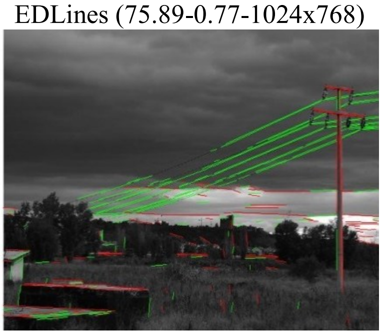

LSD (89.92-1.11-1024x768)

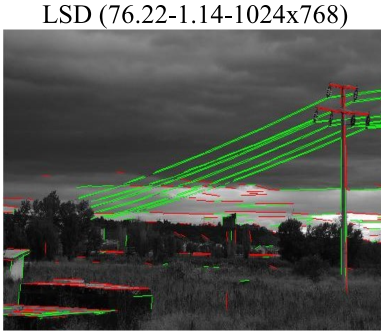

Hough (88.00-2.18-1024x768)

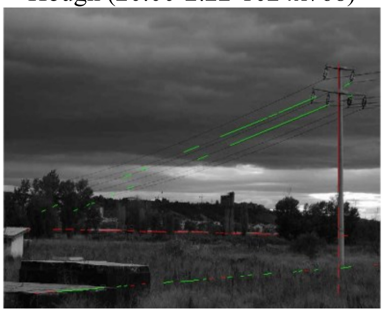

EDLines (75.89-0.77-1024x768)

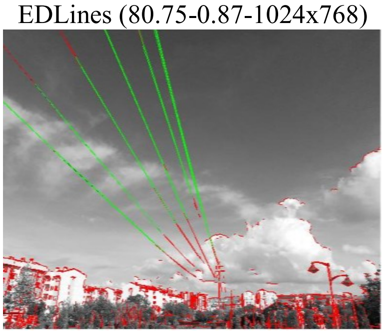

LSD (76.22-1.14-1024x768)

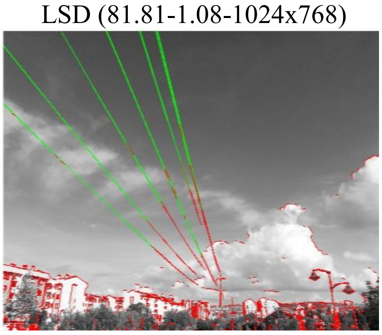

Hough (20.00-2.22-1024x768)


EDLines (80.75-0.87-1024x768)


LSD (81.81-1.08-1024x768)


Hough (71.64-2.36-1024x768)


EDLines (88.76-0.78-1024x768)


LSD (76.97-1.09-1024x768)

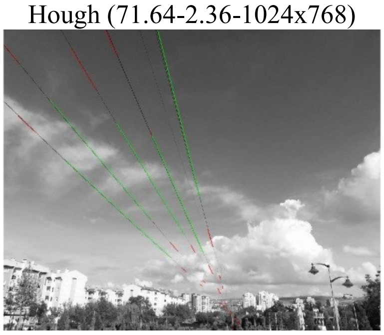

Hough (40.74-2.25-1024x768)

Fig 7. Sample results (Accuracy (%), Time (second), Size (row x column)

6. References

[1] Muratet, L., Doncieux, S., Briere, Y. ve Meyer, J., "A contribution to vision-based autonomous helicopter flight in urban environments", Robotics and Autonomous Systems, vol. 50, pp. 195-209, 2005.

[2] Singh, L., Fuller,J., "Trajectory generation for a UAV in urban terrain, using nonlinear MPC", Proc. American Control Conf., pp. 2301–2308, 2001.

[3] Sarbandi, K., Pierce, L., Oh, Y. and Ulaby, F.T., "Power lines : Radar measurements and detection algorithm for polarimetric SAR images", IEEE Transactions on Aerospace and Electronic Systems, 30, 2 (1994), 632-643.

[4] Gandhi, T., Yang M. T., Kasturi, R., Camps, O., Coraor, L. and McCandless, J., "Detection of obstacles in the flight path of an aircraft", IEEE Trans. Aerospace and Electronic Systems, vol. 39, no. 1, pp. 176–191, 2003.

[5] Yang, M. T., Gandhi, T., Kasturi, R., Coraor, L., Camps, O. and McCandless, J., "Real-time obstacle detection system for high speed civil transport supersonic aircraft", Proc. of the National Aerospace and Electronics Conf., pp.595–601, 2000.

[6] Kasturi, R., Camps, O., Huang, Y., Narasimhamurthy, A. and Pande, N., "Wire Detection Algorithms for Navigation", Technical report, Dept. of CSE, The Pennsylvania State University, 2002.

[7] Avizonis, P., and Barron, B., "Low cost wire detection system", In digital Avionics Systems Conference, vol. 1, 1999, 3.C.3-1-3.

[8] Yetgin,O.E and Gerek,O,N., "Cable and Wire Detection System for Aircrafts", Signal Processing and Communications Applications Conference (SIU), 2013.

[9] Savan, M., and Barr, D.N., "Reflectance of wires and cables at 10.6 micrometer", Center for Night Vision and Electro-optics, MSEL-NV-TR-0063, 1988.

[10] Demonceaux, C., Vasseur, P. and Pegard, C., "UAV Attitude Computation by Omnidirectional Vision in Urban Environment", Rob. Automat., pp. 2017-2022, 2007.

[11] Arnold, J.; Shaw, S.W. and Pasternack, H.; "Efficient target tracking using dynamic programming", IEEE Trans. Aerospace and Electronic Systems, vol. 29, no. 1. pp. 44–56,1993.

[12] Ji, C.X. and Zhang, Z.P., "Stereo Match Based On Linear Feature", International Conference on Pattern Recognition, pp. 875-878, 1988.

[13] P. Franti, E.I. Ageenko, H. Kalviainen, and S. Kukkonen, "Compression of Line Drawing Images Using Hough Transform for Exploiting Global Dependencies," Int. Conf. on Inf. Sci., 1998.

[14] S. Mahadevan, and D.P. Casasent, "Detection of Triple Junction Parameters in Microscope Images," Proc. of SPIE, pp. 204-214, 2001.

[15] C.X. Ji and Z.P. Zhang, "Stereo Match Based On Linear Feature," International Conference on Pattern Recognition, pp. 875-878, 1988.

[16] P. Kahn, L. Kitchen, and E.M. Rieseman, "A Fast Line Finder for Vision-Guided Robot Navigation," IEEE Transactions on Pattern Analysis and Machine Intelligence, vol. 12, no. 11, pp. 1098-1102, November 1990.

[17] P. Kahn, L. Kitchen, and E.M. Rieseman, "Real-Time Feature Extraction: A Fast Line Finder for Vision-Guided Robot Navigation," Technical Report 87-57, COINS, 1987.

[18] Canny, J., "A Computational Approach to Edge Detection", IEEE Transactions on Pattern Analysis and Machine Intelligence, vol. 8, no. 4, pp. 679-698, November 1986.

[19] Duda, R.O. and Hart, P.E. "Use of Hough Transformation to Detect Lines and Curves in Pictures", Communications of the ACM, vol. 15, pp. 11-15, January 1972.

[20] Kalviainen, H., Hirvonen, P. and Oja, E., "Houghtool –A Software Package for the use of the Hough Transform", Pattern Recognition Letters, vol. 17, no. 8, pp. 889-897, 1996.

[21] Matas, J., Galambos, C. and Kittler, J., "Robust Detection of Lines Using the Progressive Probabilistic Hough Transform", Computer Vision and Image Understanding, vol. 78, no. 1, pp. 119-137, 2000.

[22] Etemadi, A., "Robust Segmentation of Edge Data", Int. Conf. on Image Processing and its Applications, pp. 311-314, 1992.

[23] Burns, J.B., Hanson, A.R. and Riseman, E.M., "Extracting Straight Lines", IEEE Transactions on Pattern Analysis and Machine Intelligence, vol. 8, no. 4, pp. 425-455, July 1986.

[24] Desolneux, A., Moisan, L. and Morel, J.M., "From Gestalt Theory to Image Analysis : A Prob. Approach", Springer, 2008.

[25] Desolneux, A., Moisan, L. and Morel, J.M., "Meaningful Alignments", International Journal of Computer Vision, vol. 40, no. 1, pp. 7-23, 2000.

[26] von Gioi, R.G., Jakubowicz, J., Morel, J.M. and Randall, G., "LSD : A Line Segment", Technical Report, Centre de Mathematiques et de leurs Applications (CMLA), Ecole Normale Superieure de Cachan (ENS-CACHAN), 2008.

[27] von Gioi, R.G., Jakubowicz, J., Morel, J.M. and Randall, G., "On Straight Line Segment Detection", Journal of Mathematics Imaging and Vision, vol. 32, no. 3, pp. 313-347, November 2008.

[28] von Gioi, R.G., Jakubowicz, J., Morel, J.M. and Randall, G., "LSD : A Fast Line Segment Detector with a False Detection Control", IEEE Transactions on Pattern Analysis and Machine Intelligence, vol. 32, no. 4, pp.

[29] Akinlar, C., Topal, C.,"EDLines: A real-time line segment detector with a false detection control", Pattern Recognition Letters, pp. 1633–1642, 2011.

[30] Topal, C., Akinlar,C., "Edge Drawing: A combined real-time edge and segment detector", Journal of Visual Communication and Image Representation, pp. 862–872, 2012.