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Power line detection using a circle based search with UAV images

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***Abstract*— A new method for power line detection based on computer graphics algorithms is presented. The algorithm uses geometric relationships that are inherent to the circle symmetry. The method detects line segments that are linked in a posterior stage. For the detection, we use Canny and Steerable Filters. We developed two tests for validating the proposed approach. The first one uses synthetic images and the second one real power line images taken from UAVs. The results show that this method is not only efficient for line detection, but it also takes compared with state of the art algorithms a short computing time without the use of a GPU approach.**

I. INTRODUCTION

Power line detection is an important task in the inspection of electrical infrastructure prior to maintenance, for this reason, there exists interest in developing methods that reduce costs, risks and the logistic problems of manual inspection including manned flights [15], [11], [18] by using UAVs [22]. The UAVs can be used for capturing images from different views that have to be processed in order to detect power lines [13].

There exist different methods for line detection that have been used in power line detection from UAV images. They are based on edge and ridge detectors, magnitude and gradient orientation, voting schemes, line support regions, growing regions and chain codes [12], [6], [3], [9], [1], [23].

The typical procedure for line detection is to do a segmentation prior to the application of line detection. A good method for edge detection is the Canny Filter [4] which is commonly used together with a different line detection method. The classical method for line detection is the Hough transform [12], [6] which can detect lines in well contrasted and segmented images. This method was used in combination with a PCNN (Pulse-Coupled Neural Network) for removing background and clustering for power line detection [14]. In the work of Zhang [24], a process for power line detection based on Hough transform with Kalman filter is presented. In this case they use the Otsu threshold method obtaining better results than with PCNN filters.

There are other approaches for line detection based in gradient extraction stage used to find the more relevant changes present in images. Usually, these kind of approaches use a filter like Prewitt, Sobel, or Scharr.

More accurate and faster methods than the Hough transform have been developed. In the work of Burns [3], a straight line detection method based in gradient information and line support regions is presented.

Another relevant work is the Line Segment Detector (LSD) that uses growing regions and a method for the consideration of false alarms [8]. It can detect lines with a high level of accuracy, but it takes more computing time than Hough.

One of the best line detection methods, is the Edge Drawing Lines (EDLines) [1]. This method is based in Edge Drawing (ED) [21], which is used for fast edge detection and least squares line fitting. The results show that EDLines is faster than LSD with similar results in terms of lines detected.

Methods for line detection based in other kind of filters have also been developed. For example, the steerable filters have been used in order to obtain ridge detection. They are very useful for detecting power lines from UAV images [17]. According to these authors, the process take less time that LSD and EDLines but it requires GPU processing [16].

It is good to mention that some works of line detection have a post processing stage for connecting line segments or cluster interest lines [24], [17]. Recently, a method for line detection based in region growing, ridge filters and chain codes was developed in [23], but results in relation with processing time were not presented. Although many algorithms for drawing of lines and circles have been developed, such as Digital Differential Analyzer (DDA), Bresenham Line and mid-point [10], these are not related with the process of line detection.

In addition, there exist some works for Simultaneous Location and Mapping (SLAM) based on line feature detection [5]. In this case they use a constrained Hough Transform for line detection and an Extended Kalman Filter (EKF) for estimate line position accurately. Another interesting work is a SLAM based on a Rao- Blackwellized particle filter (RBPF) and an iterative end point fitting (IEPF) for line extraction. [2].

In this work, we propose a method for power line detection based on the search of lines between two opposite points. This is done by using computer graphic primitives which are efficient for drawing circles. This method is different from previous ones since it is based in geometric relationships and does not use gradient information. We call this method Circle Based Search (CBS). In addition, we add a procedure for connecting contiguous segments in order to detect longer lines.

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This paper is organized as follows: Section 2 shows filters used for power line segmentation, Section 3 presents the circle based search process for detection of valid points in lines, Section 4 explains the algorithm for line detection, Section 5 presents a detailed view in order to validate the method, Section 6 presents the results, and finally, Section 7 presents the conclusions and future work.

II. SEGMENTING STAGE

Canny Filter

The Canny filter has been used for edge detection in different applications of machine vision [4]. It has been used in the power line detection process [14], [24]. The main advantage is that it takes a short computing time during segmenting. A disadvantage of this method is that when it is used for detecting thin elements like a power line, it may detect two edges in both sides of the power line.

Steerable Filter

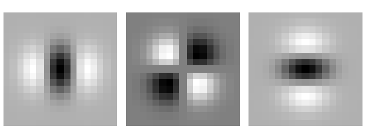
The steerable filters have been developed by Freeman [7]. These filters allow the use of rotated versions of Gaussian function based filters. The purpose of these filters is to obtain more energy points by applying them with different angles [17].

In this case, the second derivative of a Gaussian kernel is used.

$$G(x,y) = e^{\frac{x^2+y^2}{2\sigma^2}}. \quad (1)$$

This is a two-dimensional circularly symmetric Gaussian function in Cartesian coordinates x and y, where σ is the standard deviation which depends on the line's width [20].

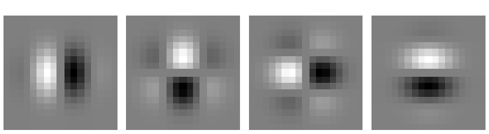
The second derivatives $G_{2i}(\theta)$, are computed for three rotations to obtain a basis in order to compute the filter rotation in every angle by using an interpolation [7]; see Figure 1.



(a) Ga (b) Gb (c) Gc

Fig. 1. Base filters G_2

For the quadrature filter, the Hilbert transform of the Gaussian derivatives is used; see Figure 2.

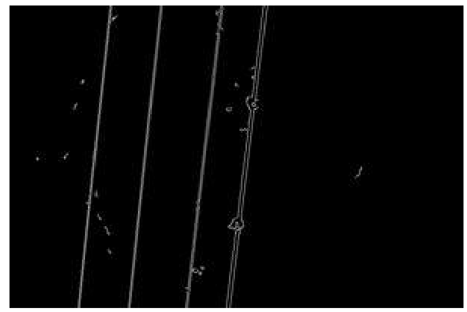


(a) Ha (b) Hb (c) Hc (d) Hd

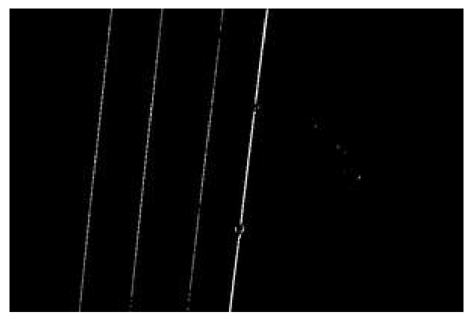
Fig. 2. Base filters H_2

By using steerable filters, it is possible to obtain the oriented energy and ridge energy in each pixel of the image. This has been used for segmented power lines in noisy images [17]; see Figure 3.

(a) Original



(b) Segmented with Canny



(c) Segmented with Steerable Filters

Fig. 3. Filters for power line segmentation.

III. CIRCLE BASED SEARCH (CBS)

Most of the image processing approaches for line detection are based on convolution kernels (filtering) and neighbour operations (connected components). Nevertheless, in order to develop a line detection approach based in a local search, it may be useful to perform an extended search rather than an eight pixel neighbourhood search. This search may begin from a pixel that belongs to a line. We found a way to use several computer graphic algorithms for primitive efficient drawing in order to perform extended comparisons in bigger neighbourhoods, and for validating the error in lines detected. In this work, we use the circle contour (Figure 4) and its symmetry to search for valid points that belong to a line in segmented images. In this case, we use the Bresenham algorithm [10].

Efficient raster circle drawing algorithms are based on their inherent octant symmetry (see Figure 5). These allow to paint a whole circle by rounding an octant. For example, from $(0, r)$, to $(\frac{\sqrt{2}}{2}r, \frac{\sqrt{2}}{2}r)$ each point (a, b) is converted to eight points by reflecting in the principal axes and in the diagonals

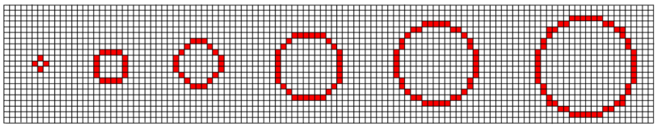


Fig. 4. Raster circles of different sizes.

($y = x$ and $y = -x$).

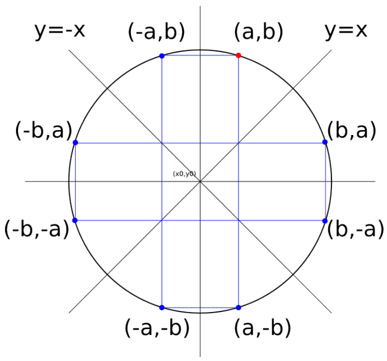


Fig. 5. Octant circle symmetry.

Additionally, this symmetry can be used to detect if two opposite points belong to a line. In Figure 6, different synthetic lines are shown, and in Figure 7 the detection of the valid point is shown. In order to have greater confidence in the detection, it is necessary to search for how many points that belong to a straight line are presented between these two opposite points.

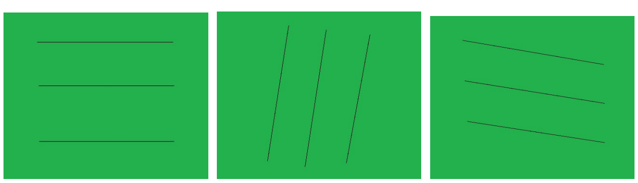


Fig. 6. Synthetic images for first test

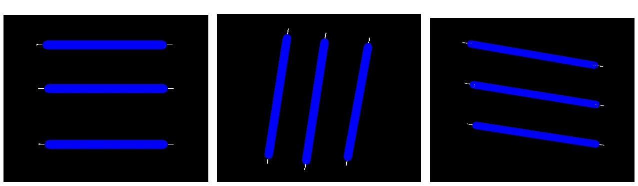


Fig. 7. Result for the obtaining of the valid point in synthetic images

IV. ALGORITHM

This algorithm allows us to detect valid points of lines. A valid point is defined as the center of a circle of searching in which it is possible to find two equidistant points that belong to a line (see Figure 8). By using a circle drawing algorithm, it is possible to detect valid points in lines. In Figure 9, some cases are shown, but the precision depends on the radius selected. For this reason, the process requires a radius with enough length to draw a circle in a grid. For example, the circles drawn in Figure 4 have different pixels radius.

CBS Line detection process

The process comprises the following stages:

- To segment the image with an edge detector, the Canny or a Steerable filter may be used.
- For all pixels in the image that are different from the background:
  1) Search for valid points by using a circle drawing algorithm.
  2) If it is a valid point, obtain the value of Dx and Dy (see Figure 8).
  3) Move along the direction of symmetry by using the values of (Dx, Dy).
  4) While (A valid point is found):
     – Move the position (x, y) to the values of $(x + skip \cdot Dx, y + skip \cdot Dy)$.
     – Search for valid points by using a circle drawing algorithm.
  5) Save the first and the final point.
  6) Trace a line between the first and the final point in order to erase the pixels associated to the line in the segmented image.

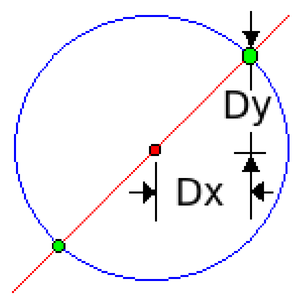


Fig. 8. Valid point.

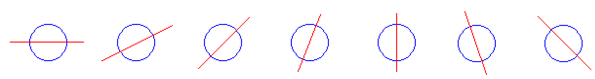


Fig. 9. Different angles of lines.

The main parameters of this method are the following:

- Search radius: This is the radius of the circle which depends on the length of the line and the size of the image. For instance, in Figure 4, we can see discrete circles of different radius. When the radius of the circle is increased, it allows to have more possibilities for evaluating angles of the line defined with more precision by its symmetrical points.
- Percentage of points detected: When a valid point is selected, it is necessary to take into account how many

points are found in a straight line between its two end points. The points are obtained by using computer graphic primitives for line tracing such as DDA or Bresehnham [10].

- Skip value: This is an increment of skip from a valid point to another. It has a way to control the velocity of the process and the accuracy. This value can be near to the circle diameter.

Linking

According with [16], there exists a set of features based on the Gestalt principals [19] that can determine if a segment is contiguous to another and can be linked in order to form longer lines.

In this case, we use the following:

- Similarity: We use the angle of the lines based in the distance of a point to a line.
- Length: The process gives priority to longer lines, since power lines are commonly the longest lines in the scene.
- Proximity: If two lines are close enough and are similar, they can be replaced by only one. The euclidean distance between its points has to be computed.

After the linking process the algorithm produce a set of lines detected. In this set, the lines are represented with the initial (x_i, y_i) and the final points (x_f, y_f).

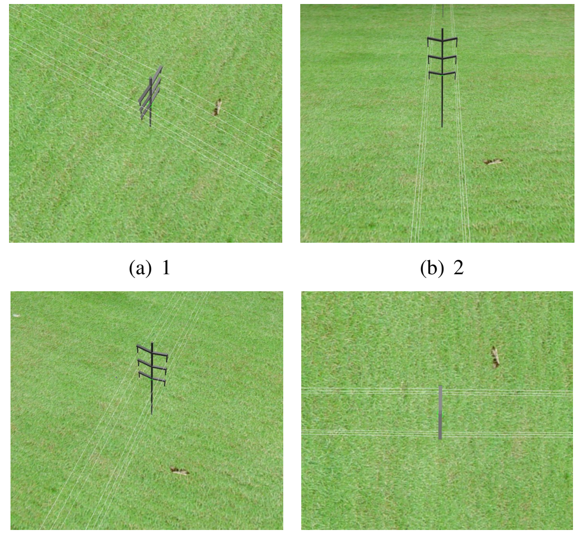
- The length of the line. It is expected that the longest lines detected after the linking stage presented at the scene are probably the power lines.
- The direction with more amount of long lines.
- The structure of the lines. They must be located in a group of parallel lines that has a symmetrical arrangement. It means that the distance between lines remain proportional from an azimuthal view.

V. EXPERIMENTAL SETUP

In this work, we developed two tests. The first one is done with synthetic images. The second one is done with real images. In these tests, we use a Canny filter. For this process, we compute the detection with different radius. We use a computer Asus G53X with a processor Core i7, 8GB of RAM and Ubuntu 12.04.

A. Synthetic images test

We use a set of synthetic images with lines in different inclinations (see Figure 6). The purpose is to evaluate the level of detection with different radius of circle in the line detection method. Also, a regular radial pattern was created in order to evaluate and compare the performance of the proposed method with lines of different angles. In this case, we evaluate the range of $[0, 2\pi]$ with increments of $\pi/16$ (see Figure 13(a)). Additionally, a three dimensional model of the power lines was built in order to generate synthetic images of the power lines with different points of view (see Figure 10).



(a) 1 (b) 2 (c) 3 (d) 4

Fig. 10. Simulated images of power lines in a 3D enviroment.

B. Real images test

For the second test, we use a set of images of power lines in structured environments in order to compare the performance and computing time of the different line detection methods.

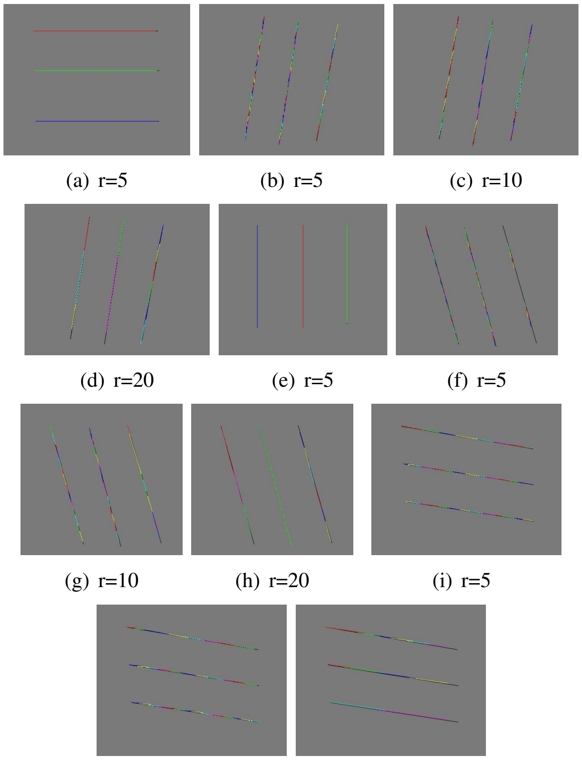
In first instance, a Canny detector was used; after that, a steerable filter was used.

VI. RESULTS

For the synthetic images test, we observed that the performance depends of the radius which needs to be long enough and also depends on the line length. In this case, we observed that it is possible to detect contiguous lines with a radius of 5 pixels, but the performance is improved with a radius increment to 10 and 20 pixels. This is shown with segments of different color that represent the detected lines. It is good to mention that the color of the lines is random and its purpose is to differentiate the segment detected. The best results in terms of continuity are obtained with a radius of 20 pixels for the evaluated images since the amount of segments is reduced. In this test, we used images of 390 $\times$ 317 pixels. The results of synthetic images are shown in Figure 11.

Although the detection by using a small radius creates many contiguous segments, the implemented process of linking allows to overcome this situation. This improves the performance of the proposed method (see Figure 12 and 13(f)). It is important to note that for vertical or horizontal lines (Figures 11(a) and 11(e)) the radius size has no important effect in generating line segments and a linking stage it is not required.

In the test of the radial pattern, we used two consecutive searches. The first search with a radius of r pixels and the second with a radius of $r - 4$ pixels in order to detect all possible lines. We obtained good results with $r = 11$ and $r = 15$ pixels for this pattern. The results of this test are



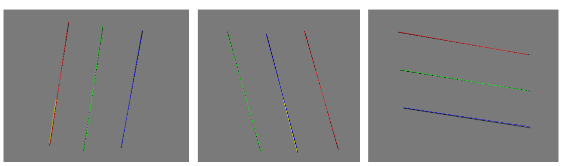
(a) r=5 (b) r=5 (c) r=10

(d) r=20 (e) r=5 (f) r=5

(g) r=10 (h) r=20 (i) r=5

(j) r=10 (k) r=20

Fig. 11. Result of detecting lines in synthetic images



(a) Linking of figure 11(a) (b) Linking of figure 11(f) (c) Linking of figure 11(i)

Fig. 12. Result of linking segments of some images of figure 11.

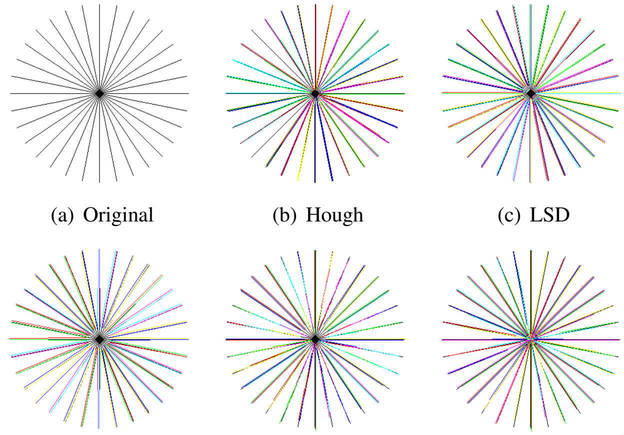
shown in Figure 13. In Figure 13(f), the linking stage is shown, and, as it can be seen, the result is improved. We can observe that two lines were not detected by Hough. Also, the lines detected by CBS were very near to the original pattern.

In Figures 14, 15, 16 and 17, the results for images of a 3D environment are shown. It is important to mention that by using virtual environments, it is possible to create different configurations of the scene for validating computer vision techniques. As we can see, the performance of the CBS is good due to the fact that it detects longer lines.

We achieve a result similar to EDLines in terms of time and lines detected, (See Table I).

For real images, we used 20 images (see Figure 18) and we obtained good results with our line detection method in different situations. In Figures 19, 20, 21 and 22, the results of comparing different line detection methods for four images are shown. In this case, we used a Canny filter for segmentation.

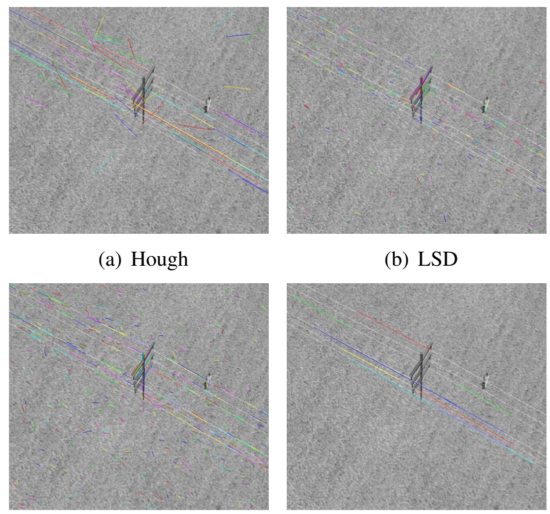
On the other hand, we used a combination of steerable filters and the CBS method for evaluating different radius.



(a) Original (b) Hough (c) LSD

(d) EDLines (e) CBS (f) Linking

Fig. 13. Comparison of performance with radial lines with an increment of $\pi/16$.



(a) Hough (b) LSD

(c) EDLines (d) CBS

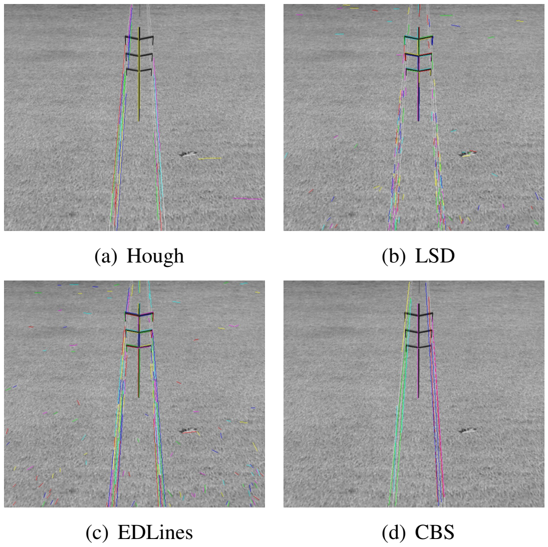
Fig. 14. Comparison between different methods for the image in the Figure 10(a).

The results are shown in the Figure 23 and 24.

Results show that the amount of lines detected by CBS are superior than when using the Hough transform and similar to the ones when LSD and EDLines are used.

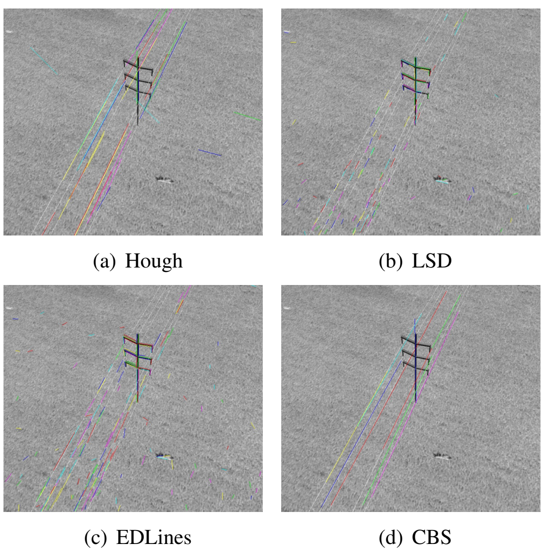
As a result, we can see that there exists a relation between the radius selected, the width of the line and the size of the image. For example, in images of a small size (308×360) with line size near to 300 pixels of length, we obtain a good detection level with a radius of 15 pixels. Although for small size images with detailed objects it is necessary to use a radius from 3 to 5 pixels for detecting these details, for power lines it is not necessary since longer lines have to be detected. When a bigger image is processed (1188×756), a bigger radius can be used to get better detection or longer segments detected.

As shown in Table I, the CBS method has a better performance time than the Hough transform, and in some



(a) Hough (b) LSD (c) EDLines (d) CBS

Fig. 15. Comparison between different methods for the image in the Figure 10(b).



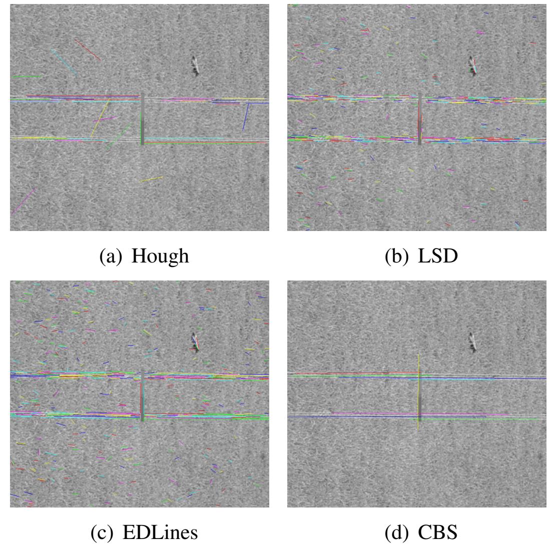
(a) Hough (b) LSD (c) EDLines (d) CBS

Fig. 16. Comparison between different methods for the image in the Figure 10(c).

cases it is better or close to EDLines. It is important to mention that when the radius is increased, this produces a longer arc in a search based circle. For this reason, our method takes more time for bigger images.

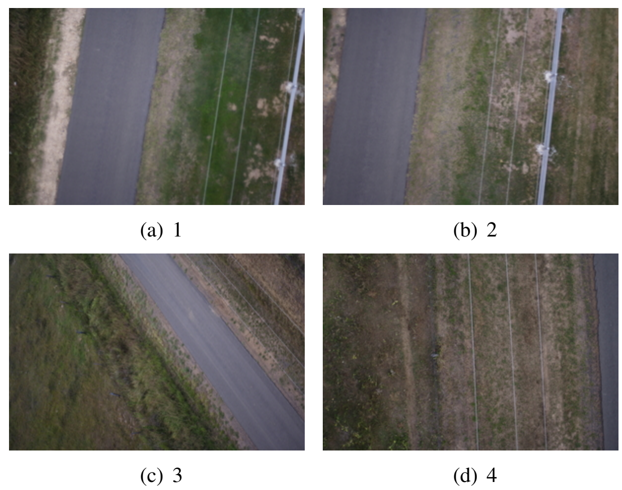
TABLE I
COMPUTATION TIMES

Image	Size	Hough	LSD	EDLines	CBS
13	333 × 333	21.1 ms	18.9 ms	5.22 ms	5.88 ms
11	390 × 317	8.7 ms	14.5 ms	3.5 ms	3.1 ms
19	800 × 533	8.69 ms	62.44 ms	6.12 ms	7.61 ms
20	800 × 533	11.41 ms	69.78 ms	6.80 ms	7.97 ms
21	800 × 533	11.83 ms	76.87 ms	6.12 ms	7.61 ms
22	800 × 533	11.41 ms	69.78 ms	8.50 ms	10.40 ms



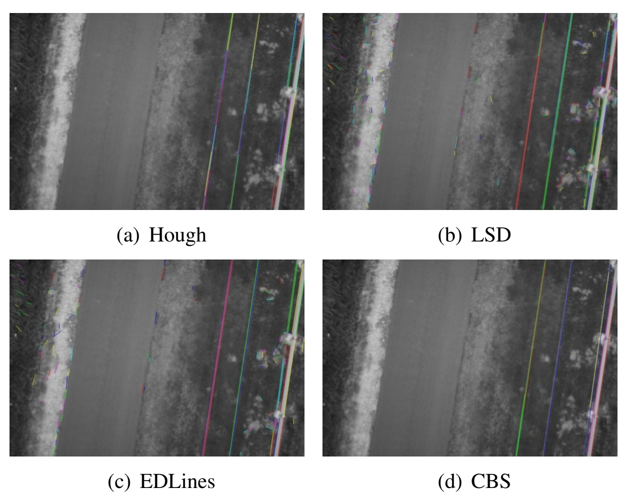
(a) Hough (b) LSD (c) EDLines (d) CBS

Fig. 17. Comparison between different methods for the image in the Figure 10(d).



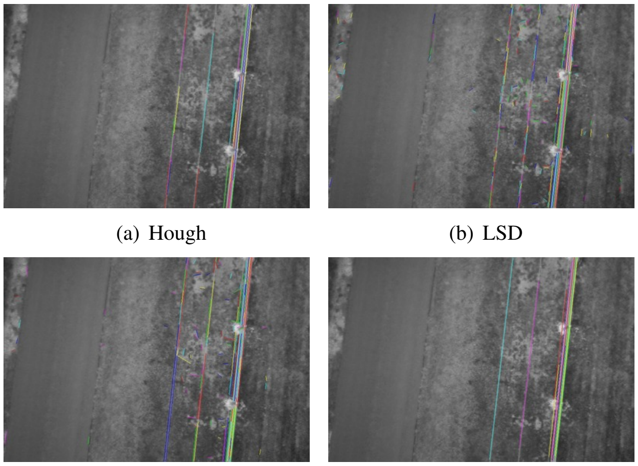
(a) 1 (b) 2 (c) 3 (d) 4

Fig. 18. Real images used in the second test with size of 800 × 533.



(a) Hough (b) LSD (c) EDLines (d) CBS

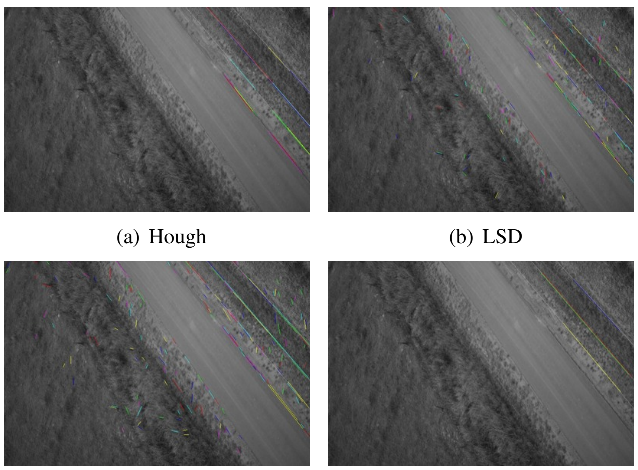
Fig. 19. Comparison between different methods for the image in the Figure 18(a).



(a) Hough (b) LSD

(c) EDLines (d) CBS

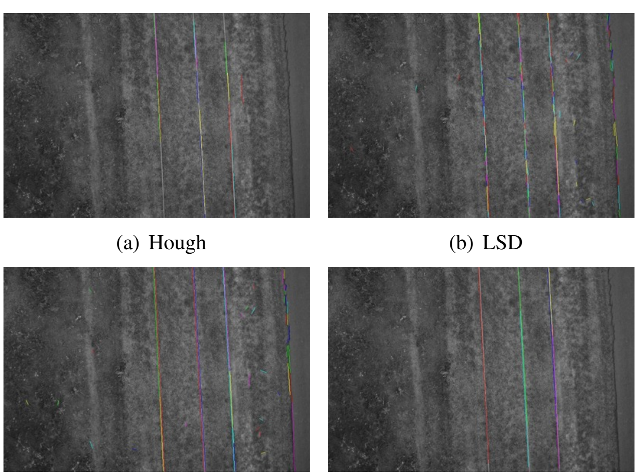
Fig. 20. Comparison between different methods for the image in the Figure 18(b).



(a) Hough (b) LSD

(c) EDLines (d) CBS

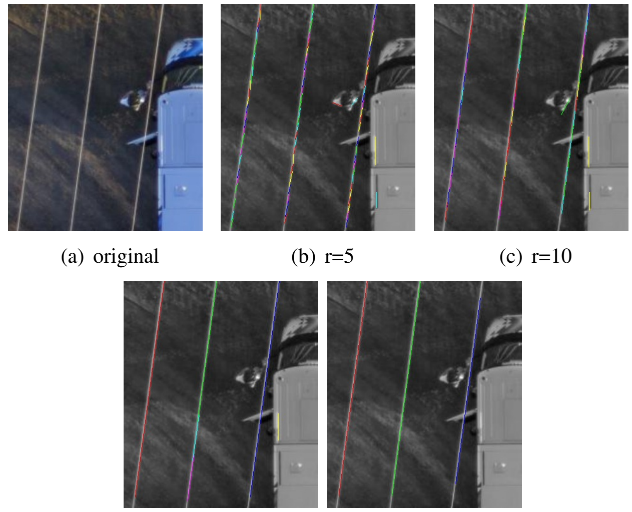
Fig. 21. Comparison between different methods for the image in the Figure 18(c).



(a) Hough (b) LSD

(c) EDLines (d) CBS

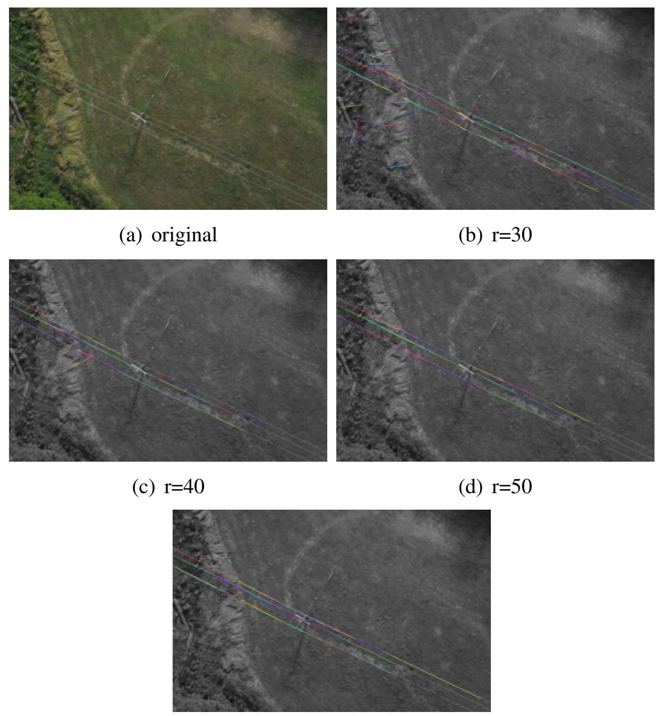
Fig. 22. Comparison between different methods for the image in the Figure 18(d).



(a) original (b) r=5 (c) r=10

(d) r=15 (e) r=20

Fig. 23. Result of detecting lines in real images using different radius and steerable filters in a small size image 308 $\times$ 360.



(a) original (b) r=30

(c) r=40 (d) r=50

(e) r=60

Fig. 24. Result of detecting lines in real images with different radius and steerable filters in a big size image 1188 $\times$ 756.

VII. CONCLUSIONS

The CBS is a new method for line detection that takes less time than Hough and LSD. The parameters of the method permit detecting lines in images with noise. In addition to this, it has a stage for connecting contiguous segments.

This method was validated using several test on real and synthetic images, obtaining satisfactory results in both cases. For synthetic images, we performed two tests: one that involved lines with different inclinations, and another one that involved lines with regular angles from 0 to 2π radians with increments of $\pi/16$.

For real image validations, we used a set of images of power lines with different inclinations taken from an UAV in an azimuthal view.

With the use of steerable filters, it is possible to obtain better results in segmentation of power lines, since only one edge is obtained, but a CPU implementation takes more time than Canny.

The proposed method detected power lines with good performance in comparison to the state of the art approaches. Even though, this method is not so accurate as EDLines or LSD for detecting short lines in complex scenes, it has good performance in scenes with longer lines. In addition, it is more suitable for power line detection in images of small size.

Another advantage is that CBS is easy to reproduce since it is based in circle drawing algorithms, like Bresenham or Mid-point. In consequence, the method uses integer math and can be suitable to be implemented in embedded systems without float point operations.

As a future work, we plan to improve the results obtained by adapting the parameters of the method in terms of best detection performance in complex environments, and implement a version of the detection method for parallel processing in GPU.

We expect to implement this process in an UAV simulator, after that in a real UAV for autonomous flight under controlled conditions.

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