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Application of single image geometric measurement algorithm in pipeline construction violation recognition and monitoring

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Abstract

In the pipeline construction site, the hot work of pipe cutting is often carried out. The safety distance between oxygen bottle and acetylene cylinder required for the pipe cutting is not less than 5m. In view of the safety working distance of oxygen cylinder and acetylene cylinder on the pipeline construction site, this paper uses UAV to inspect and detect the violation of construction rules based on geometric measurement of single image. Through the separation of the background of the image of Grabcut, the outline of oxygen cylinder and acetylene cylinder is separated from the complex environmental image. Canny edge detection and Hough linear detection algorithm are used， Edge line detected. Based on the distance measurement algorithm of single image, a priori knowledge base is established based on the structured scene of oxygen cylinder and acetylene cylinder, and the distance measurement between two cylinders is realized by taking its own as reference. Compared with the actual distance measurement results, the relative error is 10.3%, and the absolute error is less than 1m, which meets the requirements of illegal monitoring in pipeline construction site.

Keywords

Image background separation, straight line detection, projective transformation, distance measurement.

1. Introduction

With the development of natural gas and petroleum industry, the distance of pipeline transportation is getting longer and longer. Because of its flexibility and universality, fire welding is widely used in pipeline installation and maintenance. In the national standard GB50720-2011, "Technical Code for Fire Safety in Construction Sites of Construction Projects", it is stipulated: "Oxygen cylinders and acetylene cylinders in use should be vertically placed and fixed, and the distance between oxygen cylinders and acetylene cylinders should not be less than 5m." However, in the construction work, due to the shallow safety awareness and fluky psychology of construction personnel, the use of oxygen cylinder and acetylene cylinder does not conform to the safe use specifications, and there is a great safety risk. Liang Zheheng et al. applied unmanned aerial vehicle remote sensing to dynamic monitoring of illegal buildings, and through sample training, they generated a target detection model with good fitting sample data and good generalization ability, thus realizing automatic detection of illegal buildings [1-4]. H.Kun et al. proposed an improved Grabcut, which combined segmentation and multi-scale feature extraction into a unified model, and improved the accuracy of image segmentation [5]. W.Dong et al. combined Grabcut image segmentation algorithm with Tesseract-OCR technology to transform the text segmentation problem into image segmentation problem and realize the extraction of hard-coded subtitles [6]. Yang Chao introduced several machine learning algorithms and applications of image front-background separation, and proposed an automatic Grabcut algorithm based on region growing and merging, which realized fast and accurate

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automatic front-background separation [7]. Zeng Diqing used Canny edge detection and Hough line detection to detect lane lines and eliminate other interference information in the image [8-9]. Sharada Naik et al. used Canny edge detection algorithm to detect random line segments in images, probabilistic Hough transform was used to detect straight lines, and then combined with distance formula, the distance and length of random line segments were measured [10]. Wang Meizhen et al. introduced the geometric measurement method of ground objects in a single image, and realized the geometric measurement of space objects by using the prior information contained in the image itself [11-14]. G.Xingwen uses the inverse perspective transformation method to process the image on the algorithm, and combines the definitions of geometric relations such as point and line, vanishing point, vanishing line, cross ratio, etc. to realize the measurement of the distance between objects to be measured in the image [15].

In this paper, the geometric measurement algorithm of single image is applied to the illegal monitoring of pipeline construction site, and the images are captured by the front of UAV to reduce the distortion of target imaging. Due to the complex environment of the construction site and too many influencing factors, there is no fixed reference in the image measurement. Combining with the structured scene information of the safety use specification of oxygen cylinder and acetylene cylinder, the distance between two cylinders is measured by taking itself as a reference. In this paper, firstly, the outline of oxygen cylinder and acetylene cylinder is extracted completely by Grabcut before background separation algorithm. By combining Canny edge detection algorithm with Hough line detection, the edge contour lines of two gas cylinders are obtained and the coordinates of the end points of the lines are obtained. Secondly, combined with projective transformation, the coordinates of the intersection point, that is, the image coordinates of the bottom end points of two gas cylinders, are obtained by using the coordinates of the end points of the straight line. Finally, the actual distance between oxygen cylinder and acetylene cylinder is calculated by using the invariance of cross ratio. The structural block diagram for measuring the distance between two gas cylinders in this paper is shown in Figure 1.

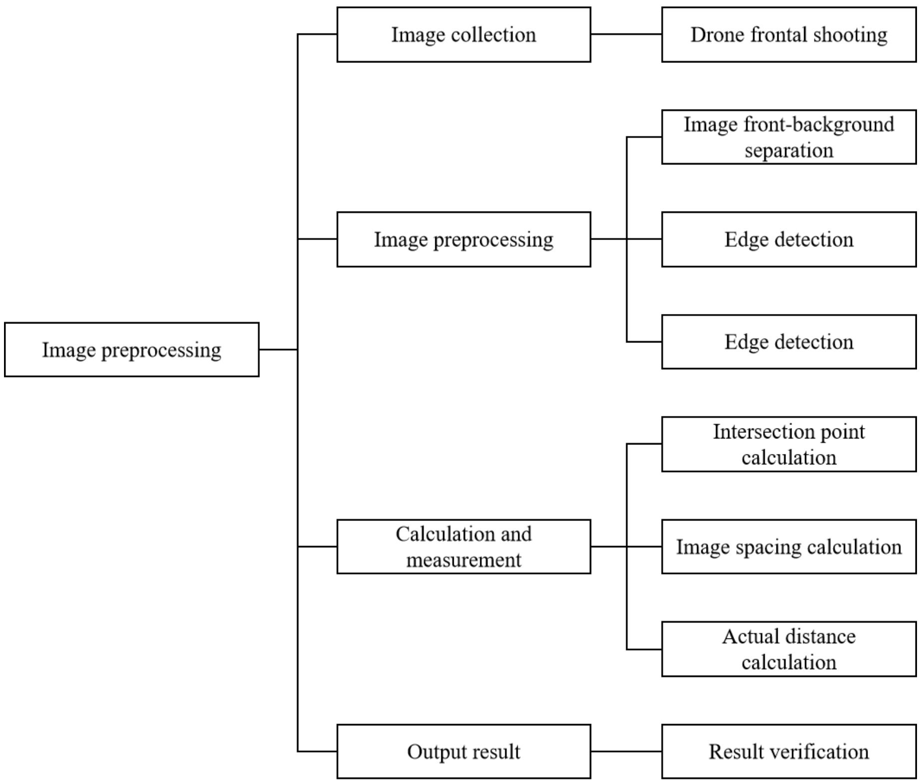

Figure 1 Structure block diagram of spacing measurement

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2. Technical ideas and research methods

2.1. Image pre-processing

The distance between oxygen cylinder and acetylene cylinder in pipeline construction site is measured based on a single image. Because of the complex working environment in the construction site, the environmental information in the collected images will greatly interfere with the distance measurement. In order to improve the measurement accuracy, it is necessary to preprocess the images.

2.1.1 Front background separation of image

In order to eliminate other interference factors such as environment, the contours of oxygen cylinder and acetylene cylinder are extracted, the background before image is separated, and the required target information is enhanced. In this paper, the following three classic image segmentation methods [16-20] are used to extract the target contour from the collected images, as shown in Figure 2. As can be seen from Figure 2, Grabcut before background separation algorithm can better extract the outline of oxygen cylinder and acetylene cylinder, and eliminate environmental interference factors.

(a) Original image

(b) FCM cluster segmentation

(c) otsu global threshold processing

(d) Grabcut front background isolated

Figure 2 image background separation

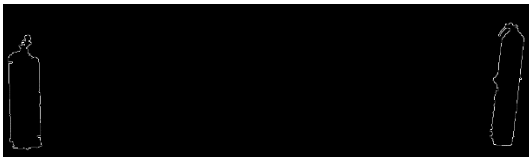
2.1.2Image object contour edge extraction

In order to extract the boundary between the target and the background in the image, edge detection is carried out on the image contour after background separation before 2(c)Grabcut in Figure 2 (c), and four common edge detection operators are used to obtain the target contour edge. The basic steps of Canny edge detection are as follows: (1) Gaussian filter is used to smooth the image and filter out noise; (2) Calculating the gradient intensity and direction of each pixel in the image; (3) Non maximum suppression is applied to eliminate the spurious response caused by edge detection; (4) Double threshold detection is applied to determine the real and potential edges; (5) Finally, the edge detection is completed by suppressing the isolated weak edge. As shown in Figure 3, the detection results of four edge detection operators are shown. It can be seen from the figure that Canny edge detection [11] in Figure 3 (d) has the best effect and the extracted target contour is the most complete.

(a) sobel operator

(b) roberts operator

(c) prewitt operator

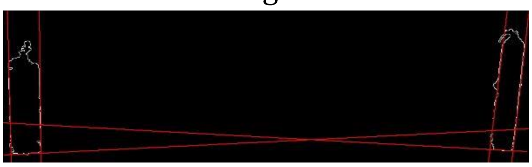


(d) Canny edge detection

Figure 3 Image edge detection

2.1.3Image target edge line detection

Hough transform is a feature extraction technique. In a parameter space, by calculating the local maximum of the accumulated results, a set conforming to the specific shape can be obtained as the Hough transform result. It uses the duality of points and lines to change a given curve in the original image space into a point in Hough parameter space through curve expression. Hough line detection algorithm defines two functions: HoughLines (standard Hough transform) and HoughLinesP (progressive probability Hough transform). The HoughLines function outputs a set of vector representations of detected lines, each line represented by a vector (ρ,θ) with two elements. Where ρ represents the length of the line from the origin $(0,0)$, and θ represents the angle of the line, which cannot output the length of the line segment in the image space. HoughLinesP can detect the two endpoints of lines in the image, each line is represented by a vector (x_1,y_1,x_2,y_2) with four elements. Where (x_1,y_1) represents the starting point of the line segment and (x_2,y_2) represents the end point of the line segment. The Hough transform is used to perform straight line detection on the target contour detected by the Canny edge in Figure 3(d). The two detection results are shown in Figure 4.



(a) HoughLines line detection

(b) HoughLinesP line detection

Figure 4 Image target edge line detection diagram

Since the equation of the edge line needs to be calculated in the subsequent measurement of this paper, the HoughLinesP function is used for line detection, and the image coordinates of the endpoints of each line segment are shown in Table 1.

Table 1 image coordinates of line segment end points

Line segment	Endpoint 1		Endpoint 2	
	x_1	y_1	x_2	y_2
l_1	12	145	16	273
l_2	74	151	76	285
l_3	30	283	67	282
l_4	1008	46	996	268
l_5	1049	62	1032	272
l_6	992	276	1018	279

2.2. Measurement of distance between oxygen cylinder and acetylene cylinder based on single image

According to the process of single image analysis, geometric measurement is divided into three main stages: geometric eigenvalue calculation, geometric size calculation and auxiliary result detection. In the geometric eigenvalue calculation stage, the homography matrix, vanishing lines and imaginary dots are calculated according to the geometric constraints of parallel, vertical, rectangle and circle provided in the image, and the measurement information of the image is recovered. In the geometric calculation stage, the proportional relationship between the image and the real space object is established, and the image scaling factor is restored. In the auxiliary result detection stage, the geometric dimension calculation results are analyzed by using the knowledge of equal height, equal distance and symmetry, the results are constrained by appropriate strategies, and the analysis results are fed back, so as to improve the final measurement accuracy.

2.2.1 Construction of a priori knowledge base

Distance measurement based on a single image mainly depends on the geometric structure information and known measurement information of the scene, which are collectively referred to as structured scene information. Generally, there are auxiliary reference objects when collecting images, and the geometric structure information and measurement information of the reference objects are known. By calculating the mapping relationship between the actual space of the reference objects and the images, the measurement of the target objects can be realized. However, due to the complex working environment at the pipeline construction site, it is difficult to find a suitable reference, and the oxygen cylinder and acetylene cylinder are moved and placed with the change of the working place. In the process of violation monitoring by UAV, it is impossible to place the reference at the shooting point anytime and anywhere. Considering that the oxygen cylinder and acetylene cylinder are standard parts, their diameters are known, and they are placed perpendicular to the ground during operation, so the oxygen cylinder and acetylene cylinder themselves are used as references for image measurement. The main prior knowledge of the pipeline construction site used in this paper is shown in Table 2.

Table 2 Main prior knowledge of pipeline construction site

Structured scene information		Describe
Geometric structure information	Parallel	The two cylinders are parallel to each other
	Vertical	The two cylinders are perpendicular to the ground
Known metric information		The diameter of oxygen cylinder is 21.9cm, and that of acetylene cylinder is 30.0cm

2.2.2Analysis of measurement principle based on single image

Parallel lines are one of the common geometric features in natural scenes, such as landmarks on roads and rectangular floor tiles in indoor scenes. Taking parallel lines as the research object, the geometric measurement method of a single image containing the characteristics of parallel lines and the calculation method of related geometric information are proposed. On the basis of the prior knowledge base, the image plane is restored to the actual spatial plane which differs from it by a scale factor. In the measured image, the homogeneous coordinates of a point p can be expressed as $p=[x,y,1]^T$. Where x,y is the x- and y-axis coordinates of the midpoint of the image coordinate system. The homogeneous coordinates of a line l can be expressed as $l=[a,b,c]^T$, where a,b,c makes $ax+by+c=0$. As shown in Figure 5, two points p_1 determine a straight line l, which can be expressed as Equation 1:

$$l = p_1 \times p_2 \tag{1}$$

Any theorem in two-dimensional projective geometry has a corresponding theorem, which can be derived by exchanging the functions of points and lines in the theorem. A line dual with two points is determined, and two lines l_1 and l_2 determine an intersection p, which can also be expressed as Equation 2 by the cross product of the two lines:

$$p = l_1 \times l_2 \tag{2}$$

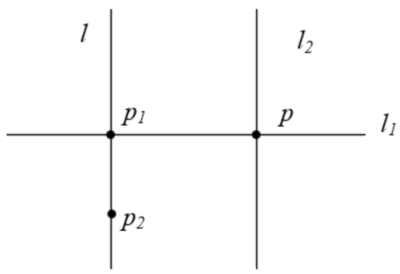


Figure 5 Points and lines

Projection transformation is a linear change. Parallel lines are mapped to the image as intersecting lines, and this intersection is called vanishing point. That is, parallel spatial lines intersect at infinity of the image, and the blanking point is the image of this intersection. All families of horizontal parallel lines intersect at a point at infinity. These points form an infinity line, and the image of this line on the image is called the horizon.

The three-dimensional space is projected onto the two-dimensional image, and the cross ratio of the straight line remains unchanged, and the cross ratio is the "proportional ratio" of four points [21]. So if there are four points on a straight line in three-dimensional space, the cross ratio of these four points will not change after they are mapped to four points on the picture. As shown in Figure 6, A, B, C and D are collinear four points.

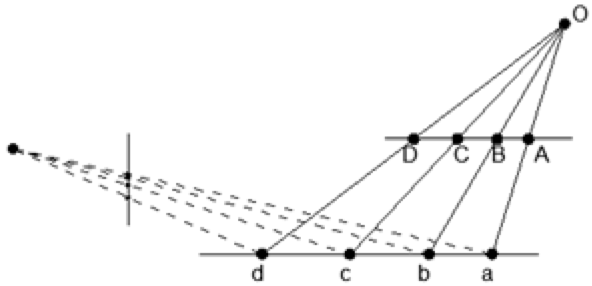


Figure 6 Projective transformation between lines

The intersection ratio is defined as Formula 3, where A and B are called base point pairs, and C and D are called equinox pairs.

$$CR(A,B,C,D)=\frac{d(A,C)d(B,D)}{d(B,C)d(A,D)}=cr \tag{3}$$

3. Results and Applications

3.1. Application of projective transformation in distance measurement between oxygen cylinder and acetylene cylinder at pipeline construction site

For the convenience of description, for the above processed image, the detected straight lines are sequentially marked as l_1,l_2,l_3,l_4,l_5,l_6. l_1,l_2 and l_3 intersect at points a,b respectively, and l_4,l_5 and l_6 intersect at points c,d respectively, as shown in Figure 7:

Figure 7 Image line segment marking diagram

Since the oxygen bottle and the acetylene bottle are placed vertically on the ground, a,b,c,d is four collinear points in the image. Among them, $d(a,b)$ is the diameter of the acetylene bottle, and $d(c,d)$ is the diameter of the oxygen bottle. Assuming that the above detected straight line equation is shown in Equation 4:

$$y_i = k_i x_i + b_i \tag{4}$$

Where $i=1,2,3,4,5,6$. From the image coordinates of the endpoints of each line segment in Table 1, the endpoint coordinates of the straight line l_i ($i=1,2,3,4,5,6$) can be substituted into the equation 4 to obtain the equation of the straight line, and then the four-point coordinates of the intersection a,b,c,d can be calculated, as shown in Table 3:

Table 3 image coordinates of intersections

Endpoint coordinates	x	y
a	16.33	283.16
b	75.95	281.65
c	990.60	275.87
d	974.92	273.99

From this, the acetylene bottle diameter $d(a,b)$, the oxygen bottle diameter $d(c,d)$, and the distance $d(b,c)$ between the oxygen bottle and the acetylene bottle can be calculated in the image, as shown in Table 4:

Table 4 Distance of each line segment in image

Line segment	Distance
$d(a,b)$	59.64
$d(c,d)$	15.79
$d(c,b)$	914.67
$d(a,d)$	958.63

According to $CR(A,C,B,D)=cr(a,c,b,d)$, $d(B,C)=$860.42cm can be calculated by formula 5 and formula 6 simultaneously.

$$\frac{d(A,B)d(C,D)}{d(C,B)d(A,D)}=\frac{d(a,b)d(c,d)}{d(c,b)d(a,d)} \tag{5}$$

$$d(A,D)=d(C,B)+d(A,B)+d(C,D) \tag{6}$$

3.2. Result verification

The actual distance between oxygen cylinder and acetylene cylinder was measured by hand-held rangefinder, and compared with the above measurement results. The results are shown in Table 5:

Table 5 Comparison of calculation results

Line segment to be found	Standard value (cm)	Calculated value (cm)	Absolute error (cm)	Relative error (%)
Two bottle spacing	780.00	860.42	80.42	10.3%

The comparison results in Table 5 show that the relative error of the distance between oxygen cylinder and acetylene cylinder measured by the geometric measurement method of single image described in this paper is 10.3%, and the absolute error is within 1m. This precision meets the requirements of illegal monitoring in pipeline construction site.

4. Conclusion

The geometric measurement method of single image is applied to the identification and monitoring of pipeline construction violations, and the outline of oxygen cylinder and acetylene cylinder is separated from the complex environment by the background separation algorithm before Grabcut, which greatly eliminates the interference factors. Combining Canny edge detection with Hough line detection, the edge lines of two gas cylinders are accurately extracted. The prior knowledge base is established by using the structured scene information of oxygen cylinder and acetylene cylinder, and the distance measurement is carried out by taking itself as a reference. Finally, the relative error of the measurement results is 10.3% compared with the actual distance, which can meet the safety monitoring of oxygen cylinder and acetylene cylinder in pipeline construction site. However, due to the complex environment of pipeline construction site, the quality of the collected images is not high, and the contour extracted in the image pre-processing is not smooth enough, and there are many burrs, which increases the image measurement error. In the later work, while improving the image acquisition quality, the algorithm proposed in this paper is optimized, and it is tried to be applied to the identification and monitoring of other violations in pipeline construction.

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