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Research on Application of Location Technology in 3D Virtual Environment Modeling System for Substation Switch Indicator

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ABSTRACT

Substation inspection work plays a very important role in ensuring the normal production and the safe operation of a transformer substation. Use of a substation inspection robot can effectively solve the omission problems of a manual inspection. It can further improve the unmanned and automation of substation and improve security of station. A substation inspection system requires the establishment of a spatial position relation between the robot and the inspection object in the monitoring station. Key technology is the spatial location of the object being detected in the substation. The position of inspection object is unknown. This paper gives technical route of monocular vision positioning system based on switch indicator sign cooperative target. The knife switch indicator is one of the most important objects in the substation inspection. Usually the switch indicator lies in the middle or top of the substation equipment and conventional method can't measure. This paper presents a substation label measurement method based on monocular vision. In this method, the label frame of knife switch indicator is as a cooperative target. The 3D coordinates and attitude of the label frame can be calculated in a camera coordinates system. At the same time, this paper introduces an extraction process of knife brake indicator label with multi-features under complex background. At last, we do simulation experiment for positioning technology of 3D virtual environment modeling system for substation switch indicator. Simulation results show that the method introduced in this paper can realize positioning of substation switch indicator label.

KEYWORDS

Substation; Switch indicator; 3D virtual environment modeling system; Location technology

1. Introduction

Nowadays, information technology has opened the door for a human to enter the intelligent society. It led to the Internet, Internet of things, e-commerce, modern logistics, network finance and other modern service industry developments. It spawned a car networking, smart grid, new energy, intelligent transportation, smart city, high-end equipment manufacturing and other emerging industries. Modern information technology is becoming the engine of operation and development of all walks of life, but this engine is facing huge test of big data. Big data first refers to the large amount of data, refers to large data sets, generally in the 10 TB size or so. But in practical applications, a lot of enterprise users put a number of data sets together. It has formed the PB level data quantity. Secondly, it refers to the data type (variety) is large. Data is from a variety of data sources, data types and formats are increasingly rich. It has broken through the previously defined structural data category, including semi-structured and unstructured data. Then the data processing speed (Velocity) is fast, in the case of very large amounts of data, and real-time data processing can be done. The last feature for big data is that the data authenticity (Veracity) is high. With the emergence of the social data, business content, transaction and application data and other new data sources, the limitations of traditional data sources are broken. The enterprise increasingly needs effective information to ensure its authenticity and security. In the environment of big data, this paper introduces an extraction process of knife brake indicator label with multi-features under complex background. At same time, this paper presents a substation label measurement method based on monocular vision.

Substation inspection work plays a very important role in ensuring the normal production, the safe operation of the transformer substation. The traditional inspection task requires daily or regular inspectors for each substation inspection, and collecting large amounts of data. In this way, it is difficult for the substation maintenance and inspection, especially the daily operation and maintenance work is repetitively strong, easily causing missing and false detection by negligence and fatigue and loss of the inspection staff.

Inspection robot for substation equipment can replace the artificial work to complete all inspection for substation high voltage equipment. Substation equipment and the inspection robot system inspect for outdoor high-voltage equipment being unattended or fewer people on duty at the substation in an autonomous or remote-controlled manner. According to task operation or preset task for the operating personnel in the mission station, it can finish automatic global path planning in the substation. Through carrying various sensors, it completes the image inspection of the substation equipment. The operators only need through the real-time data, images and other information received from a background station computer to complete the substation equipment inspection work. The station equipment inspection by using the intelligent mobile robot can improve the work efficiency and quality and play the role of synergism of depletion of numbers. It can quickly promote the process of the unattended substation. Therefore,

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Figure 1. Substation Switch Label Indicator.

the use of substation inspection robot can effectively solve the problems caused by omission of manual inspection. It can further improve the unmanned substation and automation and improve station security. At the same time, the robot inspection way has low cost compared to the multi-point video surveillance (Deng, Qiang, & Yang Simon, 2015).

The substation inspection system requires the establishment of spatial position relation between the robot and the inspection object in the monitoring station. The key technology is the spatial location of the object being detected in the substation (the position of inspection object is unknown). The knife switch indicator is one of the most important objects in the substation inspection, as shown in Figure 1.

Usually switch indicators are located in the middle or top of the substation equipment, conventional method can't measure it. This paper presents a substation label location method based on monocular vision measurement. The knife switch indicator label frame is a cooperative target. Length and width of escutcheon frame is known as the rectangle. As shown in Figure 2, the projection of plate frame in the camera target plane is a plane quadrilateral. The quadrilateral can be reflected to the space, and combined with the geometric model of plate frame, the 3D coordinates and attitude of the plate frame can be calculated in the camera coordinates system. The following paper introduces research situation of label image extraction and monocular vision measurement.

2. Research Situation at Domestic and Abroad

2.1. Research Status of Extraction Technology of Label Image

At present, research for image extraction of a substation switch indicator at domestic and international is less. Because the knife switch indicator sign in appearance content is approximation to license plate, the mature image recognition research of license plate is as a reference in this paper. The goal of the license plate image extraction is in the camera images to identify all of the license plate and the image segmentation according to the license plate number.

The work of algorithms by Hadi & Asadollah (2011) and Zou et al. (2015) needs to be discussed here. Extraction of the license plate image is based on different characteristics of the license plate with other objects; these features can be divided into three kinds of gray texture features, shape features and characteristics of color information. The method is numerous for a license plate extraction with these features. Zhu, Pu, Gao, & Xiong (2008) have proposed that the common extraction of the license plate is the main vehicle license plate locating method based on morphology, Tao & Xu (2001) have proposed vehicle license plate locating method is based on texture features, Alireza (2009) has proposed vehicle license plate locating method is based on color feature, Lu, Lu, & Yuan (2002) have proposed image location of license plate is based on neural network method. License plate recognition and extraction of existing methods have advantages and disadvantages combining with the application of various methods are an effective way to improve the reliability and robustness of the algorithm.

2.2. Research Status of Monocular Vision Positioning Technology based on Cooperative Target

Computer vision positioning is an important technology and it can be applied to many aspects. The application of geometric characteristics for the model-based monocular vision positioning (Li, Li, & Liao, 2015) (Zhao, Feng, & Cao, 2012) (Jia, 2010) (Tang, Xu, Si, Fang, & Sheng, 2014) can be divided into point, line and advanced geometric features, etc. At present, the location method (Chen, 2010) (Tang, Sun, Jia, & He, 2012) (Zhao, Guo, & Zhang, 2009) (Sun, 2010) research is based on the point characteristics and based on line feature. The problem of monocular vision positioning based on point features is also known as Perspective-N-Points (PNP) problem, through the development and research for many years, it has made quite a number of research results like Wang, Jia, Li, & Xu (2015), Feng (2013), Zheng (2013), Zhang (2011), Guo, Liu, Cao, Liu, & Tang (2014), Xiong, Zou, Zou, Peng, & Ye (2015), Fu, Sun, Liu, Xu, & Peng (2015), Hu, Lei, & Wu (2001), Zhou & Zhu (2003), and Yang, Zhang, & Xu (2011). It has been successfully applied in particular cases. For P3P problem, the mathematical model is complex; many scholars are solved by using the method of iterative solution. It often has high positioning accuracy of numerical solutions calculated by iteration method, but the iteration time is long and slow speed of calculation. Another important research issue for PNP is the multi-solution problem.

Location based on line feature (Han, Wang, Huang, Xu, & Lv, 2014) (S. Xu, He, Sun, & Wang, 2010) (Sun & Wang, 2006) (Wu, Wang, & Hu, 2003) (Ding, Zhu, & Hao, 2008) is called PNL, research is mainly concentrated in three lines of position (P3L) and four line location problem (P4L). On the issue of P4L, Sun & Wang (2006) have discussed the object location method of single parallelogram based on single image in the literature 34. The main conclusions are; the ratio between the adjacent sides, angle information of adjacent edges, since they are not projective invariants, so they cannot provide any additional useful information for object orientation of single image. When you know any set of side length of the parallelogram, the rotation matrix and translation vector can be uniquely

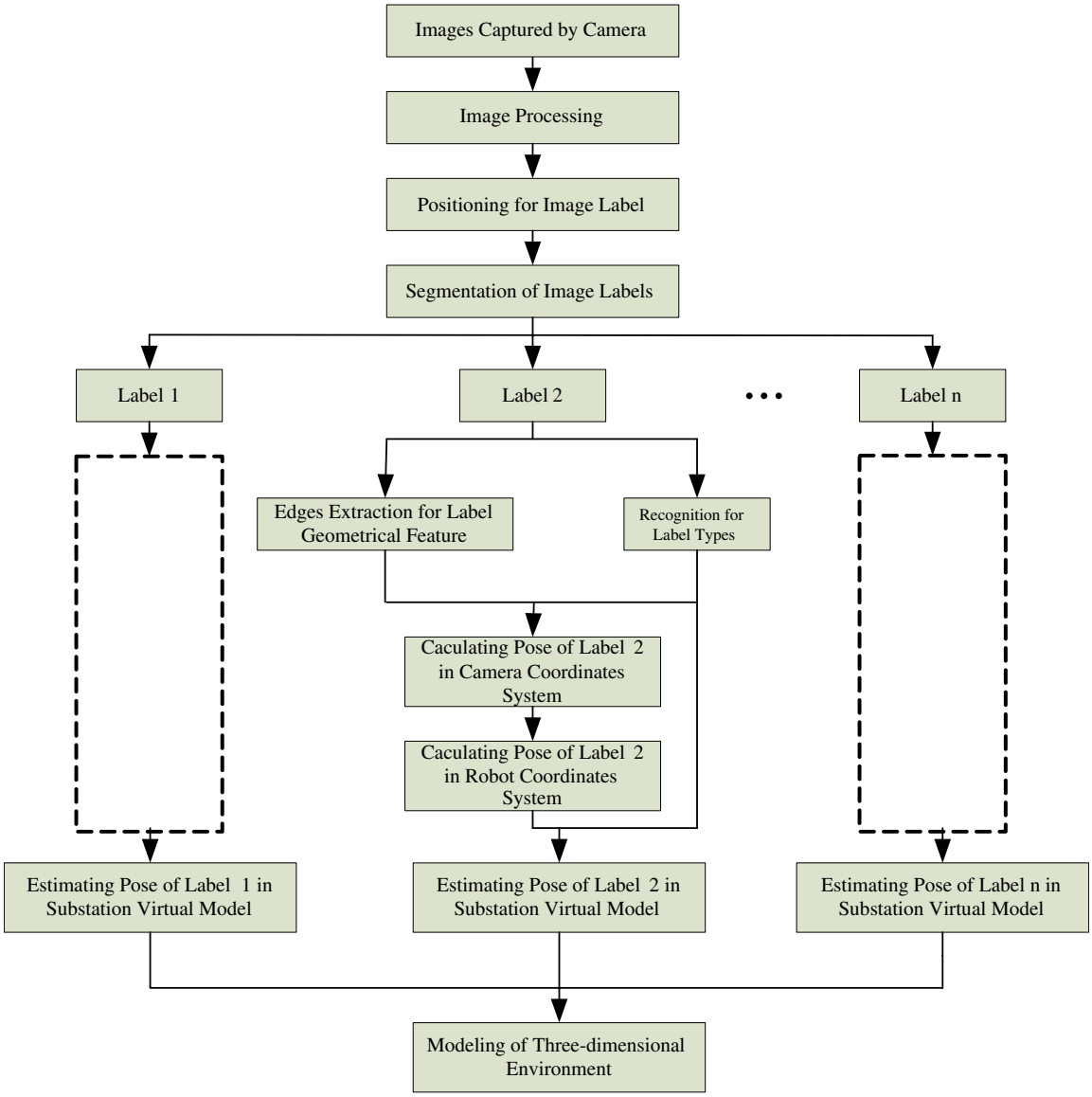

Figure 2. Technical Route Diagram of Positioning System for Substation Switch Indicator 3D Virtual Environment Modeling.

determined. Wu et al. (2003) have presented a rectangular method to determine the camera orientation. Given in the case of by a scaling factor, the linear method is obtained by Raguel's theorem to restore rectangular Euclidean metric information. In 3D information from one single image building, Ding et al. (2008) have proposed and implemented a method of extracting three-dimensional information from a single building image using rectangular structure.

According to the existing research results, positioning method of monocular vision based on point feature and monocular vision positioning method based on line feature have different characteristics. Positioning algorithm based on point feature is more mature, using an iterative method to obtain the precise solution. The shortcoming is the computation amount is large and it is easy to appear local minima in the optimization process. And it cannot guarantee the uniqueness of the analytical solution. Algorithm based on linear feature is mainly based on analytical solution. Algorithm precision itself is not high as iterative solution. But from the perspective of image extraction, extraction precision of linear feature is better than point feature. And analysis location method based on linear feature is simple algorithm, less calculation and has better real-time character.

For the research of object extraction of image label (referring to the license plate), from the front study it can be seen that using a single feature to recognize has its limitations. The current research trends are to apply combining several features to improve the robustness of target recognition and extraction. And in recent years the hardware processing speed and processing capacity continue to improve, which can ensure the feasibility of the method.

Due to monocular vision positioning method based on single geometry (point, line, curve characteristic feature) has been more mature; research trend of cooperative target monocular vision location algorithm based on geometric features has from single to the combination of multiple features direction. The benefit of this approach is to improve the robustness and reliability of positioning algorithm.

The idea of this paper is that cooperative target monocular vision positioning method is applied to the identification of the substation switch indicator sign. In this paper, research on the label image target recognition and extraction monocular vision positioning method based on cooperative target use multi-features combination way, it is consistent with the development trend of the relevant theoretical research. The paper is with a switch indicator label location in the substation

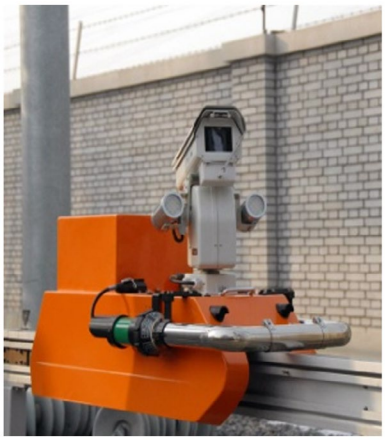

Figure 3. Inspection Robot in Substation Environment.

as the research background. It researches on monocular vision positioning method with the plate border as cooperation goals. On the basis of it, monocular vision positioning algorithm for substation knife indicator label is given.

3. Technical Route of Positioning System in 3D Virtual Environment Modeling for Substation Switch Indicator

The technical route of monocular vision positioning system based on switch indicator sign cooperative target is shown in Figure 2. Video camera captures an image, firstly, image pre-processing, and then locating and extracting the image of the label. The way of the label location is; 1) Coarse positioning for signs region according to mathematical morphology, 2) accurate positioning according to the plate texture features, 3) precise positioning combined with plate color information. Label positioning is completed, if there is more than one label image, it needs to extract different sign image.

For label images after segmentation, geometric features of plate edge are extracted. It includes four lines and four angular points. The label type is determined on the basis of the label text color, background color, and text arrangement. The length and width of each type sign is known. It can be used to get the space position for geometric features as a monocular vision measurement cooperative target sign. According to the projection on the image, the position and posture of sign can be computed using the selected location algorithm at the camera coordinates system. Due to that rotation and translation matrix between the camera coordinate system and the robot coordinate system is known, we can get position and attitude for the signs in the robot body coordinate system correspondingly. Picture of the inspection robot in substation environment is shown in Figure 3. Because the measuring point position of the robot is known, so the combination of position and attitude for signs in the robot body coordinate, position and attitude of the label in the substation world coordinate can be determined.

4. Key Technologies for Location System in 3D Virtual Environment Modeling for Substation Switch Indicator

4.1. Extraction Technique of Signs and Sign Frame in Complex Background

In order to improve the accuracy and robustness of label extraction in images, the paper adopts signs extracting method with multiple characteristics in the paper. It includes plate location method based on the structural characteristics of the sign, location method based on color feature, label location method based on texture feature. Its working process is shown in Figure 4. First, we obtain the image of the substation. Then we do the image preprocessing for the substation. It includes image enhancement, median filter, two values of images and edge detection. Then we do area location for image processing of knife switch indicator. The plate location method is based on the structural characteristics of the rectangular structure to remove non-substation images. Color feature is used to remove pseudo region in gray image. Texture features of the image are used to remove pseudo regions of switch indicator label in gray image. The algorithm can effectively solve low extraction rates and poor accuracy problems of simply relying on existing texture and color information. Finally, image feature extraction method is used to extract border image of the switch indicator label.

4.2. Target Label Positioning and Attitude Determination Technology based on Monocular Vision

Usually switch indicators are located in the middle or top of the substation equipment that conventional methods can't measure. This paper presents a substation label location method

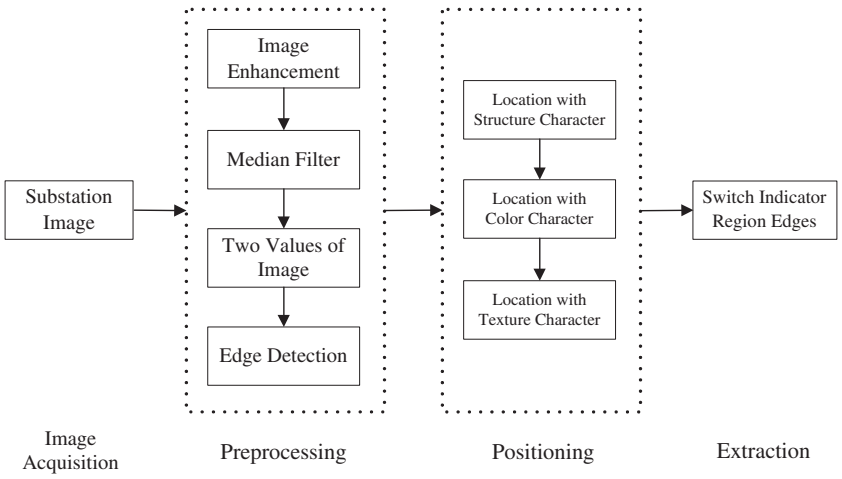

Figure 4. Label Extraction Process for Switch Indicator with Multi-features under Complex Background.

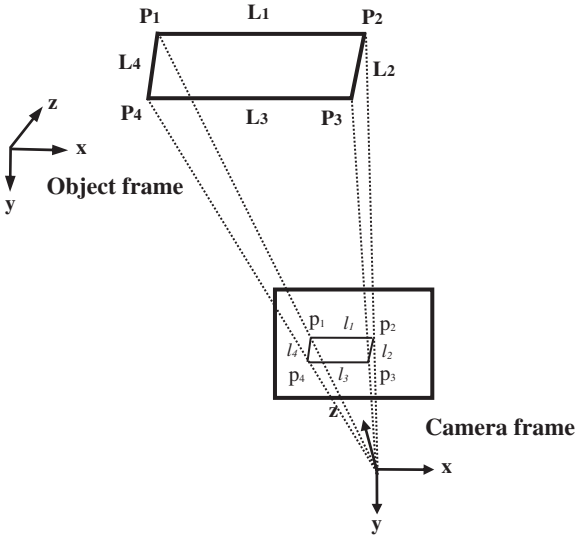

Figure 5. Schematic Diagram of Monocular Vision Positioning for Switch Indicator Cooperative Target.

based on monocular vision measurement. The label frame of knife switch indicator is a cooperative target. Length and width of scutcheon frame is known as the rectangle. As shown in Figure 5, the projection of plate frame in the camera target plane is a plane quadrilateral. The quadrilateral can be reflected to the space, and combined with the geometric model of plate frame, 3D coordinates and attitude of plate frame can be calculated in the camera coordinates system[37]. With measured sign indicator position, 3D virtual environment of the substation can be done using 3D modeling software.

The theoretical basis of monocular vision positioning technology from cooperative target is based on the corresponding relationship between a specific set of geometric characteristics of known position relation with the camera image projection on the projection image, combined with the parameters of camera, position and attitude can be computed of geometric characteristics coordinate system in the world coordinates system.

Monocular vision positioning and attitude determination method based on cooperative target is to get measured rotation transformation matrix from the object coordinate system to the camera coordinate system. Projection of label frame at the camera target plane is a closed quadrilateral. Projection model of target sign frame in the camera coordinate system is shown in Figure 5. In this paper, we will use the quadrilateral with four sides as a cooperative target and present a monocular vision positioning method based on plane rectangle; this method can obtain the unique solution of the target location. Using screw theory, the rotation transformation matrix RT can eventually be obtained from signs coordinate system to camera coordinate system.

Within the hypothesis of perspective projection model and known camera parameters. Four sides of sign frame are in the hypothesis of $L_i(i = 1 \sim 4)$. Image points $p_i i = (1 \sim 4)$ of four vertices $P_i i = (1 \sim 4)$ in the image coordinates is $p_i i = (1 \sim 4)$. The perspective projection model constrains space line L_i and image line l_i and the camera optical center to a plane, the plane is called interpretation plane. Normal vector of explain plane S_i is $\mathbf{N_i}$. Location method for substation switch indicator is as follows:

(1) Using direction vector of l_i and direction vector of $\overrightarrow{\mathbf{ot_i}}$ to calculate $\mathbf{N_i} = \overrightarrow{\mathbf{ot_i}} \times \overrightarrow{\mathbf{v_i}} = \left(a_i f, b_i f, c_i\right)^T$.

(2) By perspective projection invariance, projection of space parallel straight lines in the camera target plane is parallel. According to this theory, using two normal vectors of interpretation plane where two parallel edges of rectangle frame lie, we can compute direction vectors (A_{c1}, B_{c1}, C_{c1}) and $(A_{c3}, B_{c3}, C_{c3})$of these two edges in the camera coordinate system.

$$\left(A_{c1}, B_{c1}, C_{c1}\right)^T = \mathbf{N_1} \times \mathbf{N_3} = \left(a_1 f, b_1 f, c_1\right)^T \times \left(a_3 f, b_3 f, c_3\right)^T \tag{1}$$

Where,

$$A_{c1} = b_1 f c_3 - b_3 f c_1, B_{c1} = -a_1 f c_3 + a_3 f c_1, C_{c1} = a_1 b_3 f^2 - a_3 b_1 f^2.$$

(3) Similarly, we can compute direction vectors (A_{c2}, B_{c2}, C_{c2}) and (A_{c4}, B_{c4}, C_{c4}) of another two edges in the camera coordinate system.

$$\left(A_{c2}, B_{c2}, C_{c2}\right)^T = \mathbf{N_2} \times \mathbf{N_4} = \left(a_2 f, b_2 f, c_2\right)^T \times \left(a_4 f, b_4 f, c_4\right)^T \tag{2}$$

Where,

$$A_{c2} = b_2 f c_4 - b_4 f c_2, B_{c2} = -a_2 f c_4 + a_4 f c_2,.$$
$$C_{c2} = a_2 b_4 f^2 - a_4 b_2 f^2$$

(4) Assuming the existence of a straight line L_5, which is vertical to straight line L_1 and straight lines L_2in object coordinate system. Direction vector (A_{c5}, B_{c5}, C_{c5}) of L_5 can be calculated in the camera coordinate system under the direction vector of L_1 andL_2 in the camera coordinate system.

$$\begin{aligned}\left(A_{c5}, B_{c5}, C_{c5}\right)^T &= \mathbf{L_1} \times \mathbf{L_2} = \left(A_{c1}, B_{c1}, C_{c1}\right)^T \\ &\quad \times \left(A_{c2}, B_{c2}, C_{c2}\right)^T \\ &= \left(B_{c1}C_{c2} - B_{c2}C_{c1}, A_{c2}C_{c1} - A_{c1}C_{c2}, A_{c1}B_{c2} - A_{c2}B_{c1}\right)\end{aligned} \tag{3}$$

(5) By direction vector of line L_1, L_2, L_5 in the camera coordinate system, rotation transformation matrix R can be obtained between the object (the robot) coordinate system and the camera coordinate system.

(6) In the camera coordinate system, $\Delta P_1 O P_2$ and $\Delta p_1 O p_2$were investigated, in the conditions of known $|P_1P_2|$, $\overline{P_1P_2}$, $\overline{p_1p_2}$, $|p_1p_2|$, $\angle p_1 O p_2$, coordinates ofP_1 in the camera coordinate system can be deducted as $\left(t_1x_1, t_1y_1, t_1z_1\right)$. Coordinates of p_2 in the camera coordinate system can be gotten in the same way.

$$\angle p_1 O p_2 = \arccos\left(\frac{x_{c1}x_{c2} + y_{c1}y_{c2} + f^2}{\sqrt{x_{c1}^2 + y_{c1}^2 + f^2}\sqrt{x_{c2}^2 + y_{c2}^2 + f^2}}\right) \tag{4}$$

$$\angle O P_2 P_1 = \arccos\left(\frac{x_{c2}A_{c2} + y_{c2}B_{c2} + fC_{c2}}{\sqrt{x_{c2}^2 + y_{c2}^2 + f^2}\sqrt{A_{c2}^2 + B_{c2}^2 + C_{c2}^2}}\right) \tag{5}$$

$$t_1 = \sqrt{\frac{\left(\sin \angle p_1 O p_2\right)^2}{\left(a \cdot \sin \angle O P_2 P_1\right)^2 \left(x_{c1}^2 + y_{c1}^2 + z_{c1}^2\right)}} \tag{6}$$

Figure 6. Switch Indicator Image in Substation Environment.

(7) In the same way, coordinates of P_3, P_4 in camera coordinate system can be done.
(8) According to screw theory, translation transformation matrix T can be deduced between the object (the car) coordinate system and the camera coordinate system.
(9) Translation rotation matrix between the object (label) coordinate system and the vehicle coordinate system can be obtained by prior calibration transformation between the camera coordinate system and the vehicle coordinate system. Correspondingly, 3D position and attitude of target plate can be get in the car coordinates system.

5. Simulation Experiment

We carry out the simulation experiment for substation virtual inspection system location technology. Camera concrete parameter is chosen as $\begin{pmatrix} 800 & 0 & 0 \\ 0 & 800 & 0 \\ 0 & 0 & 1 \end{pmatrix}$. Size of image is 512×512. Switch indicator image in substation environment are firstly captured by the camera. Figure 6 is the switch indicator image acquired from camera in substation environment. We can locate switch indicator label on substation image using image extraction method. Figure 7 is the switch indicator label images obtained through image positioning. We extract four edges of the switch indicator label. Then, we use four vertexes of four edges of switch indicator label for positioning. Positioning for switch indicator label image is done using vision location method introduced in this paper. Experiments show that the method can determine special information of switch indicator label in the substation environment. Table 1 is positioning results for the switch indicator label image. Simulation experiment for location technology in 3D virtual environment modeling shows that it can realize switch indicator image location by the visual positioning method with rectangle label image of switch indicator.

Figure 7. Switch Indicator Label Located in Substation Image.

Table 1. Positioning Results for Switch Indicator Label Image.

	Parameters					
Image	α	β	γ	Tx	Ty	Tz
Switch indicator label	28.5	7.2	−8.6	−0.45	0.31	5.71

6. Conclusions

Substation inspection work plays a very important role in ensuring the normal production and the safe operation of the transformer substation. Inspection robot for substation equipment can replace the artificial to complete all inspection task of the substation high voltage substation equipment. The station equipment inspection, by using the intelligent mobile robot, which can improve the work efficiency and quality, to play the role of synergism of depletion of numbers, can quickly promote the unattended substation process. Substation inspection system requires establishing spatial position relation from the robot to the inspection object in the monitoring station. The spatial location of object being detected is key technology in the substation. The position of the inspection object is unknown. This paper gives technical route of the monocular vision positioning system from switch indicator label as the cooperative target. The knife switch indicator is one of the most important types in substation inspection objects. Usually switch indicator is located in the middle or top of substation equipment that the conventional method can't measure. This paper introduces extraction process of knife brake indicator label with multi-features under complex background. This paper presents a substation label measurement method based on monocular vision. Label frame of knife switch indicator is the cooperative target in this method. It can be calculated for 3D coordinates and attitude of the label frame in the camera coordinates system. We do a simulation experiment for positioning technology of 3D virtual environment modeling system of the substation switch indicator. Simulation results show that the method introduced in this paper can realize positioning for the substation switch indicator label.

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References

Alireza A.F. (2009). An edge based color aided method for license plate detection. *Image and Vision Computing*, *27*(8), 81–86.

Chen H. (2010). Monocular vision target positioning measure method based on cross ratio invariant (Master's degree thesis). Tianjing University.

Deng L., Qiang L., & Yang Simon X. (2015). Intelligent information technologies in fruit industry. *Intelligent Automation and Soft Computing*, *21*(3), 265–267.

Ding W., Zhu F., & Hao Y. (2008). 3D information extraction based on single building image. *Chinese Journal of Scientific Instrument*, *29*(9), 1965–1971.

Feng C. (2013). Research on target recognition and localization based on monocular vision (Doctoral Dissertation). Nanjing University of Aeronautics & Astronautics.

Fu Q., Sun X., Liu S., Xu S., & Peng K. (2015). Research on an accurate UAV self-localization method based on non-calibrated vision navigation. *Journal of Air Force Engineering University (Natural Science Edition)*, *16*(4), 5–8.

Guo R., Liu Z.-G., Cao Y., Liu X., & Tang H. (2014). Research on assembly robot accurate positioning based on vision. *Manufacturing Automation*, *36*(5), 154–156.

Hadi S.K.K., & Asadollah S. (2011). An evaluation of license plate recognition algorithms. *International Journal of Digital Information and Wireless Communications*, *1*(1), 247–253.

Han L., Wang X., Huang C., Xu M., & Lv G. (2014). Door-shaped structure based monocular vision locating method. *Optoelectronic Technology*, *34*(2), 78–83.

Hu Z., Lei C., & Wu F. (2001). A little discussion about P4P problem. *Acta Automatica Sinica*, *27*(6), 770–776.

Jia Y. (2010). Research on target localization method for mobile robot based on monocular vision (Master's degree thesis). Chongxing University.

Li X., Li Z., & Liao X. (2015). Design of positioning system for industrial robot based on monocular vision. *Machine Tool & Hydraulics*, *43*(9), 35–38.

Lu E., Lu F., & Yuan X. (2002). The license plate location method of neural network. *Journal of Nanjing University of Science and Technology*, *26*, 500–508.

Sun B. (2010). Moving object tracking and localization based on monocular vision. *Sichuan Ordnance Journal*, *31*(4), 85–88.

Sun F. and Wang W. (2006). Object location of a single image based on single parallelogram. *Acta Automatica Sinica*, *32*(5), 746–752.

Tang X., Sun Z., Jia X., & He D. (2012). Camera calibration in monocular vision localization. *Geospatial Information*, *10*(3), 100–103.

Tang Y., Xu J., Si S., Fang M., & Sheng Y. (2014). A monocular vision target localization method based on NAO robot. *Journal of Changchun University of Science and Technology (Natural Science Edition)*, *37*(5), 95–98.

Tao L., Xu G. (2001). Color issues and application in machine vision. *Chinese Science Bulletin*, *46*(3), 178–190.

Wang K., Jia S., Li X., & Xu T. (2015). Mobile robot mileage calculation method based on monocular vision from ground characteristics. *Journal of Optics*, *35*(5), 237–243.

Wu F., Wang G., & Hu Z. (2003). Linear method for camera intrinsic parameters and location determined by rectangular. *Chinese Journal of Software*, *14*(3), 703–712.

Xiong J., Zou X., Zou H., Peng H., & Ye M. (2015). Visual positioning technology research of picking robot based on dynamic target. *Journal of System Simulation*, *27*(4), 836–838.

Xu S., He, Sun, X.X., & Wang C.Y. (2010). A new vision positioning algorithm for targets with different heights. *Chinese Journal of Scientific Instrument*, *31*(3), 546–552.

Yang G., Zhang X., & Xu X. (2011). An analytical solution of non-coplanar P4P problem with uncalibrated camera. *Chinese Journal of Computers*, *34*(4), 748–754.

Zhang C. (2011). Research on active safety technology of vehicle based on monocular vision (Master's degree thesis). University of Electronic Science and Technology.

Zhao Y., Guo L., & Zhang L. (2009). Spatial localization algorithm based on monocular vision. *Journal of North-Western Polytechnical University*, *27*(1), 47–50.

Zhao L., Feng Y., & Cao Y. (2012). Optimization of surf parameters in monocular visual odometry. *Computer Technology and Development*, *22*(6), 6–10.

Zheng Q. (2013). Target recognition and localization based on monocular vision (Master's degree thesis). Shandong University.

Zhou X., & Zhu F. (2003). A few discussion of uniqueness conditions of the solution to the P3P problem. *Chinese Journal of Computers*, *26*(12), 1969–1701.

Zhu C., Pu J., Gao L., & Xiong Z. (2008). License plate location algorithm based on TopHat transform and text texture. *Journal of Beihang University*, *34*(5), 541–545.

Zou Y., Zhai J., Zhang Y., Cao X., Yu G., & Chen J. (2015). Research on algorithm for automatic license plate recognition system. *International Journal of Multimedia and Ubiquitous Engineering*, *10*(1), 101–108.