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Design and Implement of Control System for Power Substation Equipment Inspection Robot

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Abstract—**This paper introduces the design and implement of a novel control systems for power substation equipment inspection robot. According to the real condition of the power substation equipment inspection, the overall structure of the robot control systems are described, and a new monocular robot's navigation method based on colorful image processing was proposed. By the use of image partition of the HSI model and the mathematic morphology, the trajectory and distinguish the stop-sign drew beforehand from the image are obtained. Then the parameters of navigation and positioning are given by "sampling estimated" method. And the industrial operation of the system shows that the control system can form a kind of full monitor system for substation to greatly improve the safety, dependability and reality of the substation inspection.**

I. Introduction

In the power generation and distribution industries, the term substation is used in many ways. Various outdoor facilities ranging from switchyards at generating stations to quipment at utilities or at industrial facilities that switches or modifies voltage,frequency or other characteristics of primary power are called substations.

Periodic inspection and maintenance(PiM) shall be performed to verify proper system operation and general system upkeep[1]-[3]. PiM helps ensure the quality of an end user's electricity by enhancing the reliability of substations. PiM accomplishes this increased reliability by monitoring equipment over time in order to isolate conditions that indicate impending failure. The goal is to determine whether corrective action is required and, if so, to take that action before equipment fails.

Since the mid-eighties, several robot systems were developed for the distribution network, such as the TOMCAT system developed in the United States[4], ROBTET system [5] developed in Spain and the robot systems for underground distribution lines developed in Hydro-Québec's Research Institute [6].

Nowadays, substation equipments are inspected by electric power workers in our country. It not only costs much manpower and material resources, but is also inefficient and insecure. In order to resolve this contradiction and take into account the traditional operating model of substation, mobile robot system for monitoring equipment in substations is a much better choice to solve the above problems.

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II. ARCHITECTUR OF ROBOT CONTROL SYSTEM

Fig.1 The robot photo

The robot system can provide a kind of mobile platform for substation equipments inspection. The platform may integrate different nondestructive testing device such as on-line thermal imagers, visible light CCD camera, voice processing device and Intrusion detection Alarm processing device. And the inspection robot system can replace workers to inspect equipments in substation automatically or remote-controlled.

A. The Overall Structure Of The Rrobot

The overall structure of the robot system mainly comprises base station subsystem, mobile vehicle subsystem, robot control subsystem and substation equipment detection device consisted of visible light CCD camera, infrared thermal image camera and microphone. Mobile vehicle subsystem, which consists of mobile vehicle control system and communication system, is the overall robot system mobile platform and a information collection carrier. The base station subsystem, which includes base station computer, wireless bridge, network hubs and other hardware, is the structure of PC and Windows operating system. The main tasks of the base station subsystem are human-computer interaction and receiving various operating instructions to the robot motion control system. Base station computer is placed in the monitoring center and consists of base station frame, electronic map, status alarm processing,global path planning, real-time/history database, and detecting work module. Fig. 2 shows the overall structure of the inspection robot system.

B. Mobile Vehicle Control System

The mobile vehicle control system (MVCS),which is main part of the overall robot system, consists of PC-104 main boad, PMAC2A-PC104 motion controller and motor drivers. MVCS takes charge of movement and behavior control in the process of robot inspection. In order to carry out robot path planning and inspection works, MVCS needs to collect various external environment data such as ultrasonic, laser radar, GPS and so on. Robot dynamic models will be ertablished by real-time reception of local planning results and decompose the received speed instruction to each motor, and then PMAC motion controller can control the motors after the sustainable speed of each motor is calculated. There are four motors in the vehicle body, among them two motors will drive movement of the vehicle body, and other two motors will realize the movement of Pan & Tilt. The mobile vehicle control system structure is shown in Fig.2.

The work subsystem is mainly responsible for the job which the robot needs to do during the inspection such as the acquisition and transmission of image and sound, automatic charging for storage battery.

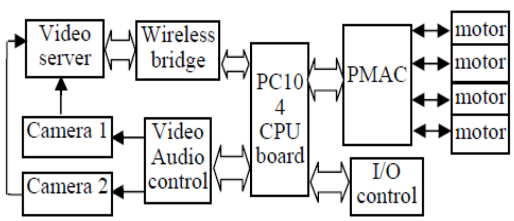

Fig2. Mobile vehicle control systems structure

III. MOBILE VEHICLE NAVIGATION AND POSITIONING USING MONOCULAR VISION

In order to complete equipments inspection tasks, the mobile vehicle ought to move along the inspection line, and can stay to achieve detection tasks with detecting device. Therefore, the mobile robot system requires a global understanding of the power substation environment and the ability to dynamically plan in it.

The visual navigation employed in the paper is line-trajectory’s following method. The navigation line is yellow belt with width 10cm on the power substation ground, and there are some stop signs marked along the mobile vehicle navigation line, the mobile vehicle can stay at the stop sign and call a given function module to achieve the corresponding task. The stop sign specially designed in the system is a 3×3 block shown in Fig.3, one side length of the block is 8 cm. As a reference sign, the center block has two colors , blue and red, the other blocks are black or white. And coding the different distribution of black and white blocks , one can get 256 kinds of combination,i. e., 256 kinds of signs 。

A. Image Data Preparation

Due to the complex outdoor ground environment circumstance and the variational light intensity, there are some interference information and noise in the image from data-acquisition device. In order to improve image processing accuracy, we should deal with the preparation step before image recognition.

First, convert the bitmap color image from HSI to RGB model, the conversion formula is as follows:

$$I = \frac{(R+B+G)}{3} \tag{1}$$

$$S = 1 - \frac{3\min(R,G,B)}{(R+G+B)} \tag{2}$$

$$H = \cos^{-1}\left(\frac{(R-G)+(R-B)}{2\sqrt{(R-B)^2+(R-B)(G-B)}}\right) \tag{3}$$

With H for hue, S for saturation, I for intensity .

The HSI color model owes its usefulness to two principal facts. First, the component , I, is decoupled from the color information in the image. Second, the hue and saturation components are intimately related to the way in which human beings perceive color. These features make the HSI model an ideal tool for developing image processing algorithms. By H and S Threshold adjustment , one can get the color characteristics of light under different illumination conditions, and the feature Extraction of navigation line and stop sign is good. The H and S thresholds of the navigation line and stop sign blocks are shown in Tab.1.

Tab.1 H andS thresholds

	H	S	I
Navigation color	(0.09,0.15)	(0.15,1)	——
Stop sign color（Red）	(0,0.02) || (0.98,1)	(0.25,1)	——
Stop sign color（Blue）	(0.54,0.66)	(0.17,1)	——

One can segment real-time acquisition image according to

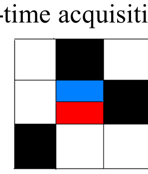

Fig.3 Stop sign

the thresholds. Scanning the every pixels of the image, the pixels according with navigation line color and stop sign colorwill be labeled pure yellow, pure red and pure blue

,namely (255,255,0), (255,0,0) and (0,0,255), respectively. And the other pixels of the image will be labeled as gray by the formula as follows:

$$gray = 0.299*R + 0.578*G + 0.114*B \quad (4)$$

The robot is interested in yellow pixels , red pixels, blue pixels and white/black pixels around red and blue pixel. Then the useful information can be saved by binarization of pixels changed into grayscale pixels. Because the surrounding of the block in the stop sign is white or black, one can find an arbitrary number from 0~255 to distinguish the both . For simple the following image processing, the yellow pixels, red pixel and blue pixels will be labeled as grayscale T1,T2 and T3, respectively.

After preprocessing, the whole image can be changed into a grayscale, and the object can be basically segmented. And the interference information will be some isolated point or region formed by those pixels of grayscale T1, T2 and T3.Next, by the erosion and dilation morphological operations, one can get rid of the interference information pixels that the grayscale are 0, T1, T2 and T3 with 5×5 template, respectively.

The erosion of A by B , AΘS , is defined as follows：

$$A\Theta S = \{x|(S)x \subseteq A\} \quad (5)$$

which, in words, says that the erosion of A by S is the set of all points x such that B, translated by x, is contained in A. Set S is commonly referred to the structuring element in erosion, dilation and in other morphological operations. In erosion, every object pixel that is touching a background pixel is changed into a background pixel. In dilation, every background pixel that is touching an object pixel is changed into an object pixel. Erosion makes the objects smaller, and can break a single object into multiple objects. Dilation makes the objects larger, and can merge multiple objects into one.

The dilation of A by S, A□S, is defined as follows：

$$A\square S = \{x|(S)x \cap A \neq \emptyset\} \quad (6)$$

Thus, the dilation of A by S is the set of all x displacements of the origin of S,$ such that S $ and A overlap by at least one nonzero element.

B. Navigation Line Parameters Extraction

At first, one can request buffer whose size will be equal to that of the original image data, and only the greyscale, T1, pixels that can be involved in navigation line can be saved, the other pixels will be changed into white.

Then, one can scan the every size of connected component in the image by 8-connected domain, and only the bigget connected component can be saved, the other connected components will be changed into white. Accordingly, the navigation line can be extracted from the image. The process and results of image processing is shown as Fig.3, which, a2 and b2 are the results after color extraction andmorphological image processing, respectively,a3 and b3 are the last partition results of navigation line after Statistics of connected components. It is obvious that the image processing method can be well and truly segmented the navigation line, even if there is in the Complex Backgrounds such as leaves and ground cracks.

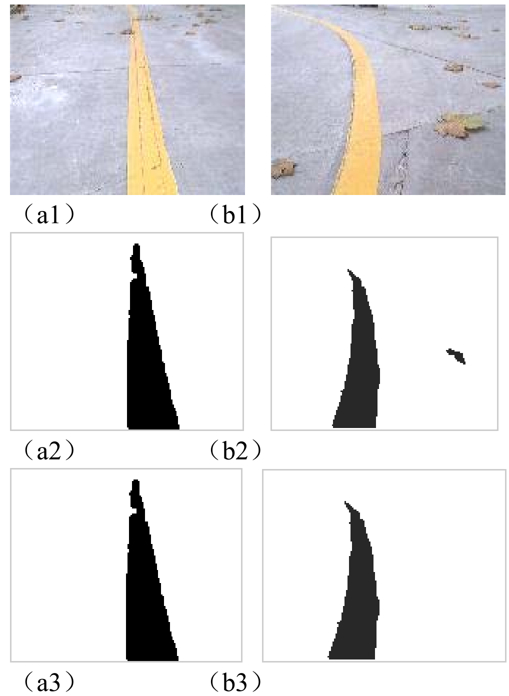

Fig.3 Image processing

The next step is to calculate the navigation line parameters which are heading angle between the robot heading and guide line, and the lateral distance between the robot and guide line. The classical Hough transform algorithms as it is concerned with the identification of straight lines in the image has a big time complexity, but also may bring a lot errors from obtaining the turning curve line parameters.

In the paper, the "sampling estimated" method is adopted to calculate the parameters of navigation line.

First, one can scan the image by the rules such as interlaced scanning, and calculate the maximum and minimum of the row of pixels with grayscale, T1 . Then, the midmum of the max and min of the row can be saved, if the difference between the max and min is smaller than the maximal width of the guide line, otherwise, it is neglected. Thus, the coordinates, S, comprised of the guide line midmum is obtained, and one can get the slopes of a line segment connecting two points from the beginning and the end of S, respectively. By sorting these slopes, one can got rid of some oversize slopes, then the midmum, which is the slope of the navigation line, of the remaining slopes can be obtained. And the algorithm above is so-called the "sampling estimated" method. The method can be not only applicable to straight navigation line, but also applicable to the curve navigation line, The method can produce high computing speed, and can calculate the accurate navigation line parameters, even if there are some holes and edge Interference in the navigation line.

The lateral distance can be replaced by the distance from the image centre to navigation line. One can calculate the navigation line midpoint according to the points of S, then calculate the distance from the midpoint to the image centre. Taking into account the heading angle obtained above, one can easily get lateral distance by using Pythagorean theorem.

The robot vehicle has four wheels, the two front wheels are driving wheels and the two rear wheels are caster wheels , the robot vehicle is steered by differential drive, and the proportional control method is used to control the robot movement. After obtaining the heading angle and the lateral distance parameters, one can get the control variables, the Velocity difference of the two driving wheels, by the experience proportional coefficient. Therefore, the robot position and posture real-time adjustment can be realized through controlling the difference of the driving wheels.

IV. STOP SIGN ID EXTRACTION

One can find out the pixels of grayscale , T1 , in the image, and set these pixels to white. Thus , one can get the statistic of connected regions with grayscale T2 and T3, respectively, and the color block is the stop sign feature if the two area are both equal, the two area centroid distance is invariant, and the both area aspect ratios are 2:1. In order to improve the veracity of image recognition, the tip-tilt image correction is needed before recognition, if the slope of a line segment connecting the two centroid is more than 15 degrees.

Next, we will discuss how to recognise the stop sign ID. In the counter-clockwise direction, one can orderly compute the grayscale distribution statistics of 8 regions around the block above the region of grayscale, T3. In order to recognise the ID of the block above the region of greyscale T3, for example, we first compute black pixels quantity in lower half of the block, and the block can be regarded as a black block if black pixels quantity is more than two thirds of half of the block,. Followed from analogy above , The colors of other blocks can be easily obtained. We may assume that the black can be set 1 and the white can be set 0, then an region comprised of 8 blocks around the stop sign feature can be formed an 8 bit binary number, which is the stop sign ID number.

In the robot practical operation, not every stop sign ID will always be recognised untill its appearing in the image. And the advantage of this kind of stop sign feature is that the recognition and positioning are easy and exclusive even if image gathered from different direction around the stop sign, and that the stop sign ID numbers are sufficient for the robot inspecting tasks in the power substation.

V. CONCLUSIONS

As a kind of intelligent robot, the power substation equipments inspection robot needs a reliable and stable control system. The robot system has been put into operation in Tianjin Electric Power Co., and the operation shows that the robot system can be fully meet the requirements of power subsation inspection task.

REFERENCES

[1] BAI Ya-wei,ZHENG Yuan-feng,et al. Substation Equipments Inspection and Defect Management System Based on Centralization Control Pattern[J]. Power System echnology, 2006,30(Supplement)：186-188.

[2] Zhao Jiaqing. Computer Centralized SCADA System on Unmanned 220kV Substation. Automation of Electric Power Systems. 2003, 27(8):78~80.

[3] Shen Xiang, Zhu Xiangying, Jin Naizheng. Design and Application for Unmanned Substation Remote Monitoring and Control System. Automation of Electric Power Systems. 2004, 28(2):89~90.

[4] Parker, L. , Draper, L. , “Robotics applications in maintenance and repair”, Chapter in Handbook of Industrial Robotics, 2nd edition, Shimon Nof (ed.), Wiley Publishers, pp. 1023-1036, 1999.

[5] Penin, L.F. , Aracil, R. , Ferre, M. , Pinto, E. , Hernando, M., Barrientos, A., “Telerobotic system for live power lines maintenance: ROBTET”, 1998 IEEE International Conference on Robotics and Automation, Volume 3, pp. 2110-2115, May 16-20 1998.

[6] Jean-Francois Allan, Ghislain Lambert, Samuel Lavoie and Stéphane Reiher, “Development of a mobile robotic platform for the underground distribution lines”, Proceedings of the 2008 IEEE/ASME International Conference on Advanced Intelligent Mechatronics pp.406-411, July 2 - 5, 2008, Xi'an, China.

[7] Li Xiangdong Lu shouyin etc. Design and analysis on the architecture of an intelligent iterative inspection robot. Robot. 2005, 27（6）：502-506.

[8] LynnRenee Fodrea. Obstacle avoidance control for the remus autonomous underwater vehicle[D]. Naval postgraduate school. Master thesis.2002-12.

[9] L. E. AguilarM. P. Soueres.M.Courdesses. S. Fleury. Rotust Path-following Controlwith Exponential Stability for Mobile Robots [C]. Proceedings of the 1998 IEEE International Conferenceon Robotics & Automation Leuven, Belgium. 1998-5.

[10] FANG Zheng, YANG Hua . Study on Embedded Intelligent Robot Platform. Robot . 2006,28（1）：54-58.

[11] QIN Zhi-bin;,QIAN Hui, ZHU Miao-liang. Implementation of Multi-agent Based Hybrid Architecture for Autonomous Mobile Robots. Robot,28（5）：478-482.

[12] Zhang Xiping. Constructing Experience for .Substation Remote Image Monitoring and Control System. Automation of Electric Power Systems 2004, 28(16):97~99.

[13] [Zhen zhaneg, Tu Guangyu, etc. Flow Control Realization for Integrative Information Transmission in Substation. Automation of Electric Power Systems. 2003, 27(24):40~44.

[14] Li Hengchao, Zhang Jiashu. Research of remote monitoring system based on embedded Web[J] . Journal of Southwest Jiaotong

[15] University,2003,38(3)：263-266.

[16] Fu Chuang, Ye Luqing, Yu Ren et al. Predictive maintenance for hydropower plant based on MAS and ANN[J].Proceedings of the CSEE,2005,25(6)：81-87.