An Image-based Intelligent System for Pointer Instrument Reading

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***Abstract* – This paper proposes an image-based system for pointer instrument reading (PIR). The main contributions are twofold. First, we introduce binary descriptor such as ORB(Oriented FAST and Rotated BRIEF) for registering the images of pointer instruments. Second, we propose a Circle-based Regional cumulative Histogram (CRH) method to finely locate the pointer. The CRH method is robust to illumination, and is relative fast compared to previous methods. Experimental results demonstrate the effectiveness and practicability of our image-based PIR system.**

Index Terms* – *Pointer instrument reading, ORB-based registration, circle-based regional cumulative histogram.

I. INTRODUCTION

Pointer analog instruments such as the thermometer and barometer are widely used in transformer substations and other power systems. Currently, most of them are still read by human, which is time and labor consuming. It has immense amounts of significant values to achieve an automatic reading system for pointer instruments.

To read the value of pointer instrument, several image-based methods have been proposed in recent years [1-8]. These methods mainly include two steps: 1) dial region detection and 2) pointer location. For dial region detection, most previous methods employ template matching [1,4] or ellipse fitting [2], which mainly rely on the prior shape feature. These approaches are effective and real-time for some special types of pointer instruments. However, they cannot generalize to our case where there are different types of circular instruments with different practical setups (e.g., different viewpoints, scales, and resolutions). As for pointer location, Hough transform with image subtraction method is perhaps the most popular scheme in most systems [3, 4, 5, 7, 8]. In our test, Hough transform is sensitive to the noise from scale values, scale lines, and other factors. And it is expensive in computational and memory cost, which is impractical to run in embedded devices. Also the actual operation pointer generally does not permit adjusting to the reference position for image subtraction method. Some works also directly scan the density along with the detected circle [6], and judge the location by a threshold. This method is fast but sensitive to illumination.

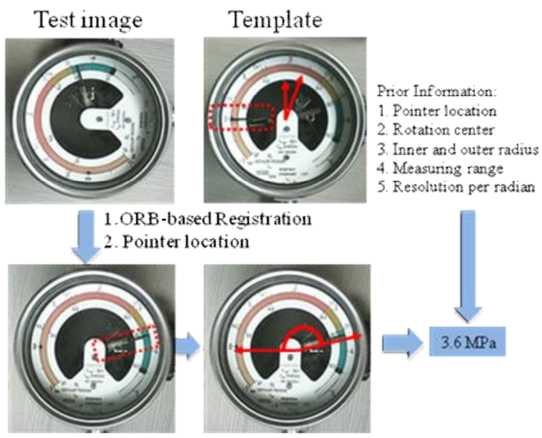


Fig.1 Our image-based system for PIR.

In this paper, we present a novel image-based intelligent system for pointer instrument reading (PIR), as shown in Fig.1. Specially, we first collect all the templates of the used instruments with their prior information such as *pointer location, rotation center, inner and outer radius, measuring range and the resolution per radian*. For a test image, to precisely align the test image over its template, we introduce image registration procedure based on an advanced binary descriptor (Oriented FAST[9] and Rotated BRIEF[10], ORB [11]). The registration based on ORB descriptor is fast compared to some other well-known descriptors such as SIFT [12] and SURF [13]. After registration, we propose a Circle-based Regional cumulative Histogram (CRH) method to finely locate the pointer. Specially, we first accumulate the density within a tiny patch along with the pre-processed ring between the inner and outer circles. Then, a histogram is yielded and the minimum location is the pointer location. Our CRH method is faster than Hough transform and is robust to illumination. Once the pointer location is obtained based on the aligned image, we can easily work out the reading with prior information.

The rest of this paper is organized as follows. The extraction of templates with their prior information, and the ORB-based image registration are described in Section II. The pointer location method is presented in Section III. The experimental results are exhibited in Section IV. We conclude the paper in Section V.

II. TEMPLATES AND REGISTRATION

This section describes the extraction of templates with their prior information, and the ORB-based image registration. In practical engineering applications, as a result of the different setups of camera (e.g., different viewpoints, scales, and resolutions), dial tilt and so on, the lens surface is not parallel to the dial. It will produce parallax [14] affecting PIR. Template and registration are utilized to solve these problems.

A. Templates and prior information

This subsection shows how to extract the prior information of the template image for various pointer instruments .We use four types of instruments in our experiments, as illustrated in Fig. 2. And we annotate the coordinates of key points for each type of pointer instruments. Information like the rotation center, inner and outer radius, location of the pointer, measuring range and the resolution per radian of template images is kept. Besides, we shift the template instrument into the middle of image to facilitate the calculation.

(a) (b) (c) (d)

Fig.2 Four types of pointer instruments.

B. ORB-based registration

This subsection gives the details of image registration based on ORB algorithm. For a test image, to precisely align the test image over its template and accurately locate the instrument region, we adopt image registration procedure using local binary descriptor (Oriented FAST and Rotated BRIEF, ORB). Registration between images $A(x)$ and $B(x)$, is to find a spatial transform T such that the two images match best under the similarity measure S [15]. Considering only the global spatial transformation with rigid, affine and projective in our situation, we simplify registration problem to matching and projection processing by the homography matrix H . The registration based on ORB descriptor is fast compared to some other well-known descriptors such as SIFT and SURF.

ORB. ORB, which is built on the well-known FAST (Features from Accelerated Segment Test) keypoint detector and the BRIEF (Binary Robust Independent Elementary Features) descriptor, is robust to noise, lighting, blur and affine transformation. While there are several problems should be fixed for taking FAST detector and BRIEF descriptor in ORB algorithm.

First, owing to the two drawbacks of FAST detector: 1) it does not produce a measure of cornerness and has large responses along edges; 2) it does not produce multi-scale features. ORB adopts 1) setting the threshold low enough to get more than N keypoints with a target number N of keypoints, ordering them according to the Harris measure and picking the top N points; 2) employing a scale pyramid of the image and producing FAST features (filtered by Harris) at each level in the pyramid, respectively. In addition, in order to describe the orientation of a keypoint, ORB uses a simple and effective measure of corner orientation--the intensity centroid, which gives a single dominant result.

Second, BRIEF descriptor, is a bit string description of an image patch constructed from a set of binary intensity tests, is very sensitive to in-plane rotation and it will result in low variance and high correlation with only steering BRIEF according to the orientation of keypoints. ORB obtains 256 good binary features through a greedy search algorithm to make final binary tests having high variance and lower correlation.

Matching. In this paper, the default parameters of ORB are used, and the size of descriptor is $n = 256$. Owing to the difference of light, affine and rotation transformation, we test various situations and choose the number for keypoints as 2000 in our experiments. Feature matching is executed by comparing the similarity of the descriptors, which can be expressed through the Hamming distance with XOR operation. LSH [16] is used to enhance the speed of finding the nearest neighbor. Similar to SIFT, the ratio T of the nearest and next nearest neighbor distance is used to match feature, and we choose the threshold as 0.8 which means that the feature point corresponding to the nearest neighbor distance is considered when $T < 0.8$

We take the video as input data and set the template image according given type of pointer instrument. After converting each frame into a gray image, we detect key points and extract ORB feature, and choose the stable input frame of which the numbers of matching pairs are larger than the threshold.

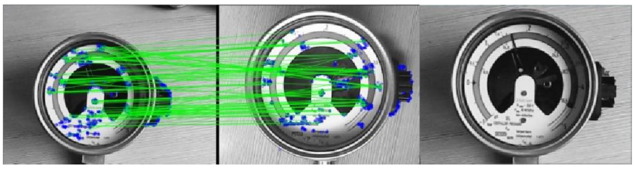
Projection.We conduct projection processing after getting stable input frame. Perspective transformation is a commonly projection transformation model expressing the relationship between two images, and it is based on the homography matrix H (a linear transform matrix used for image correction and registration). Conversion formula is as follows:

$$\begin{bmatrix} x' \\ y' \\ 1 \end{bmatrix} = H \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} \tag{1}$$

where x, y, x', y' are the keypoints' coordinates of the rows and columns of the template and test images respectively.

We also adopt the RANSAC algorithm [17] combined with the estimation method of homography matrix to remove the mismatch (outliers) and resolve the homography matrix H . Then the test image aligned over its template in space and the accurate instrument region can be located in the test image according to the formula (1). So we can see that the accuracy of matrix H is important which will be utilized in CRH method.

Fig. 3 depicts the image registration based on ORB algorithms: the template image is captured with the distance about 20cm and the viewpoint about zero degree rotation between the camera and dial, and the test image with about 25cm and 10-degree rotation, (a) is the matching result between the template and test images. (b) is the result of registration. It can be seen that the registration instrument region in the image is the same as its template which shows the image registration based on ORB algorithm works well.



(a) (b)

Fig.3 An illustration of image registration:(a) is the matching result, (b)is the registration result.

IV. POINTER LOCATION

The pointer in the instrument is always turned around the axis in the sector or circle region, and exhibits a deep color compared with a light dial. This significant feature can be utilised for PIR. In this section, we propose CRH method to finely locate the pointer after image enhancement.

A. Image enhancement

Generally, the original image obtained by CCD contains variation and noises due to changes of light, object projection and space radiation interference. Gaussian filter is adopted to remove random sharp noise. However, the image becomes blurred due to the smoothing operation. We use Laplacian sharpening method[18] to enhance the image contrast and make the details more clearly. Experimentally, we run smoothing process again after sharpening processing to obtain high contrast with clear appearance. Finally, the image is enhanced and it is better to get stable and accurate reading results.

B. Pointer location using CRH method

Fig. 4 shows the proposed CRH method. We first remove the interference areas such as numbers and symbols from the pointer rotation region of the template image through a preset intensity threshold, because their intensity values may be similar with the pointer. Then, after mapping operation through the inverse homography matrix H', we take the pointer as the only dark object in its rotation region of the test image. Further, the angle of the pointer can be located through a gray-scale histogram. Specific steps are as follows:

(1) Using the rotation center, inner (if Fig. 2 (b) or (d) is used, the value is zero) and outer radius from the priori information, we obtain the pointer rotation region $S_1=\{R_1,P_1\}$ of the template image which is a circular ring sector region. P_1 is the pointer region, and R_1 is the remaining region.

(2)We set intensity threshold T according to the dark features such as pointer, numbers and symbols on the dial. Then divide $R_1=\{R_{11},R_{12}...R_{1i}...R_{1n}\}$ into continuous tiny patches R_{1i} with each occupying 1-degree, and calculate the intensity value $I(u)$ ($u\in R_{1i}$) for all points within each patch. Points whose intensity value are greater than T are mapped to the corresponding region $R_2=\{R_{21},R_{22}...R_{2i}...R_{2n}\}$ in the rotation region $S_2=\{R_2,P_2\}$ of the test image through the inverse homography matrix H', thus R_2 also removes the numbers and symbols. Calculate average intensity value $M_{1i}=(\sum_{v\in R_{2i}} I(v))/K$ (Where $v=H'u, I(u)>T$, and K is the number of points within each patch) for each tiny patch R_{2i} to yield a histogram, and choose the minimum $M_1=\min\{M_{11},M_{12}...M_{1i}...M_{1n}\}$ and its index.

(3) Because the pointers of the test and template instrument may be at the same location, so step (2) did not consider the pointer region P_1. Therefore, we also calculate the minimum M_2 of average intensity value and its index for region P_2.

(4) Comparing M_1 with M_2, the smaller one represents the pointer location of the test image and its index is the pointer rotation angle from the horizontal line. According to the pointer measuring range and the resolution per radian, we can obtain the pointer reading by the linear relationship between the resolution per radian and angle.

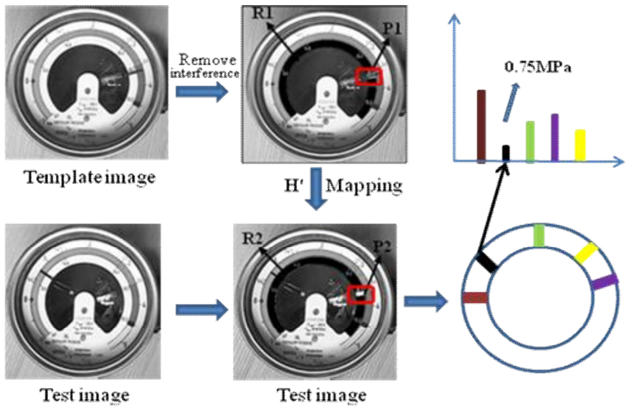


Fig.4 The CRH method for pointer location.

V. EXPERIMENTAL RESULTS

In this section, we will show experimental results of the proposed method. Experiments are taken on a PC with Intel (R) Dual-Core CPU, E5500 @ 2.80 GHZ, 4.00 GB of RAM and Windows 7 with VS2010. The resolution of digital camera is 640×480. Elapsed CPU time and absolute error are used to evaluate our method, where absolute error is obtained by actual readings and recognition readings. We take the first type pointer instrument of Fig. 1 as example which scaling range is -1~ 5MPa, and its template image is the same as Fig. 3 illustrated.

Table I shows the experimental results, the test images are captured with the distance about 25cm and the viewpoint about 20-degree rotation between the camera and dial in a sunny noon. The actual reading is the average reading of 6 persons. From the measurement results, the maximum error of indication is 0.02Mpa and the average recognition time is 324ms, which meet the requirements for real-time and preciseness in engineering.

TABLE I
EXPERIMENTS DATA OF FIRST TYPE POINTER INSTRUMENT

Actual readings (MPa)	Recognition readings (MPa)	Absolute errors (MPa)	Recognition time (ms)
-0.23	-0.22	0.01	332
-0.71	-0.70	0.01	319
0.06	0.08	0.02	325
0.73	0.75	0.02	312
1.25	1.25	0.00	322
1.63	1.61	0.02	330
2.25	2.24	0.01	332
3.23	3.25	0.02	340
3.75	3.74	0.01	316
4.04	4.05	0.01	312

To test the robustness of the method，we took two sets of images of the first type pointer instrument in our laboratory, one set with multiple viewpoints, the other with multiple scales. According to the data of experiments, we portray the error curve show in Fig. 5. We can see that the maximal absolute error is 0.02PMa when the viewpoint and scale respectively less than 60-degree rotation and 43cm, which greatly satisfy the actual installment requirements. It is proved that the method proposed by this paper is feasible.

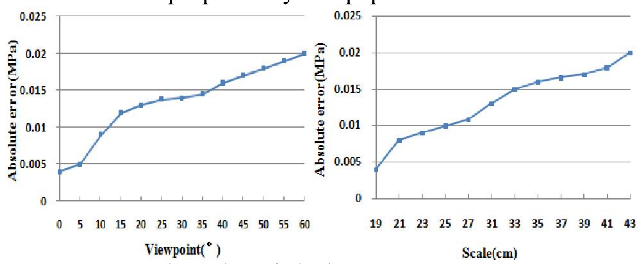


Fig. 5 Chart of absolute error curve.

VI. CONCLUTION AND FUTURE WORK

The paper presents a novel image-based intelligent system for (PIR). It adopts the ORB registration algorithm to detect the meter device region, solves the problem that the lens surface is not parallel to the dial and facilitates the setup of camera. Meanwhile, a new CRH method is proposed, which doesn't have to use subtraction method and Hough transform to determine the rotation center and radius. To improve the recognition speed, the method limits the angle's search range according to the specific instrument. The whole method has low complexity, good real-time and high recognition accuracy. For instruments with different shapes in measurement & instruments industry, the method can be used only by changing the rotation center and radius. As the method based on intensity comparison and the glass surface of instrument will produce high reflection whitening the image when the light is too strong, so the main error comes from the influence of illumination. For the case, we can add a polaroid in front of the lens to greatly reduce the light, so that image whitish phenomenon would be well improved. Next we will further improve the algorithm to make the PIR more accurate and lower computational time, and run it in embedded devices. In the electric power system, this method has bright applied prospects.

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