A Novel Scale Recognition Method for Pointer Meters Adapted to Different Types and Shapes

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***Abstract*— Nowadays plenty of pointer meters are used in the field of chemical industry and electrical power system. To avoid reading their indication manually, many algorithms based on computer vision have been proposed to read pointer meters automatically. These methods, however, are limited to meters whose scales are uniform, and their accuracy is vulnerable to the error in the recognition of a meter's center. In this paper, a novel automatic reading algorithm of pointer meters based on scale seeking is proposed to overcome the weaknesses of the existing methods. Differing from the popular angle-based methods, we obtain the indication of the meter by comparing the distances between the peak of pointer and its nearest scales. The position and values of all scales can be automatically acquired and inferred by using our scale seeking and value inference algorithms, which is independent of any prior information in a database. Experiments prove that the algorithm can be applied to both meters with uniform or non-uniform scales effectively.**

I. Introduction

In the field of chemical industry and electrical power systems exist many meters that can indicate states of the production lines and systems. A majority of these meters are pointer meters due to their strong resistance to electromagnetic interference, simple structure and low maintenance cost [1]-[3]. However, they do not have any digital interfaces and their indication is usually read manually, which is time-consuming and inconvenient [4]. Moreover, human errors are likely to appear due to the observation angle and visual fatigue, making human reading results unreliable [5]. Therefore, it is significant to find a more accurate, robust and repeatable way to read the indication of pointer meters [6].

In the past few years, many automatic reading algorithms based on computer vision were proposed to solve this problem. Alegria et al. proposed a meter reading method that obtained the pointer by image subtraction and transformed all scales into a horizontal line. The indication value was calculated through angle proportion [7]. Belan et al. proposed a segmentation-free approach that found the pointer directly on a gray scale image. Knowing the meter center and the position of the lower limit scale from a database, the reading was obtained according to the rotation angle [8]. Huo et al. first used perspective transformation to acquire the positive image. Then edge detection and Hough transform were used to recognize the pointer. Finally, the reading was obtain by the relation of pointer, zero-scale line and max-scale line [9]. Gao et al. proposed a reading method that used random sample consensus (RANSAC) to fit the meter circle and speeded up robust feature (SURF) method to detect a meter's region. Hough transform was utilized to find the pointer and the reading was calculated by the angle method [10].

The above methods can be applied to reading tasks to some extent, but their weaknesses are obvious. Most of them can be used in meters with uniform scales only, which limits their application to the non-uniform scale meters. Furthermore, they need to find the meter center and thus fail to read square shape meters whose centers are hidden behind the panel. Finally, prior information such as the position of lower and upper limit scales is needed, making it inconvenient to use. In order to overcome their drawbacks, we propose a novel automatic reading method based on scale seeking for pointer meters of different types and shapes. This work has made the following contributions.

- A novel scale seeking algorithm is proposed to recognize scales of a given meter. The iterative movement and dynamic adjustment of the searching box enable it to recognize all the scales regardless of length and inclination angles.
- Scale value recognition and inference methods are then presented, making it possible to get scale values printed on the meter panel automatically. The use of scales as one of the filter condition enables it to avoid recognizing words and symbols on the meter panel.
- A distance-based reading calculation method is proposed. Only the peak of the pointer and its nearest two scales are utilized such that it is possible to read pointer meters of different shapes.

The rest of the paper is organized as follows: Section II illustrates the detail of our algorithm. Experiments and results are presented in Section III. Section IV concludes this paper.

II. Recognition Algorithm

The algorithm proposed in this paper reads the indication of pointer meters using a distance-based method, i.e., the reading is calculated according to the relation of distances between the pointer and its nearest two scales. To realize it, the pointer and all scales need to be recognized and values of each scale are automatically determined for the calculation of reading. The work can be divided into five parts, namely pointer recognition, scale seeking, scale value recognition, scale value inference and reading calculation. The flow chart of the proposed algorithm is shown in Fig. 1.

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A. Pointer Recognition

Images captured from a camera usually contain complex background and noises, which interfere the recognition of a pointer. To avoid interference and simplify calculation, pre-processing including meter area extraction [11], graying, filtering and binarization should be taken to get binary image before recognizing the pointer.

Considering the fact that a pointer is usually the longest line in a meter, we use progressive probabilistic Hough transform (PPHT) [12] to recognize it. For each line that is found by PPHT, the following formula is used to select the longest one:

$$l = \sqrt{(x_s - x_e)^2 + (y_s - y_e)^2} \tag{1}$$

where (x_s, y_s) and (x_e, y_e) are coordinates of the start point and end point for the pointer respectively. We define that a start point for the pointer or scales is the point near the meter center, and an end point is the one far away from it, which is shown in Fig. 2. They can be determined by simply comparing the distances between line points and the meter center which is usually replaced by the image center in practice.

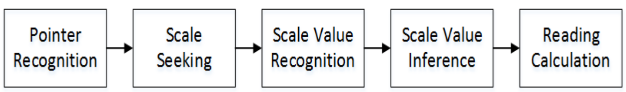

Figure 1. The flow chart of the proposed algorithm

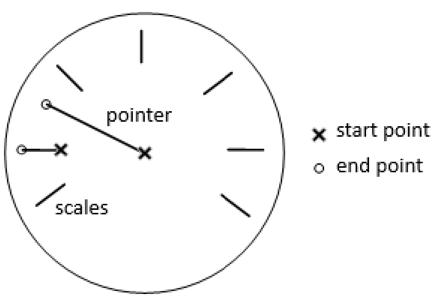

Figure 2. Start point and end point of the pointer and scales

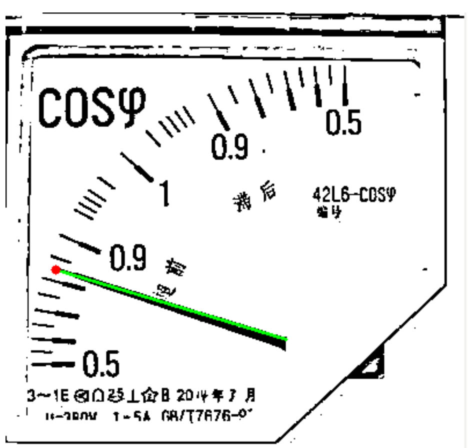

Figure 3. The recognized pointer

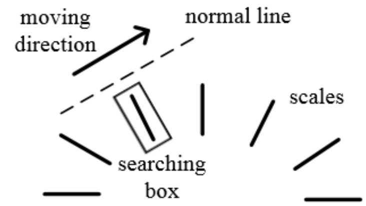

Figure 4. Movement of the searching box

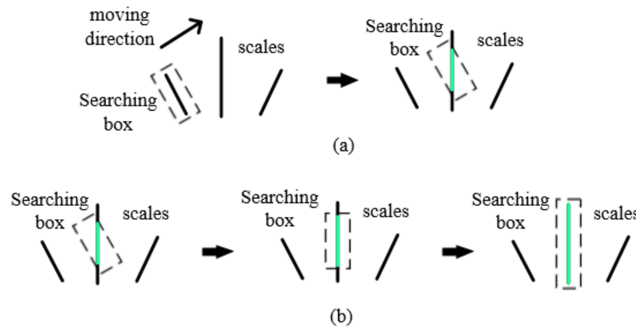

Figure 5. The process of seeking a certain scale (a) The fixed inclination angle and length (b) Adjustment of the searching box

Although the recognized pointer line does not completely coincide with the central line, it does not affect the reading accuracy because only the end point of a pointer is used in this algorithm. The recognized pointer with its end point denoted as a red dot is shown in Fig. 3.

B. Scale Seeking

The position of all scales on a meter panel can be determined automatically by using a scale seeking algorithm. Since scales are not independent of one another, we can seek the next scale according to the one found previously. Assuming that the adjacent scales have the same inclination angles, we move the current searching box forward along the normal direction of the previous scale, as shown in Fig. 4. The seeking process continues iteratively until no more scale is found within the maximum attempt count for seeking. When it comes to the initial condition of the searching box, we assign the end point of the pointer to its center and its inclination angle is the same as that of the pointer.

One of the difficulties in scale seeking is that a scale cannot be fully recognized if the inclination angle and length of a searching box are fixed. As shown in Fig. 5(a), only part of a scale is found. To solve this problem, the proposed algorithm adjusts the inclination angle and length of the searching box dynamically while recognizing the scale rather than moving it forward directly. This process ends when the newly recognized line is not longer than the previous one, and then the iteration of moving continues. The dynamic adjustment of the searching box is shown in Fig. 5(b).

As mentioned above, the inclination angle α of the scales and pointer can be calculated via:

$$\alpha = \begin{cases} \arctan\left(\frac{x_e - x_s}{y_s - y_e}\right), & y_e < y_s \\ sgn(x_e - x_s) \cdot 180° + \arctan\left(\frac{x_e - x_s}{y_s - y_e}\right), & y_e > y_s \\ sgn(x_e - x_s) \cdot 90°, & y_e = y_s \end{cases} \tag{2}$$

To move the searching box forward, we use:

$$\begin{cases} x' = x + s \cdot \cos\alpha \\ y' = y + s \cdot \sin\alpha \end{cases}, \quad dir = CW$$
$$\begin{cases} x' = x - s \cdot \cos\alpha \\ y' = y - s \cdot \sin\alpha \end{cases}, \quad dir = CCW \tag{3}$$

to update its center to the next position (x', y'), where s is the step length and *dir* is the searching direction flag.

In this algorithm, we use PPHT to find lines in the searching box. The specific steps are shown in **Algorithm 1** and the flow chart of this algorithm is shown in Fig. 6.

The above steps seek scales clockwise beginning from the end point of the pointer. To seek them counter-clockwise (CCW), just set direction flag *dir* to CCW in Step 1. The scale seeking process and result are shown in Fig. 7.

Algorithm 1. Scale Seeking of Pointer Meter

Input: The meter image *Img*, end point of the pointer (x_e, y_e), step length s, searching box length l and maximum attempt count M.
Output: Scale list L={scales}

1. Set direction flag dir = CW
2. **Initialization**: searching box center $c=(x_e, y_e)$, use formula (2) to calculate searching box inclination angle α, $m = 0$.
3. **Do**
4. Update center c using formula (3)
5. **If** PPHT → $Img = \varnothing$ **Then**
6. $m = m + 1$
   Else
7. **Do**
8. Get the longest line
   Update α using formula (2)
   Update c to the line center
   $l = l + 1$, $m = 0$
   While PPHT → *Img* is longer than previous line
9. Append previous line to L.
   End If
   While $m \le M$

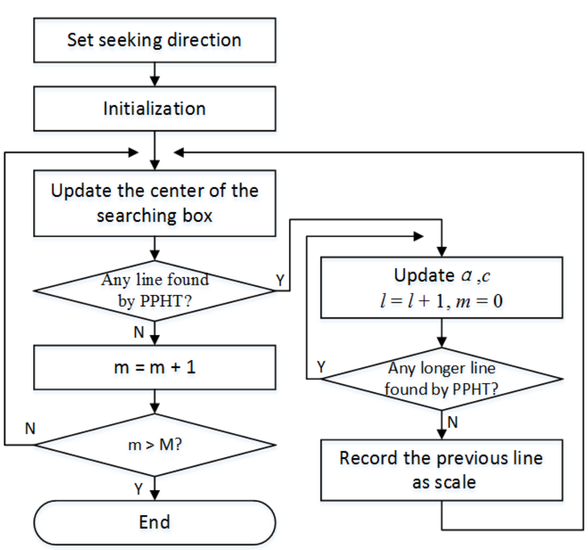

Figure 6. The flow chart of scale seeking algorithm

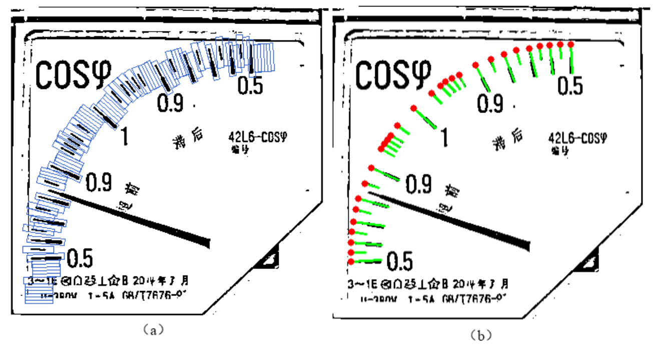

Figure 7. Result of scale seeking.
(a) The scale seeking process (b) The scales that are found

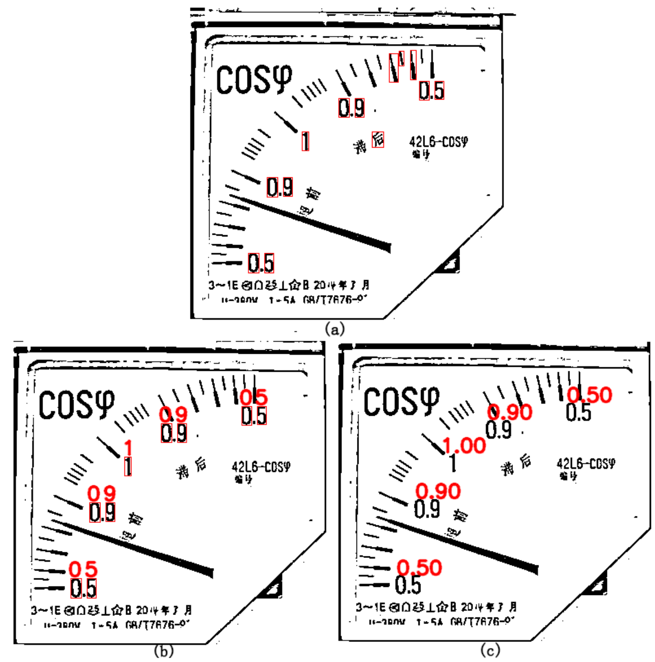

Figure 8. Result of scale value recognition (a) False candidates (b) The determined single number (c) Scale values combined from single numbers

C. Scale Value Recognition

In order to recognize the scale values automatically rather than getting them from the database as prior information, scale value recognition is utilized in this paper. This algorithm is based on connected domain analysis and neural networks [13]-[28].

We first find all connected domains of a binary meter image [13]. Then, traditional conditions including the ratio of height and width of minimum bounding rectangle and the ratio of pixel count and rectangle perimeter are used to filter irrelevant words and noises roughly. It can be seen in Fig. 8(a) that some scales and characters that are similar to numbers are wrongly identified as candidates. These false candidates can be removed by considering the distance between the connected domain and each scale for the reason that they are usually far away from any scale.

After finding all number candidates, convolution neural network (CNN) [14] is applied to determine the exact number. The determined single number is shown in Fig. 8(b).

To get the actual scale values, we need to combine group of single numbers to an integer via:

$$v = \sum_{i}^{n-1} d_i \times 10^i \tag{4}$$

In (4), number groups can be represented as $\overline{d_{n-1}d_{n-2}, \dots, d_i, \dots, d_1 d_0}$. For decimals, we fix the point behind the first number, i.e., $\overline{d_{n-1} . d_{n-2}, \dots, d_1 d_0}$. The recognized scale values are shown in Fig. 8(c).

D. Scale Value Inference

After recognizing the scale values from the meter, we need to determine which scales they belong to. Besides, since most of the scales do not have values printed on the meter panel, their values need to be determined using the scale value inference algorithm.

First, for each scale value that is recognized before, calculate the distances between its center and start point of all the scales. Assign it to the scale whose distance is shortest. Then, use formula (5) to determine values for the rest scales:

$$v_i = \frac{v_{02} - v_{01}}{n+1} \times i + v_{01} \quad ,i = 1,2,\dots,n \tag{5}$$

where v_i represent scales without values and v_{01}, v_{02} are the left and right scales that have been determined and nearest to v_i.

E. Reading Calculation

The method proposed in this paper calculates the reading of indication based on the relation of distances between the pointer and its nearest two scales. Hence no meter center or rotation angle is needed. Assumed that the end point of the pointer is (x_e, y_e) and a, b, c are the coefficients of line equation of the scale, the distance can be calculated as:

$$l = \frac{|a \cdot x_e + b \cdot y_e + c|}{\sqrt{a^2 + b^2}} \tag{6}$$

The reading can be determined using:

$$r = v_1 + \frac{l_1}{l_1 + l_2} \cdot (v_2 - v_1) \tag{7}$$

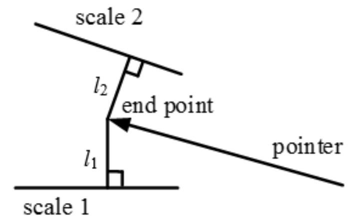

Figure 9. The distance-based reading method

where l_1 and l_2 are the distances from the end point of the pointer to the scales that are nearing to it respectively, and v_1 and v_2 are their values. The distance-based method is shown in Fig. 9.

III. Experiments and Results

In this part, experiments on scale seeking and reading accuracy are carried out to verify the robustness and effectiveness of the proposed method. The tested pointer meters include those with types of uniform scales or non-uniform scales, and shapes of circle or square.

The method is run on a computer with the following configuration: Intel(R) Core(TM) i7-5500U CPU @2.4GHz ×4, 500GB 2.5 inches Samsung SSD hard disk, 8GB 1600MHz DDR3 memory.

A. Experiment on Scale Seeking

The experiment on scale seeking is conducted to test the robustness and adaptability of the proposed method. In this experiment, we evaluate four circle meters and four square meters, two of which are meters with non-uniform scales.

The result is shown in Fig. 10. We can see that in spite of different pointer position, meter types and meter shapes, the scales can be precisely and effectively recognized, which shows the robustness of our method. Note that the proposed method can find scales of different length because the searching box will dynamically adjust its length in accordance with the scale.

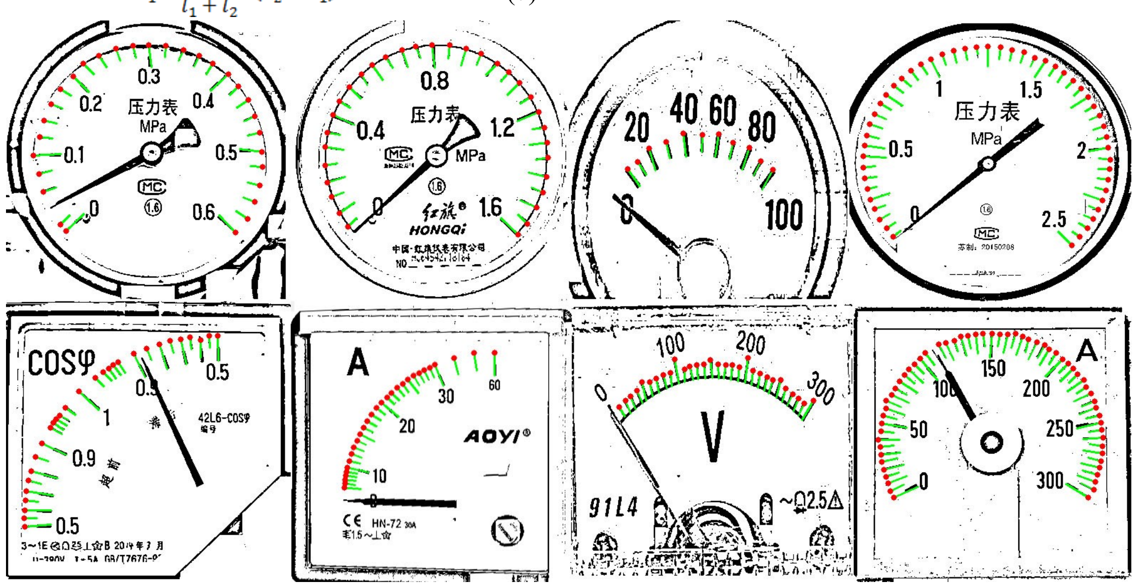

Figure 10. Scale seeking on different pointer meters

TABLE I. READING RESULT OF THE PROPOSED METHOD

Test case	pressure gauge							power factor meter			
	Manual reading values (MPa)	Algorithm of [9]			Ours			Ours			
		Algorithm reading value (MPa)	Absolute error (MPa)	Time (ms)	Algorithm reading value (MPa)	Absolute error (MPa)	Time (ms)	Manual reading values (MPa)	Algorithm reading value (MPa)	Absolute error (MPa)	Time (ms)
1	0.05	0.041	0.009	23.6	0.051	0.001	178.3	0.55	0.554	0.004	143.7
2	0.10	0.091	0.009	22.2	0.102	0.002	175.6	0.60	0.603	0.003	147.1
3	0.15	0.142	0.008	32.3	0.148	0.002	168.7	0.65	0.645	0.005	145.1
4	0.20	0.191	0.009	21.4	0.201	0.001	174.5	0.70	0.698	0.002	136.6
5	0.25	0.242	0.008	31.1	0.252	0.002	177.3	0.75	0.751	0.001	140.1
6	0.30	0.298	0.002	24.5	0.303	0.003	180.9	0.80	0.798	0.002	139.0
7	0.35	0.345	0.005	22	0.348	0.002	172.1	0.85	0.848	0.002	139.6
8	0.40	0.394	0.006	21.7	0.401	0.001	178.8	0.90	0.902	0.002	141.5
9	0.45	0.452	0.002	28.5	0.449	0.001	147.7	0.95	0.948	0.002	145.7
10	0.50	0.502	0.002	28.2	0.501	0.001	147.5	1.00	0.998	0.002	143.8
Average			0.006	25.55		0.0016	170.1			0.0025	142.2

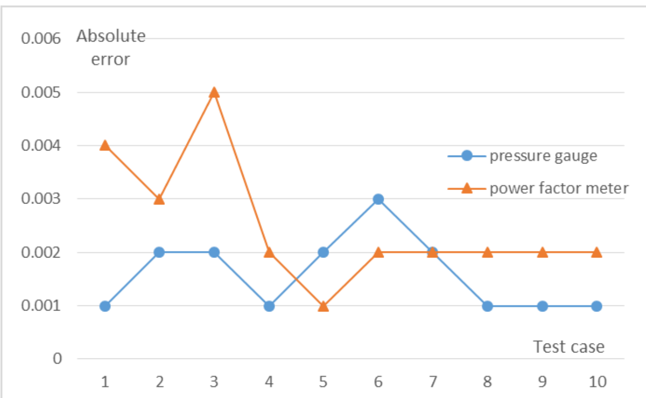

Figure 11. The absolute errors of the proposed method

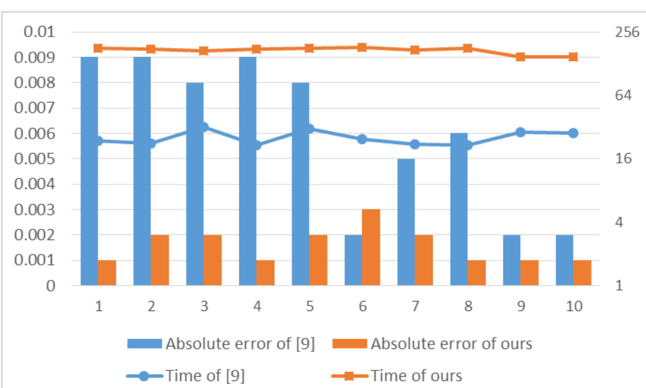

Figure 12. Comparison to current method

B. *Experiment on Accuracy and Rapidity*

To evaluate the accuracy and rapidity of the proposed method, we use it to read the indication of a pressure gauge and a power factor meter, both of which are widely used in the energy chemical industry and electrical power system. Moreover, to compare with our method, the algorithm of [9] is also tested on the same pressure gauge since it only works with meters of uniform scales.

The reading process is in real time, and we record the manual reading values, the algorithm reading values and the time consumed for different indication. The experimental result is recorded in TABLE I. The absolute error of the proposed method is shown in Fig. 11 and the comparison result is shown in Fig. 12.

From TABLE I and Fig. 11, we can see that for our method, the maximum absolute error is 0.005, the maximum time is 180.9 ms, the average absolute errors are 0.0016 MPa and 0.0025 respectively, and the average time is 170.1 ms and 142.2 ms. As shown in Fig. 12, our method performs more stable and achieves less absolute error than algorithm of [9]. A reasonable explanation for the higher time is that the proposed method includes additional steps such as scale value recognition, which gets rid of large amount of prior information and provides great convenience for researchers. These results show that our method is accurate and has high speed.

IV. CONCLUSION

In this paper, a novel automatic reading algorithm of pointer meter based on scale seeking is proposed, which can be applied to read both uniform and non-uniform scale meters. Differing from the existing angle-based algorithms, we seek all the scales on the meter and calculate the reading based on distances, making it possible to read square shape meters whose centers are hidden behind the panel. Besides, scale value recognition and scale value inference algorithms are proposed, which enables it to get rid of prior information from databases. The experiments prove that the proposed method is robust and accurate. Some proven network learning methods [22]-[26] should be tried to speed up the present training process in the future.

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