A Fast Region Segmentation Algorithm for Water Meter Image Based on Adaptive Seed Point Selection

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Abstract. This paper presents a fast region segmentation algorithm segmentation based on adaptive selection of seed points and without distance evaluation for water meter image. When the binary image of water meter is segmented, in order to better balance the precision and efficiency of segmentation, the algorithm adaptively selects some points in a specific line of the image as seed points. At the same time, the algorithm adopts a method similar to the connected component analysis algorithm, which takes the value of the point to be detected rather than the distance between the seed point and the point to be detected as the basis for region growth, which not only preserves the characteristics of high segmentation accuracy of the region segmentation algorithm, but also improves the segmentation efficiency. By analyzing the segmentation results of different algorithms for the same water meter image and their algorithm complexity, it is shown that the proposed algorithm has the highest segmentation efficiency, but the accuracy is not lower than other algorithms.

Keywords: Image processing · Region segmentation · Water meter · Connected component analysis

1 The Introduction

The traditional manual water meter reading is time-consuming and laborious, which is gradually replaced by the modern and automatic water meter digital reading. Some methods are installing smart water meters and reading the meter digital directly, but the original meter needs to be replaced [1–3]. Another method is to directly take images of the original water meter dial and send the images back to the server for image recognition. This method does not need to replace the water meter, has lower cost and simple operation, and becomes a better choice in some cases [4, 5].

There are many methods for water meter image recognition, some of which use deep learning to directly recognize water meter digital on the image, but this method requires a large amount of training for the algorithm and sufficient training samples [5–7]. Another approach is to segment the single digital of water meter and then recognize

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them easily using existing image recognition algorithms. In the face of different styles of water meters, this method is obviously more robust.

Therefore, the process of using the second method is usually to first segment the dial digital and then recognize the digital. In the process of digital segmentation of water meters, the main methods used are manual segmentation algorithm, vertical projection algorithm and connected component analysis algorithm [8–10]. The accuracy of manual segmentation method is very low, requiring a high degree of consistency of each water meter image, and the segmentation results are prone to appear unrelated connected component. Vertical projection algorithm segmentation accuracy and efficiency are not high. Although the connected component analysis algorithm is accurate in image segmentation, it needs to analyze all pixel points, so the algorithm has low efficiency. In the face of water meter images of complex scenes, its shortcomings will be more obvious.

Region segmentation algorithms are usually used to process color images or grey images [11]. Therefore, aiming at the binary image of water meter, this paper tries to improve the region segmentation algorithm, so as to improve the segmentation efficiency while maintaining a high segmentation accuracy.

The content structure of this paper is arranged as follows: The Sect. 2 analyzes the principles and shortcomings of manual segmentation algorithm, vertical projection algorithm, connected component analysis algorithm and region segmentation algorithm. The Sect. 3 describes the algorithm principle of the improved region segmentation algorithm in detail, including adaptive seed point selection and the realization of these operations without distance evaluation; The Sect. 4 analyzes the segmentation effect and complexity of manual segmentation algorithm, vertical projection algorithm, connected component analysis algorithm and improved region segmentation algorithm through experiments. The Sect. 5 is the summary of the paper.

2 Disadvantages of Binary Image Segmentation Algorithms

Manual segmentation algorithm is based on prior knowledge, directly in a specific position to segment the image. Although this method is simple and efficient, it relies too much on prior knowledge and requires highly consistent features of the images to be segmented, so the robustness of the algorithm is poor.

Vertical projection algorithm is usually used to deal with binary images. As shown in Fig. 1, assume that the image size is m * n. There are four connected components in the image: L1, L2, L3 and R, among which L1, L2 and L3 are the target connected components. The sum of the pixel values of each column is counted:

$$z = \sum\nolimits_{1}^{n} g \tag{1}$$

Where “z” is the sum of the pixel values for each column of pixels, and “g” is the pixel value for each point. Since the processed image is a binary image, the pixel values are only 0 and 1, so the value of “z” is actually the sum of the number of pixels with a pixel value of 1 per column.

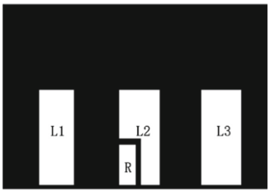


Fig. 1. Binary image

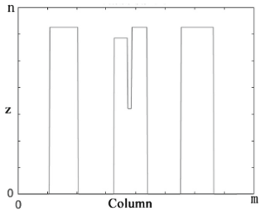


Fig. 2. The statistical results

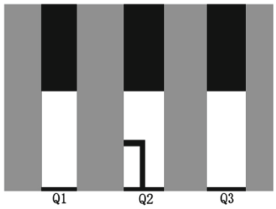


Fig. 3. Segmentation results

Statistics on the z of each column, the statistical results of m columns were plotted (see Fig. 2). The statistical graph presents the feature of "peak - trough - peak". Since the sum of pixel points with the value of 1 between the target components are 0, they correspond to the trough position in the statistical graph. Therefore, the trough position is taken as the image segmenting line to complete image segmentation. Through segmentation, Q1, Q2 and Q3 are obtained. The connected component R is not the target region, but it is segmented as a part of Q2 (see Fig. 3). Therefore, the accuracy of vertical projection method is poor.

Connected component analysis is a common binary image segmentation algorithm. The function of the algorithm is to find the connected component in the image. Before segmenting, you need to create an tag array of the same size as n * n, with the element value initialized to 0.

First, line-by-line detection is carried out from the first row of pixels in the image. If the value of the pixel point is 0 or the value of the element in the corresponding position of the tag array is 1, the pixel point is directly skipped. When finding the pixel value is 1, and its position in tag array element has a value of 0, will immediately change the value of the corresponding position of the tag array is 1, and to detect the four-neighbors, after the detect, if found a pixel value of 1 point, regard it as the point in the same connected component, the next point of the surrounding, until connected component cannot expand a new point came in, This segmentation is over.

As shown in Fig. 4 below, when the pixel point at position (1,2) is detected, its value is found to be 1, and the corresponding element value on the tag array is 0, so the value at position of the tag array (1,2) is changed to 1. When detecting the elements of four-neighbors, it is found that the elements at the positions (2,1) and (1,3) can also be extended in. Similarly, four-neighbors detection is performed on the elements at position (2,1) and (1,3), and the elements at position (2,3) are extended. At this time, no new points can be expanded. The segmentation is over. Figure 5 shows the tag array after the segmentation.

Next, the pixel point at position (1,3) is detected. Although its value is 1, the corresponding element of the tag array is 1, so it is skipped directly. Next, (1,4), (1,5)…(n,n) are detected in sequence. According to the rule of line-by-line detection, when the pixels at position (n,n) are detected, the image segmentation is completed and the algorithm is finished. The segmentation result is shown in the Fig. 6.

0	1	1	0	0	0	0	0	0	0
0	1	1	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	1	0	0	0	0	0	0	0	0
0	1	1	0	0	0	0	0	0	0
0	1	1	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

Fig. 4. Binary image

0	1	1	0	0	0	0	0	0	0
0	1	1	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

Fig. 5. Tag array

0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	1	0	0	0	0	0	0	0	0
0	1	1	0	0	0	0	0	0	0
0	1	1	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	1	0	0	0	0	0	0	0	0
0	1	1	0	0	0	0	0	0	0
0	1	1	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

Fig. 6. Segmentation results

As can be seen from the above, the algorithm needs to detect all pixels and find all connected components, which are not all connected components. Therefore, a large number of irrelevant connected components need to be screened, and the efficiency of the algorithm is reduced.

The region segmentation algorithm first needs to determine the seed points and thresholds. The determination of seed points can be divided into manual selection and automatic selection. The determination of threshold needs to select an appropriate value according to prior knowledge. As shown in Fig. 7, suppose the coordinates of the seed point S is (i,j), and the threshold is T. Sequentially detect a(i−1,j−1), b(i−1,j), c(i−1,j+1), d(i,j−1), e(i,j+1), f(i+1,j−1), g(i+1,j), h(i+1,j+1) these eight points. Perform the following calculation, where "x" is the pixel value of the current point:

$$T \leq |S - x| \tag{2}$$

If the above formula holds, then this point is merged and used as the seed point for the next round of detection, otherwise the next point is detected. When all these points are calculated, the current round of detection is completed, and the next seed point is replaced. Create an output array with the same size as the image, mark the points that have been detected, and then not detect again. Suppose that when the detection is completed, points e, f, g, and h are merged in. Next time, points b, c, S, g, and h will not be detected when using e point as the seed point next time, as shown in Fig. 8. Until the last seed point is replaced, and no new seed points are merged in, the algorithm ends. At this time, the output array is the result of this segmentation.

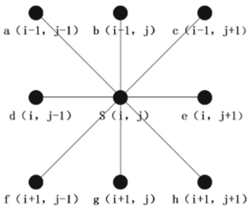


Fig. 7. Take S point as the seed point

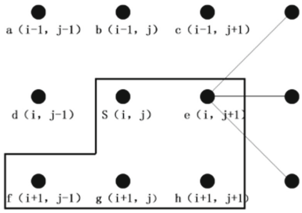


Fig. 8. Take e point as the seed point

3 Improved Region Segmentation Algorithm

Since the image to be segmented is a binary image, according to its characteristics, an improved region segmentation algorithm is proposed. This algorithm can automatically select seed points and does not need distance evaluation. As shown in Fig. 9, it is assumed that the size of the image is m * n.

middle row

0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	1	1	0	0	0	0	0	0
1	1	0	0	0	0	1	0	0	0	0	0	0	0
1	1	0	0	0	0	1	0	0	0	0	0	0	0
1	1	1	0	0	0	1	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0

Fig. 9. Image to be segmented

The abscissa of the middle row:

$$L = \lceil m/2 \rceil \tag{3}$$

Where "L" is the middle row, "m" is the height of the image. Because the digital in the water meter image must pass through the L line, all the pixel points in the L line of the image are taken as the alternative points of seed points. When a region segmentation is completed, the next seed point is found from the candidate points through the L line in order to segment all the connected components.

Therefore, the alternative point coordinates are (L,1), (L,2)…(L,n).

In addition to the output array with the size of m * n, A one-dimensional tag array A is set up to mark whether the elements in line L have been detected. The length of the array is equal to the number of alternative seed points. The array element value is initialized to 0, indicating that the corresponding pixel is not detected.

Start the detection from the point (L,1), and set the value of the array A[1] to 1, indicating that the element has been detected, and the detected point will not be detected. At this time, the value of point (L,1) is found to be 1, so the eight neighbors are detected with this point as the seed point.

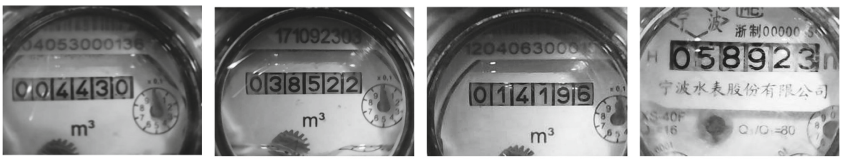
First, detect (L-1,1). Instead of evaluating the distance between (L,1) and (L−1,1), check the value of (L−1,1), which is 1, mark it in the output array, merge it in and serve as the seed point for the next round of detection. Then, the abscissa of (L−1,1) is judged. Since $L-1 \neq L$, the operation is finished. Next, check (L−1,2), (L,2), (L+1,2), and (L+1,1) in the same way. When check (L,2), in addition to completing the operation described before, since its abscis-axis is equal to L and its ordinate is 2, the value of A[2] needs to be set to 1. After the detection is completed with (L,1) as the seed points, the points just merged will be used as the seed points for a new round of detection until all the merged points are detected as the seed points and no new points are merged. The region segmentation is completed this time, and the output array is the connected component found.

Next, look for the next seed point based on array A and the binary image. The value of second alternative point (L,2) is 1, but because value of the A[2] is 1, it has already been detected, so it is skipped. Look at the third alternative (L,3) and set the value of A[3] to 1. The value of (L,3) is 0, skip this point and look at (L,4), (L,5), (L,6)…, when looking at (L,7), since the value of (L,7) is 1 and $A[7] = 0$, this point is taken as the seed point for A region segmentation. The operation of the final alternative points (L,N) is completed in the above way, the algorithm ends.

4 Experiment and Analysis of Result

4.1 Experiment Preparation

In order to verify the accuracy and efficiency of the improved region segmentation algorithm in water meter digital image segmentation, in this paper, four segmentation algorithms are used for experimental comparison, which are manual segmentation algorithm, vertical projection algorithm, connected component analysis algorithm and improved region algorithm. The experimental platform is MATLAB software, its version is 2018A.



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

Fig. 10. Images of ordinary household water meter

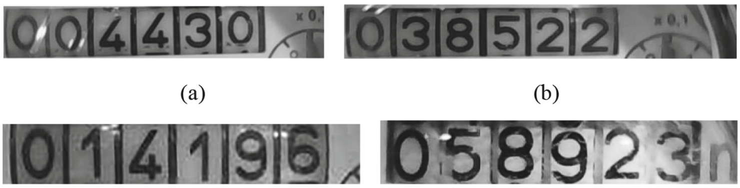
The experimental images are grayscale images of general household water meters and they are from some residential areas. Here are four images of water meters, a, b, c and d, with size of 640 px * 480 px (see Fig. 10).

4.2 Preprocessing of Water Meter Images

Because these water meter images contain not only the dial digits, but also the dial contour, number and other information, it is necessary to extract the images of the digital range before the images are segmented. The dial digits are concentrated in the center of the image, and the grey values of the digital pixel are small and the pixel points are continuous, which is obviously different from the background. The digital region of the water meter can be located in the following ways.

First, if the water meter image is not a grayscale image, it is first transformed into a grayscale image. Since the experiment uses grayscale images directly, this step can be skipped.

Next, the edge detection of the image is carried out. Robert operator is used in detection, because as a first-order differential operator, Robert is simple, the amount of calculation is small, and the reaction is sensitive to details [12]. In this step, a binary image containing the edges of each component in the water meter image is obtained.



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

Fig. 11. Digital image of water meter extracted by positioning

After the edge detection image is obtained, corrosion operation and closed operation are carried out [13]. There are still many small clusters in the image after the image closing operation, which affect the location of the digital range of the water meter, so they can be removed. It can be seen that the white area of the final image is the approximate area of the water meter digital. The digital range of water meter is extracted by projection segmentation algorithm [14] (see Fig. 11).

Next, the extracted image is processed by binarization. Binary image refers to dividing the values of all pixels on the image into 0 and 1. Thresholds need to be determined in the division, which can be obtained by using OSTU [15, 16]. Through binarization processing, all the values representing the digital gray scale of the water meter are 1 and the background pixel value is 0.The resulting binarization image also needs to trim the upper and lower edges (see Fig. 12).

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

Fig. 12. Binary image

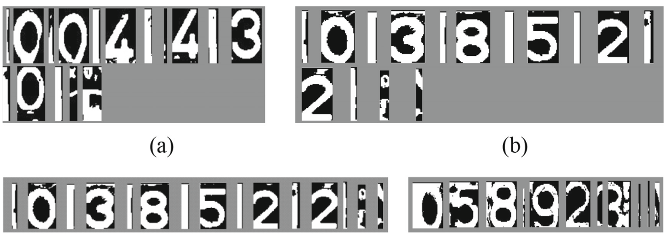
4.3 Segmentation of Water Meter Images

Use manual segmentation, vertical projection algorithm, connected component analysis algorithm, and improved region segmentation algorithm to segment the binary image.Moreover, the more disconnected components of the image to be segmented, the more obvious the number gap will be.

Therefore, in addition to the manual segmentation algorithm, other methods are divided into two steps: one is to segment the image, the other is to screen the segmentation results. Here are the components that were segmented by different algorithm (for easy seeing, the components image is placed on a grey background, same below) (see Fig. 13, Fig. 14, Fig. 15 and Fig. 16):

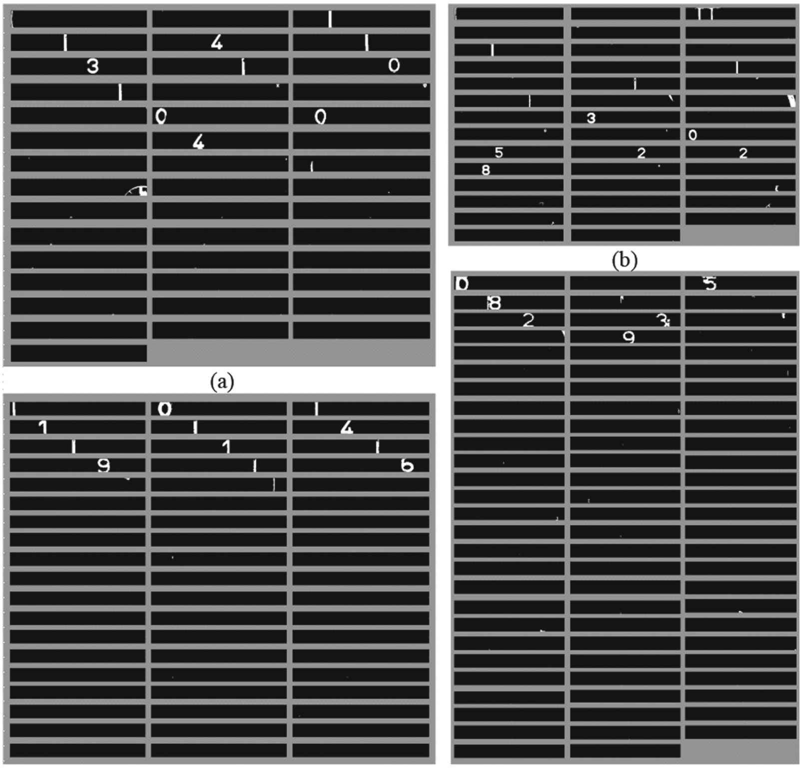
(a) (b) (c) (d)

Fig. 13. Manual segmentation algorithm



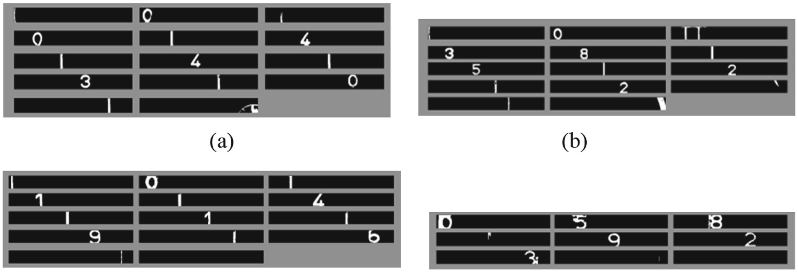
(a) (b) (c) (d)

Fig. 14. Vertical projection algorithm



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

Fig. 15. Connected component analysis algorithm



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

Fig. 16. Improved region segmentation algorithm

The following is the statistics of the total number of segmented components (Table 1):

Table 1. Components obtained by different algorithms

Segmentation algorithm	Manual segmentation	Vertical projection	Connected component analysis	Improved region segmentation
Image of a	6	16	43	14
Image of b	6	13	41	14
Image of c	6	15	57	14
Image of d	6	11	80	15

As can be seen from the above image and table, the total number of components segmented by the connected component analysis algorithm is far more than that of other algorithms. The total number of components segmented by the vertical projection algorithm and the improved region segmentation algorithm are similar. The more total number of obtained by segmentation, the more times of screening, thus reducing the segmentation efficiency.

The following are the results after screening the above connected components (see Fig. 17, Fig. 18, Fig. 19 and Fig. 20):

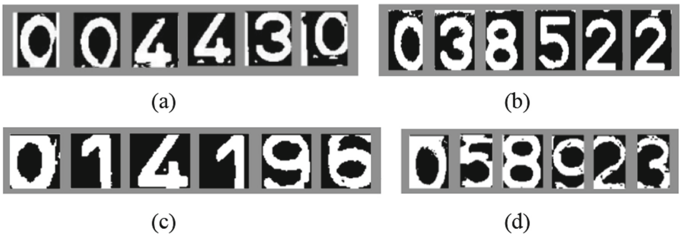


Fig. 17. Manual segmentation algorithm

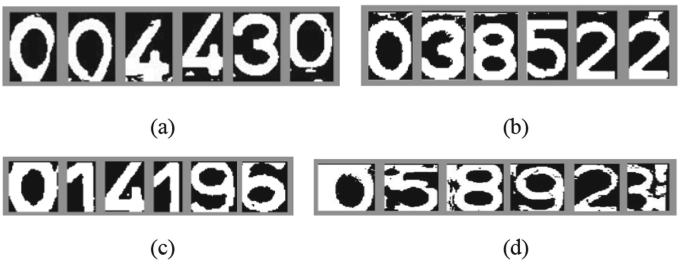


Fig. 18. Vertical projection algorithm

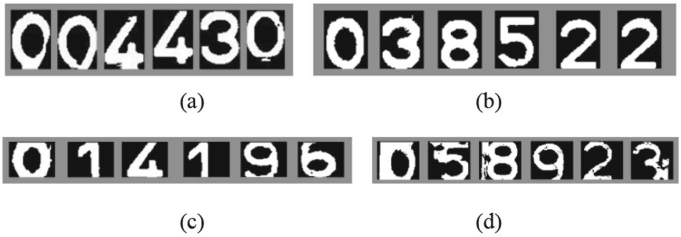


Fig. 19. Connected component analysis algorithm

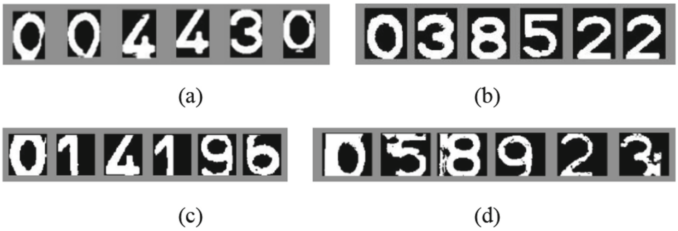


Fig. 20. Improved region segmentation algorithm

From the screening results, it can be seen that the segmentation results of manual segmentation algorithm have a large number of unrelated connected components, and the segmentation accuracy is poor. The vertical projection algorithm also has a small number of disconnected components. Both the connected component analysis algorithm and the improved region segmentation algorithm have the best segmentation accuracy because they do not contain unrelated connected components.

The time complexity analysis of the four algorithms is as follows (Table 2):

Table 2. Time complexity of the four algorithms

Segmentation algorithm	Manual segmentation	Vertical projection	Connected component analysis	Improved region segmentation
Best situation	O(1)	$O(n^2)$	$O(n^2)$	O(n)
Worst situation	O(1)	$O(n^2)$	$O(n^2)$	$O(n^2)$

It can be observed from the above table that the time complexity of the improved region segmentation algorithm in this paper is only higher than that of manual segmentation in the best case. In the worst case, except the manual segmentation algorithm, the time complexity is $O(n^2)$. However, since the vertical projection algorithm needs to count the sum of pixel values in each column, and the connected component analysis algorithm needs to detect the whole graph, the constant term of their time complexity is greater than 1. However, the improved region segmentation algorithm in this paper usually only detects a limited number of pixels, and the time complexity constant term is usually less than 1. Therefore, the time complexity constant term of the improved region segmentation algorithm in this paper is less than the vertical projection method or the connected component analysis method. Summarizing the above experimental results and theoretical analysis, the following conclusions can be drawn:

(1) Since the improved region segmentation algorithm does not need to detect all the pixels of the image, while the connected component analysis algorithm needs to detect all the pixels of the whole image, the improved region segmentation algorithm significantly reduces the meaningless components segmented compared with the connected component analysis algorithm, thus improving the efficiency of screening the segmentation results.
(2) Since the improved region algorithm segmented specific connected components, while the manual segmentation algorithm and the vertical projection algorithm segmented connected components based on prior knowledge, the accuracy and robustness of the algorithm were higher than those of the manual segmentation algorithm and the vertical projection algorithm.
(3) In general, because the improved region segmentation algorithm can only detect a limited number of pixels, it can only detect all pixels of the image in extreme cases, so its constant term of time complexity is smaller than the connected domain analysis algorithm and vertical projection algorithm.

5 Conclusion

This paper presents a fast region segmentation algorithm for water meter images based on adaptive seed point selection. Firstly, the principles and disadvantages of manual segmentation algorithm, vertical projection algorithm and connected domain analysis algorithm are introduced. Then the principle of the improved region segmentation algorithm is described in detail, including the process of automatic seed point selection and the improvement of the algorithm. Finally, the above algorithms are used to test a household water meter image. The experiment includes image preprocessing, the extraction of digital range, and the analysis of the experimental results of various segmentation algorithms and the time complexity of the algorithm.

Through the analysis, it can be concluded that the algorithm proposed in this paper retains the advantages of accurate segmentation of the region segmentation algorithm, and the sum of components segmented by the algorithm is small, so it is convenient for screening. Since the proposed algorithm does not need to estimate the distance and detect the whole image point by point, the accuracy of the proposed algorithm is not lower than that of other algorithms and the efficiency is improved.

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