A New Interface Detection Technology Based on Fusion Boundary Enhancement

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Abstract. An interface detection method based on fusion boundary enhancement is proposed, and can be used to extract the oil water interface in the test tube accurately. Boundary extraction is carried out by using differential operators, morphological operations of image processing. The fusion of Sobel differential operator and morphological operations is used to enhance image boundary. Differential operators search the derivative extreme value in the image. The morphological method detects the boundary based on expansion and corrosion of boundary. Otsu optimal threshold and boundary tracking method accurately locate boundary in image. Compared with the traditional boundary detection operator, the fusion boundary detector is capable of accurately extracting the oil water interface.

Introduction

With the decrease of oil reserves, the exploitation of heavy oil resources is becoming important. Produced heavy oil contains water. Separating water from oil is implemented by means of oil emulsion. The detection of oil water interface can be used to measure the water content in the oil. In the laboratory, the heavy oil is placed in the glass tube, and the emulsion is added to form the oil water emulsion layer [1, 2]. The water gradually separated from the oil, so the oil water interface is gradually formed. At present, the detection of interface in the test tube is mainly implemented in manual mode. The error of manual reading is relatively large. Because of the strong adhesion of heavy oil, the contact automatic detection [3-5] is difficult to resist heavy oil coherence, and can't be used for a long time. Video capture and analysis technique can be used in the interface detection, and automatically extract interface information. The result is objective and reliable.

Industrial camera collects the formation process of oil water emulsion interface in test tube. Video is delivered to the processor, and the core interface detection software is installed on the processor. Software automatically extracts the interface generating process. Inside the test tube, after mixing heavy oil with demulsifier, the water layer locates in bottom of the tube, and the oil layer lies in the middle of the tube, as shown in Fig.1. Heavy oil is bonded to the test tube wall, and as a result, the tube boundary containing heavy oil is ambiguous. The accurate detection of the interface is difficult.

Interface detection, in Image processing technology, is named as edge detection. Differential operator and morphology method are typical edge detection methods. The former mainly includes the first order differential and second order differential operator. The latter includes morphological corrosion, expansion, open and close operation methods [6, 7]. Both of which are based on template gradient operator. The wall of the test tube made of glass material is transparent. In the top of tube wall, adhesive heavy oil is hanging to the tube wall. Air and oil layer interface is concealed by noise information. Detected by conventional differential edge detection methods, the boundary of tube wall in the above position is cracked. In the bottom of tube, the water and test tube wall is transparent and the boundary information is not obvious. Partial boundary information of water areas is lost by differential operators.

Serious image noise is caused by heavy oil adhesion. Because of noise information, to extract interface of oil air interface, oil water interface by using differential operator is infeasible. Both of the water and glass tube are transparent, the interface is difficult to detect. Morphological methods may lost partial edge information, and tube boundary containing water layer is not completely by morphological methods. One of the two methods is difficult to extract the accurate interface location.

Fusion of these two methods, differential and morphological operation, is proposed in the paper. After image is fused by the above methods, the boundary gradient information in image is enhanced. Not all the large gradient amplitude pixels are boundary pixels, and gradient amplitude threshold criterion is required. The Otsu adaptive threshold method is used to obtain tube interface accurately [8].

A Fusion Boundary Enhancement method

Boundary enhancement is to extract gray value of each pixel neighborhood in image firstly. The enhancement algorithm can highlight the difference of the gray value of neighborhood pixels. Boundary enhancement is implemented by calculating the gradient amplitude and can enhance the test tube boundary. Differential operator detects the boundary by finding the maximum and minimum value of the first derivative image. And usually the boundary is positioned in the direction of the gradient. The morphology is used to find the boundary by combining corrosion and expansion methods. Fusion of morphological transformation and differential transformation, the boundary extraction results of image are superimposed. Boundary information can be enhanced further more.

The boundary detection algorithm is based on the first and second order derivative of the image intensity. Derivative calculation is sensitive to noise. Most of filters can reduce the effect of noise, but also lead to the loss of boundary strength. The bilateral filtering method is effective in the enhancement of the edge information and noise reduction.

After be bilateral de-noised, Fig.1 is described as image $f(x, y)$. Image $f(x, y)$ is be respectively enhanced by Sobel differential operator, morphological closing operation, morphological gradient method [9]. The three resulting images are defined as $f_s(x,y)$, $f_c(x,y)$ and $f_m(x,y)$. The gray value of the pixels in any position (x, y) within the three images is represented by eight binary codes. Eight binary codes of every pixel (x, y) in both of the image $f_s(x,y)$ and the image $f_c(x,y)$ are calculated by Or operation at every bit. The eight binary codes of every pixel (x, y) in both of the Or resulting image and the image $f_m(x,y)$ are calculated continuously by Or operation at every bit. The resulting image is defined as $f_F(x,y)$. $p(x,y)$ is any one pixel of the image $f_F(x,y)$. The formula of the fusion boundary enhancement method is the following:

$$f_F(\mathrm{x,y}) = f_s(\mathrm{x,y}) \mid f_c(\mathrm{x,y}) \mid f_m(\mathrm{x,y}) \tag{1}$$

Among the three images, $f_s(x,y)$, $f_c(x,y)$ and $f_m(x,y)$, for each pixel $p(x,y)$ of them, if all of the three binary code value of the k-th bit of any one pixel $p(x,y)$ are 0, the binary code value of k-th bit of corresponding pixel $p(x,y)$ in the image $f_F(x,y)$ is 0. Any one of the three binary code value of k-th bit of $p(x,y)$ are 1, the binary code value of k-th bit of $p(x,y)$ is 1.

The interface extracted by Adaptive Otsu threshold

The boundary enhanced image $f_F(x,y)$ is binarized by adaptive Otsu threshold method[10]. Threshold method is one of image segmentation methods, gray thresholds are selected to discriminate two or more classes of gray levels in an image. An adaptive Otsu threshold algorithm with the advantages of both bi-windows and Otsu threshold can treat gray image into high-performance binary image. For each pixel, its adaptive threshold is the maximum of intensity variances between neighborhood object pixels and neighborhood background pixels. The step of adaptive Otsu threshold method is as follows.

(1) Select two neighborhoods for every pixel.

For each pixel $p(x,y)$ in image of $f_F(x,y)$, select two windows with the sizes of $n\times n$ and $m\times m$ respectively, which are determined by image objects (n and m are odd integers). The inspected pixel

p is located at the center of windows.

(2) Calculate the variance of neighborhood image.

If the gray level of neighborhood $s(x, y)$ of pixel $p(x,y)$ is h, these pixels in neighborhood $s(x,y)$ are divided into two groups by threshold j ($0<j<h$-1). Group A includes all these pixels whose gray values are less than or equal to j, and group B includes the other pixels whose gray values are greater than j. ($w_A(j)$,$M_B(j)$) and ($w_B(j)$,$M_B(j)$) denote the number of pixels and the average gray level in groups A and B respectively. M_T is the average gray level value of all the pixels in image $s(x,y)$, and $\sigma^2(j)$ is the variance between the two groups.

(3) Calculate the optical neighborhood threshold.

The variance of each gray level j ($0<j<h$-1) is calculated by formula (2). The gray value corresponding to the greatest variance is the resulting threshold T of image $s(x,y)$. $T_{Otsu}(N_p^n,j)$ and $T_{Otsu}(N_p^m,j)$ are determined by maximal between-class variance $\sigma^2(j)$, denote the two optimal window thresholds of pixel p.

$$\begin{cases} T_{Otsu}(N_p^n, j) = \arg\max_{0\le j<l}\{\sigma^2(j)\} \\ T_{Otsu}(N_p^m, j) = \arg\max_{0\le j<l}\{\sigma^2(j)\} \end{cases} \quad (2)$$

(4) Binarize image.

For each pixel p, the minimum gray value between $T_{Otsu}(N_p^n,j)$ and $T_{Otsu}(N_p^m,j)$ is chosen and pixel $p(x,y)$ is thresholded by formula (3). Finally, the binary image $f_b(x,y)$ for all indices x and y is obtained.

$$f_b(x,y) = \begin{cases} 0, & f_F(x,y) < \min\{T_{Otsu}(N_p^n, j), T_{Otsu}(N_p^m, j)\} \\ 1 & \text{otherwise} \end{cases}, \text{for each } p \in f_F(x,y) \quad (3)$$

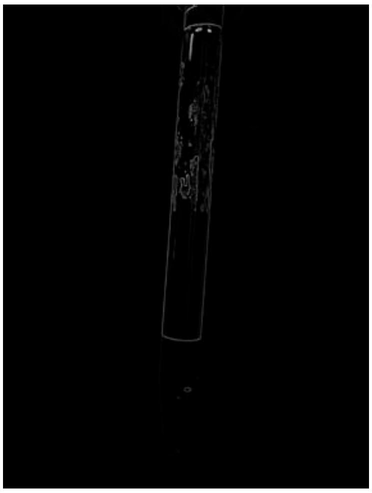
Boundary fusion enhancement experiment

Fig.1 is the image of a test tube in which heavy oil is be separated for oil water mixture. Water is in the bottom of the tube, and its color is near to the glass tube. Heavy oil is located in the middle of the tube, and has high viscosity. The top wall of tube is bonded by heavy oil.

Fig.2 is the result image resulted from bilateral filterer. The noise in Fig.2 is obviously less than in Fig.1. Fig.3 is the boundary gradient image obtained by the Sobel edge extraction method. Boundary information in the Fig.3 is highlighted, but the upper right corner boundary of the tube is fuzzy. Fig.4 is the morphological gradient image of Fig.2, the boundary of Fig.4 is smooth and nearly complete. The intensity of boundary information in Fig.4 is also weak. Fig.5 is the fused image of Fig.2, which is calculated by formula (1). The boundary information in Fig.5 is strengthened and complete.

Fig.1. The original tube image

Fig.2. The bilateral filtering image of Fig1



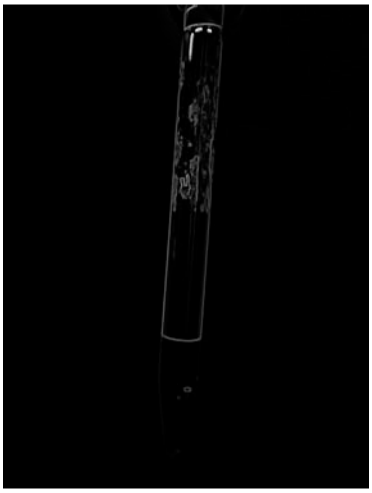
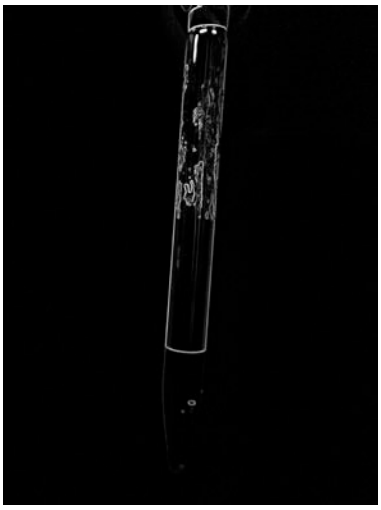


Fig.3. The Sobel gradient image of Fig.2   Fig.4. The morphological gradient image of Fig.2

Fig.6 is the binary image of Fig.5 by adaptive Otsu threshold method. Trace the boundary from the binary image, and obtain the boundary contour of test tube. Boundary fitting is implemented by minimum external rectangle. Fig.7 is the external rectangle fitting image. By means of affine transformation, the tube in Fig.7 is being put in vertical position, and showed in Fig8. The oil water interface is marked in the Fig.8.



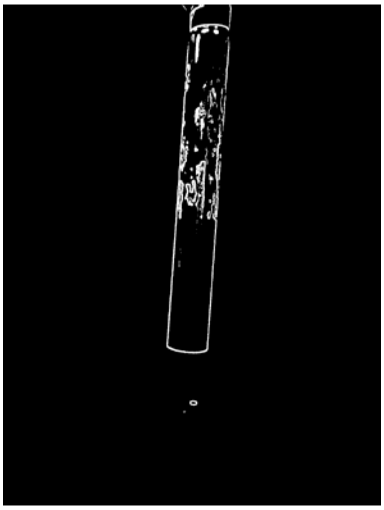


Fig.5. The fused image of Fig.3 and Fig.4 by formula (1)   Fig.6. The binary image of Fig.5

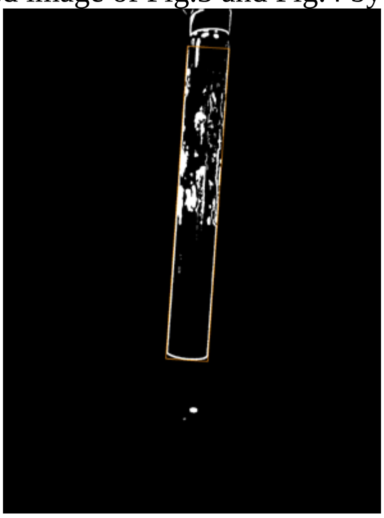


Fig.7. The external rectangle fitting image   Fig.8. The vertical tube and marked interface

Conclusion

A new interface detection technology based on fusion boundary enhancement technology is proposed, in which differential operator is combined with the morphological gradient operation. The method is used for extracting water oil interface in glass tube. Both the tube boundary and oil water interface information are enhanced. The boundary experimental result of the new method is better than differential operator or morphological gradient operation.

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