Real-time detection and tracking method for liquid surface of glass container

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Abstract

To overcome the problems of dynamic liquid surface measurement of glass containers, such as low detecting precision, complicated operations and poor stability of test, a new kind of non-contact liquid surface automatic detection method based on machine vision was proposed. By combining the glass container liquid surface movement and structure characteristics, using gradient difference of inter-frame and KCF tracking algorithm, combined with similarity matching accurately extract liquid surface region. Determine the height of liquid glass containers, realizing real-time tracking and positioning of the glass container moving surface. Experiment results show that when the minimum unit of glass container is 1 ML, the average error is within a quarter of a milliliter, the average mean square error is less than 10^{-1}. The verification process is relatively stable, the false positive is within 1%, and the accuracy of the liquid surface can meet the measurement requirements of the relevant industries.

Keywords

KCF tracking; Machine vision; Motion tracking; Similarity matching; Verification of glass containers.

1. Introduction

Glass containers are widely used in the life, medical and chemical engineering. The accurate measurement of the glass container liquid surface directly affects the liquid content. And it is essential. Currently, image processing technology has been widely used in glass container flaws detection and liquid flow rate detection and other fields. However, at present, the liquid surface detection of the glass container adopts artificial detection. It is inefficiency, high cost, vulnerable to external environment and subjective factors. Therefore, it is significance to automatically detect the liquid surface of glass container based on image processing technology.

Glass containers have many specifications on account of the different environment and application. Therefore, the shape of the concave surface is not fixed when the liquid is deposited in different glass containers. As shown in Fig. 1, the color of commonly used glass containers can be divided into transparent color, brown and milky backside stripes, and the non-transparent color makes the liquid surface of the container less recognizable in the image. In the process of liquid injection, it causes liquid surface morphology to be unstable, which makes the accurate detection and tracking of the liquid level difficulties. The liquid surface detection and tracking of glass container is applied in industrial environment, which requires high robustness, good real-time ability, and high-accuracy.

Fig. 1 Examples of common glass containers

Huang et al [1]. proposed a method for detecting the liquid surface by processing the liquid surface image with the benchmark. It uses the refraction principle of light. Identify the position of the benchmark in the virtual fracture point of the liquid surface, and determine the height of the liquid surface indirectly. However, there is a large deviation between the position of fracture point and the lowest position of the liquid surface, so this method has low accuracy.

Sun et al [2]. proposed the method of using the container parameters and the gray-scale features of the no-liquid region to determine the height of the liquid surface by calculating the relative distance between the liquid surface and the top of the container. However, this method is only applicable to the liquid surface measurement of the known container parameters, and it is less suitable for complex, brown glass containers.

Sun et al [3]. proposed the method of using grayscale projection of the glass container image obtained in the horizontal and vertical direction. It uses the gray-scale features of the liquid surface area to locate the height of the liquid surface. But if the container has the tick mark, the result of its gray-scale projection will interfere with the liquid surface measurement. And this method is sensitive to light intensity, low robustness, unable to meet the requirements of industrial metrology stability and accuracy.

Xu et al [4]. proposed a method of locating the liquid surface by template matching. The container level image is matched by intercepting the liquid surface area image in the glass container as a template. This method is high accuracy for the same type of container, but the template needs to be rebuilt for different types of containers or liquids. The operation is complicated and inefficient.

Meng et al [5]. improved the above methods, using the linear filtering and Otsu [6] algorithm to extract the liquid surface area, and then through the Harris corner detection to determine the location of liquid surface. However, this method is only applicable to transparent glass containers, and this method is in-valid for opaque or low light-transmission containers, such as the milky backside stripes glass container.

To solve above problems, this paper presents a method for the detection and tracking of liquid sur-face based on inter-frame gradient difference and combining with KCF [7, 8, 9] (Kernelized Correla-tion Filters) and similarity matching [10]. Firstly, in order to reduce the pitch parallax caused by the liquid surface rise and fall [11], this paper builds a set of imaging system of glass container liquid surface. Pre-adjust the horizontal position of the camera and the liquid surface through the electric slider. Then, the initial frame is extracted as the reference image, and the similarity matching is made with the single frame image after sampling from the frame. The dynamic region of adjacent frames is calculated by using the inter-frame gradient difference [12-14]. It initializes and uses KCF to track the region of the liquid surface. Finally, similarity matching and KCF tracking are calculated as results to obtain the liquid surface region, and locate the lowest liquid surface as the liquid surface positioning result. The block diagram of the imaging system and liquid surface tracking method is shown in Fig. 2.

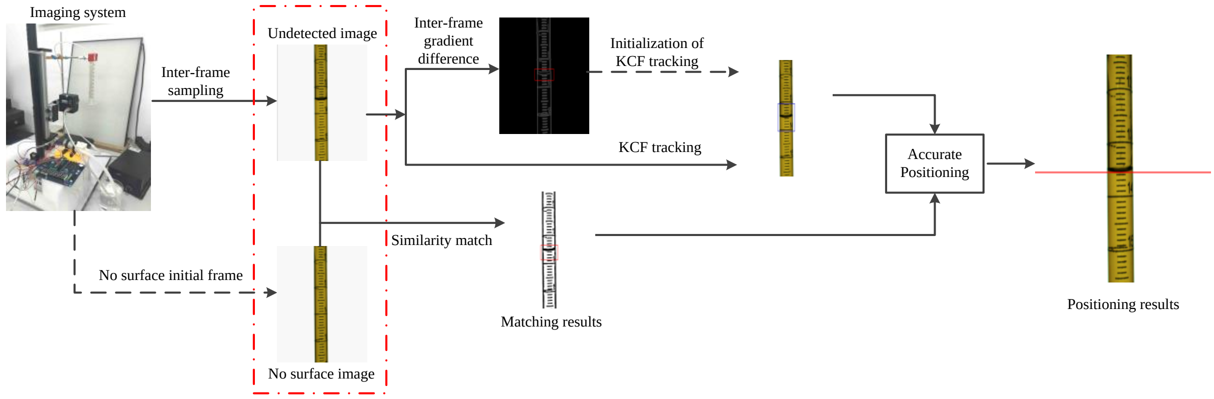


Fig. 2 Block diagram of algorithm

2. Imaging System

The glass container liquid surface detection based on image processing, its imaging system mainly uses the pointolite or camera position fixed. It has the problems of illumination unbalance, strong interference environment light and pitching parallax bigger. For the above problems, this paper sets up an imaging system based on area light source and electric slider. It is shown in Fig. 3.

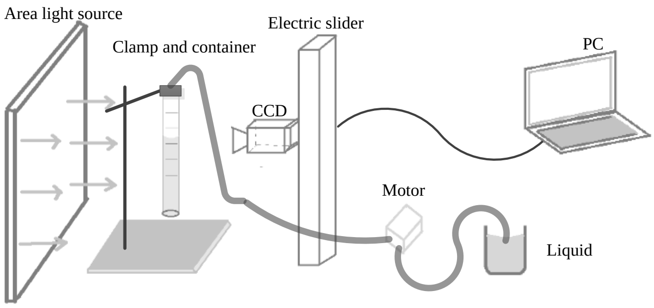


Fig. 3 Imaging system diagram

The system mainly consists of the light source, liquid filling and image Processing. The light source adopts the area light source, which is composed of LED array and has good uniformity of light. It can effectively reduce the problems such as heavy shadow and light spot caused by the light of complex environment. The liquid is drawn by the hose through the injection motor and injected into the glass container fixed by the holding platform, it is injected slowly along the wall of the pipe, the speed of it controlled by the injection motor. Image processing part consists of CCD camera, electric slider and PC. The camera is used to heads-up the liquid surface of the glass container to reduce the visual error caused by the pitch of the parallax. Then, image information is transmitted to the PC for process and display in real-time.

3. Initial Positioning

Firstly, the glass container without liquid was used for image acquisition. No liquid surface image was obtained as a reference image, which was captured by CCD camera in real-time. The real-time images were similarity matched with reference image. Then, the inter-frame gradient difference is used be-tween the real-time image and the acquired image. The KCF tracking algorithm is used to locate the region of suspected liquid surface.

3.1 Similarity Matching

During the image acquisition, there is a slight gesture offset of the glass container, and the tick mark of the glass container interferes with the positioning of the liquid surface. Similarity matching can ignore slight gesture offset and interference. And the suspected liquid surface is determined by comparing the region similarity of the real-time image with the reference image.

The detection image and the reference image are graying respectively, and then binarized using Otsu algorithm to obtain images I and O respectively. Pixels having a value of zero in the image I and the image O are taken as sample sets P_i and P_o, re-spectively. The sample point d corresponding to the sample point d' of the nearest neighbor search [15] is adopted, where the sample point d is from the sample set P_o and the sample point d' is from the sample set P_i.The Euclidean distance [16] is shown in Eqn. (1).

$$S_i = \sqrt{(d_x - d'_{ix})^2 + (d_y - d'_{iy})^2} \tag{1}$$

Where, (d_x, d_y) represents the coordinates of the sample d. S_i is the Euclidean distance of the sample d with the sample d'_i.

$$S = \min\{S_1, S_2, \cdots, S_i\} \tag{2}$$

Where, S represents the nearest distance of sample d. Set distance threshold S_U, if $S < S_U$ considers the match to be successful, and remove sample d' from the sample set P_i to sample d, otherwise it will not be processed, as shown in Eqn. (3).

$$P_i = \begin{cases} P_k & S < S_U \\ P_i & S \geq S_U \end{cases} \tag{3}$$

Where, P_k represents the excluded sample set. Using Eqn. (1)~(3) to search all samples in P_o, the largest connected region in the sample set P_i is the suspected liquid surface region.

3.2 Inter-frame Gradient Difference

In the dynamic changes of liquid surface, the glass container position is fixed in the adjacent frames. The dynamic liquid surface is extracted from the inter-frame gradient difference between the real-time image and the adjacent frame image.

$$G = \begin{bmatrix} F'_x \\ F'_y \end{bmatrix} = \begin{bmatrix} \dfrac{\partial F}{\partial x} \\ \dfrac{\partial F}{\partial y} \end{bmatrix} \tag{4}$$

In Eqn. (4), F represents the original image and G represents the gradient image of the image F.

$$k(x,y) = \begin{cases} 255 & g_1(x,y) - g_2(x,y) \geq K_U \\ 0 & g_1(x,y) - g_2(x,y) < K_U \end{cases} \tag{5}$$

Where, $g_1(x,y)$ represents the pixel value of the previous frame G_1 at (x,y). And $g_2(x,y)$ represents the pixel value of the previous frame G_2 at (x,y). K_U is the threshold obtained by Otsu [6], and $k(x,y)$ represents the pixel value of the result image K at (x,y). K is the image of dynamic change obtained through Eqn. (4) and (5).

3.3 KCF Tracking Algorithm

The inter-frame gradient difference provides the first detection of liquid surface dynamic changes in the image. The KCF tracking algorithm is used to calculate the strongest response position of the target region in the next frame image as the tracking result. The KCF target input is updated and the liquid surface position in the subsequent image is tracked. The KCF algorithm needs to shift and sampling in the target region. It need establish a sample circular matrix and Fourier diagonalization.

$$X = F \cdot diag[\hat{x}] \cdot F^{H} \tag{6}$$

Where, F represents the Discrete Fourier Transform matrix, and $\hat{x}$ represents the Discrete Fourier Transform of single sample x. $diag$ represents the diagonalization of vectors. For linear problems, linear regression is used to solve the sample training problem. w minimizes the least square error between sample x and target y of the function $f(z) = w^{T} z$, z denotes the target's characteristic and transforms into a regression:

$$\hat{w} = \frac{\hat{x} \odot \hat{y}}{\hat{x}^{*} \odot \hat{y} + \lambda} \tag{7}$$

Where, $\hat{y}$ is the Discrete Fourier Transform of the regression target y of the sample x. λ is the regularization parameter that controls the over fitting, and $\hat{w}$ is the Discrete Fourier Transform of the parameter w.

For the nonlinear problem, the kernel regression is used to solve the sample training problem. $w = \sum_{i} \alpha_i \varphi(x_i)$ is the objective function, which is converted into $f(z) = \sum_{i} \alpha_i k(x_i, z)$, $k(x_i, z)$ is the kernel function of sample x_i and z. The derivation is transformed into regression:

$$\hat{\alpha} = \frac{\hat{y}}{\hat{k}^{xx} + \lambda} \tag{8}$$

Where, k^{xx} is the self-correlation of the first row vector of the circular matrix, and $\hat{k}^{xx}$ is the Fourier transform of k^{xx} is the real vector.

The response of each sample is calculated by Eqn. (9) by means of w or α in the linear regression equation.

$$\hat{f}(z) = (\hat{k}^{xz})^{*} \odot \hat{\alpha} \tag{9}$$

Where, $f(z)$ is the response vector of all the samples, and the largest element in vector $f(z)$ means that the sample corresponding to the element has the strongest response. It is the liquid surface region of detection.

4. Accurate Positioning

According to the similarity matching and KCF tracking algorithm, the suspected liquid surface area is identified. Then, R_1 and R_2 are the rectangular region as the results. The inter-frame gradient difference or the upper frame detection region is denoted as R_3.Suspected liquid surface regional relationship is expressed as:

$$I = \begin{bmatrix} 1 & 1 & 1 & 0 & 1 & 0 & 0 & 0 \\ 1 & 1 & 0 & 1 & 0 & 1 & 0 & 0 \\ 1 & 0 & 1 & 1 & 0 & 0 & 1 & 0 \end{bmatrix} \tag{10}$$

Where, the elements of matrix I represent the intersection of two pairs of suspicious regions. 1 represents the intersection, and 0 represents the disjoint. The matrix I column shows the existence of various situations.

$$C = \begin{bmatrix} C_{R_1R_2} & C_{R_1R_3} & C_{R_2R_3} \end{bmatrix} \tag{11}$$

In Eqn. (11), C_{xy} in matrix C represents the union of region x and region y, which is $C_{xy} = x \cup y$. And the liquid surface region is $S = CI$. Manually detect the liquid surface, looking for the lowest point of the liquid surface as the position. The image of the liquid surface region is a set of points. The maximum vertical axis of the point is the lowest height of the liquid surface. It is the position of liquid level.

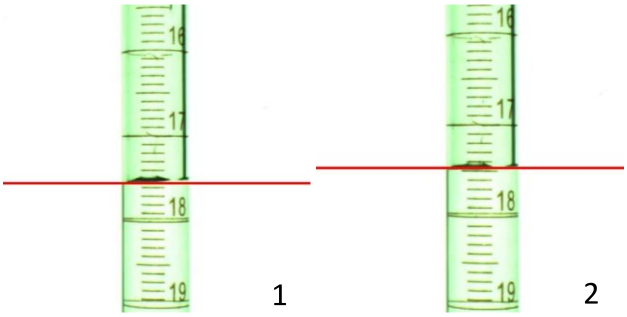
$$H = \max\{h_1, h_2, \cdots, h_i\} \tag{12}$$

Where, h_i represents the height at each point in the set. And H is the height of the liquid.

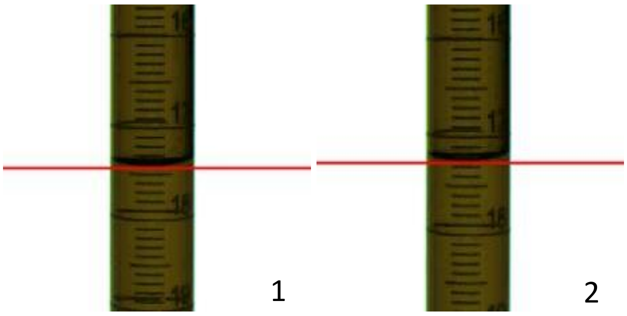
5. Experimental Analysis

5.1 Stability Analysis

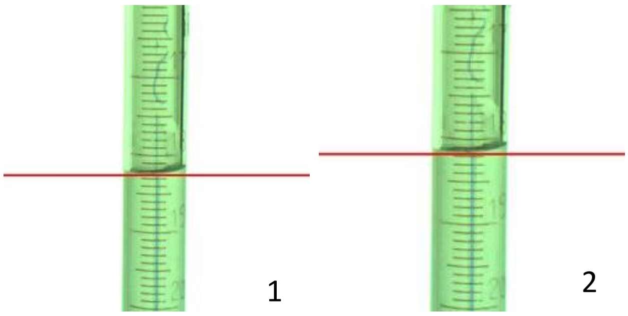
Select transparent, brown and milky backside stripes glass containers for liquid surface detection and tracking. The detection and tracking of the liquid surface is shown in Fig. 4. The sampling sequence is shown in the lower right corner of image. The sampling interval is five frames.



(a) Transparent glass container



(b) Brown glass container



(c) Milky backside stripes glass container

Fig. 4 liquid surface detection and tracking results

The transparent glass container in Fig. 4 is a 20 ml burette. The brown glass container is a 25 ml burette. And the milky backside striped glass container is a 25 ml burette. In this paper, 20ml and 25ml of transparent color, brown and milky backside striped glass containers were selected. Three experiments were tested in each glass container. The light intensity and liquid injection speed were adjusted appropriately before each experiment. Table 1 shows the test results.

Table 1 False positive of glass container

Category	Number of frames	Number of false	False positive
Transparent 20ml	6674	23	0.34%
Transparent 25ml	6154	12	0.19%
Brown 20ml	5512	28	0.51%
Brown 25ml	6358	31	0.49%
Milky 20ml	4864	42	0.86%
Milky 25ml	5748	37	0.64%

The statistical results show that the detection and tracking stability. The false positive of Liquid surface detection and tracking is less than 1%. It meet the production needs.

5.2 Accuracy Analysis

The experiment was conducted to extract the transparent 100ml cylinder, brown 20ml burette and milky backside striped 25ml burette. Part of the data is shown in Tables 2, 3, and 4 from sampling of tracking and detection results at regular intervals.

Table 2 Error of transparent glass container (ML)

Standard values	Detection value	Error	Standard values	Detection value	Error
37.1	37.0	0.1	56.0	56.1	-0.1
39.2	39.0	0.2	57.9	58.0	-0.1
41.1	41.0	0.1	60.0	60.0	0
43.2	43.1	0.1	61.0	61.0	0
45.0	45.0	0	62.8	63.0	-0.2
46.9	47.1	-0.2	64.0	64.0	0
49.0	48.8	0.2	65.9	66.0	-0.1
50.9	50.3	0.6	67.0	67.0	0
52.6	52.8	-0.2	68.8	69.0	-0.2
54.3	54.8	0.5	70.4	70.0	0.4

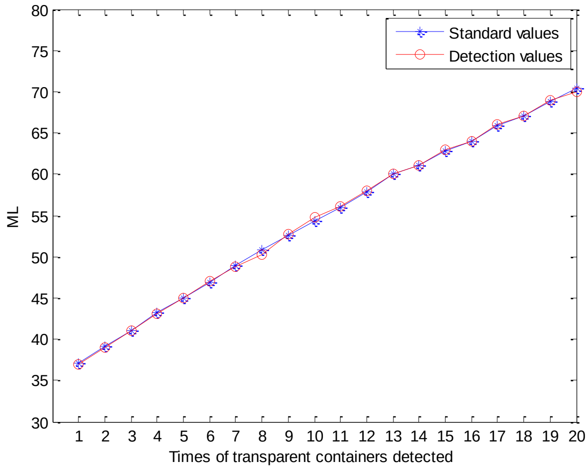
Table 3 Error of brown glass container (ML)

Standard values	Detection value	Error	Standard values	Detection value	Error
16.00	16.00	0	13.57	13.52	0.05
15.69	15.71	-0.02	13.50	13.47	0.03
15.40	15.40	0	13.42	13.38	0.05
15.10	15.05	0.05	13.20	13.18	0.02
14.78	14.81	-0.03	12.93	12.92	0.01
14.50	14.51	-0.01	12.85	12.85	0
14.20	14.22	-0.02	12.80	12.77	0.03
13.90	13.93	-0.03	12.60	12.58	0.02
13.70	13.65	0.05	12.30	12.30	0
13.61	13.58	0.03	12.00	12.00	0

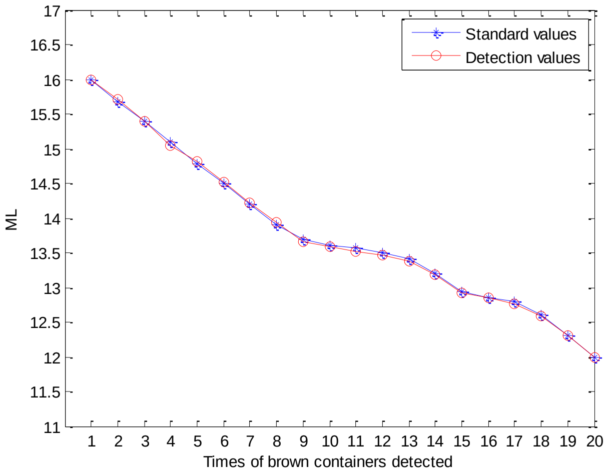
Table 4 Error of milky backside striped glass container (ML)

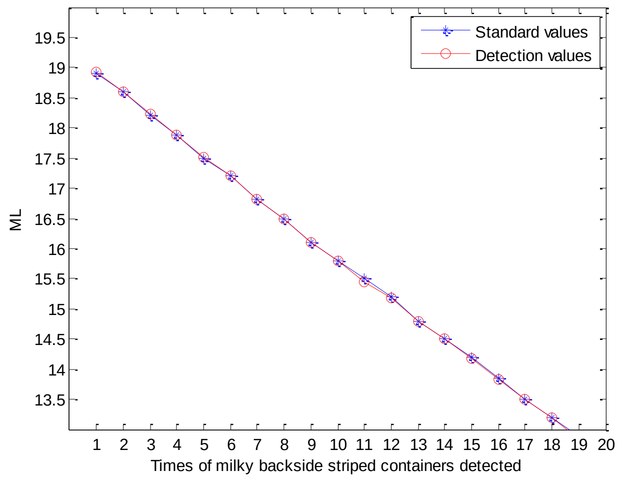
Standard values	Detection value	Error	Standard values	Detection value	Error
18.90	18.93	-0.03	15.50	15.45	0.05
18.60	18.60	0	15.20	15.17	0.03
18.20	18.23	-0.03	14.80	14.80	0
17.88	17.88	0	14.50	14.50	0
17.50	17.51	-0.01	14.20	14.17	0.03
17.20	17.20	0	13.85	13.82	0.03
16.81	16.82	-0.01	13.50	13.50	0
16.50	16.50	0	13.20	13.20	0
16.10	16.10	0	12.90	12.86	0.04
15.80	15.79	0.01	12.60	12.58	0.02

The Standard values and the Detection values line chart are shown in Fig. 5.



(a) Transparent glass container





(b) Brown glass container (c) Milky backside stripes glass container

Fig. 5 Glass container actual measured value and the measured value comparison chart

The error is mainly composed of systematic error and visual error. The statistical experimental results obtained the mean square error (MSE) of the liquid surface tracking and detection results of the transparent glass container (100ml), the brown glass container (20ml) and the milky white backside striped container (25ml). It shows in Table 5:

Table 5 MSE of data

Transparent container	Brown container	milky backside striped glass container
0.0278	$3.0395*10^{-4}$	$2.6816*10^{-4}$

As shown in Table 5, the size of the MSE is related to the minimum unit of glass container tick mark. The minimum unit for transparent glass containers is 1 ML, and the minimum unit for brown glass containers and milky backside striped containers is 0.1 ML. The error and MSE are small, indicating that the detection value and the actual height of the liquid are small, and the measurement accuracy can meet the production demand.

6. Conclusion

This paper sets up a glass container liquid surface imaging system. It eliminates the pitch of the parallax. In this paper, similarity matching, inter-frame gradient difference and KCF tracking algorithm are used to obtain the suspected liquid surface region. The lowest point of the concave surface is accurately positioned as the liquid height. Experiments show that the proposed algorithm enhances the stability of liquid surface detection and tracking. It is suitable for the liquid surface detection and tracking in a variety of conventional glass containers and improves the liquid surface detection accuracy. Compared with the traditional method, the detection efficiency is significantly improved and reduces the false detection rate. The design of the liquid surface detection and tracking program is feasible. The detection accuracy and speed can meet the requirements of industrial measurement.

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