Image Mosaic in Visual Detection of Wellbore

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Abstract—Based on the research on the visual detection system, this paper analyzes the characteristics of wellbore video (image), proposes the key techniques of image processing, and designs the methods of image mosaic. The experiment results show that when the image correction, the perspective transform, the image registration, and image fusion are implemented, a panoramic image of wellbore can be obtained. This study provides a new perspective for the visual detection and the technology reserves for further quantitative evaluation of visual detection.

1. Introduction

Downhole wellbore detection is of great engineering significance to ensure stable production of oil wells. Common wellbore detection methods include multi-arm wellbore diameter, electromagnetic flaw detection, ultrasonic wave, etc. Multi-arm diameter is used to measure the change of inner diameter for wellbore detection [1]; electromagnetic flaw detection logging is based on electromagnetic induction principle to measure wellbore thickness [2]; and ultrasonic wave logging is based on ultrasonic principle.
to measure wellbore thickness [3]. Visual logging can also detect downhole wellbore. Visual logging is intuitive, efficient and highly reliable [4]. In 2017, Xi'an ShiYou University developed a new generation of VideoLog, which can transmit full frame rate HD-video over ordinary armored cables [4]. VideoLog visual logging equipment is widely used in wellbore detection, falling fish fishing, downhole operation quality evaluation and downhole accident treatment, and has achieved good application results. At present, visual logging results can only be qualitative evaluated and interpreted, while quantitative evaluation will be the development direction of visual detection. Quantitative evaluation requires correlation processing of detection video (image). The key technologies of video (image) processing include image eccentricity correction, image angle transformation (vertical view transforms to front view), image expansion transform (cylindrical image expands into rectangular image) and image mosaic (panoramic mosaic of rectangular image).

Based on the study of the visual detection system, this paper analyzes the characteristics of the detection video, puts forward the key technology of visual image processing, and finally takes the image mosaic as the key research content, designs the image registration and image fusion method, and gives the actual processing results of downhole wellbore. The processing of visual detection image provides a new detection perspective for visual detection of wellbore and lays a foundation for visual quantitative evaluation in the next step.

2. Visual Detection System

2.1. Composition of Visual Detection System
The visual detection system is mainly composed of ground system, logging cable, downhole transmission unit, downhole video coding unit, and industrial camera as shown in Figure 1. Under the illumination of visible light source, the industrial camera completes the continuous video shooting of the target area with a certain focal length and angle of view. The downhole video coding unit encodes the video uploaded by the camera in a certain format, and the encoded video is uploaded to the downhole transmission unit. The downhole transmission unit completes the transient storage and high-speed transmission of downhole video. Logging cables are the transmission medium for power and video. The ground system mainly realizes the functions of ground control instruction issuing, downhole video receiving, downhole video decoding and storage, etc. With the logging cable down, the downhole wellbore and media video results are displayed and stored by the ground system. Before the whole test, it is required to clear the well so that the liquid in the well can meet the conditions of visible light transmission.

2.2. Features of Visual Detection Video
The visual detection system requires the well fluid to have certain light transmittance during well logging, and the video obtained by the camera is the short-distance wellbore video. Since the camera is
located above the wellbore, the detection video angle is overlooking angle, thus the video image will be deformed, that is, the image close to the lens is larger, while the image far from the lens is smaller. In order to facilitate the observation, angle of view conversion and image correction are needed. When the downhole detection system is lowered, the motion video (image) is shown in Figure 2. In Figure 2, the white ring is the wellbore coupling surface (this is caused by the strong reflection of the coupling surface), and the small white-spot is the liquid bubble in the wellbore. The motion video can be regarded as the composed of multiple frames of images. For the convenience of description, the following are described by images instead of videos.

![Figure 2 Motion video (image)](image)

3. Detection Image Processing Key Technology

3.1. Image Eccentricity Correction

When the camera is located in the center of the wellbore (center), the wellbore center, camera mirror center and imaging center are all on the z axis. The imaging of the wellbore near the mirror plane is larger, while that far from the mirror plane is smaller, as shown in Figure 3. When the image result is projected onto the xoy plane, the sidewall imaging result is a symmetric ring, as shown in Fig.3(b). If the observation point a is selected in Fig.3(a), the imaging results correspond to the midpoint a’ in Fig. 3(b).

When the camera deviates from the wellbore center (eccentricity), the wellbore center, mirror center and image center are not on the same straight line. Setting the mirror center on the z axis to construct the three-dimensional coordinate system, as shown in Figure 4. For simple description, assume that the camera in Figure 4 deviates from the wellbore center $y_0$ unit along the negative y axis direction. The wellbore imaging results are projected on the xoy plane, as shown in Fig. 4(b). In Figure 4(b), $y'_0$ is the small circle center (i.e. the imaging center at the lower boundary of the wellbore), $y''_0$ is the large circle center (i.e. the imaging center at the upper boundary of the wellbore), and $a''$ is the imaging point of observation point a. For the same target wellbore, when the camera is eccentric, the imaging results are asymmetric in the xoy plane. However, image symmetry can be achieved by translating the image, that is, in Figure 4 (b), the image in Figure 4 (b) will coincide with the image in Figure 3 (b) by translating the small circle by $y'_0$ unit along the positive y direction and translating the large circle by $y''_0$ along the positive y direction, so as to achieve eccentricity correction.

![Figure 3 Center Image of camera in wellbore](image)
In engineering, centralize the camera as much as possible by adding a centralizer. Strictly speaking, however, the camera still has eccentricity and rotation in the well, so subsequent image processing needs to be corrected.

### 3.2. Image Expansion Transformation and Correction

Because of the angle of view, the video image obtained by the camera is a vertical view. For quantitative detection and analysis, the angle of view transformation (that is, the vertical view image is converted into the front view image) and the expansion transformation are needed for the image after the eccentric correction. The overhead ring image in Fig. 3(b) is expanded into a rectangular front view image, and the result is shown in Fig. 5. The expanded relation is:

\[
\theta = \begin{cases} 
\arctan \frac{y}{x} & x \geq 0 \\
\pi + \arctan \frac{y}{x} & x < 0
\end{cases}
\]  

\[r = \sqrt{x^2 + y^2} \]  

Take the positive x direction in Figure 3 (i.e., in Figure 5, \( \theta = 0 \) ) as the starting point, expand a circle counterclockwise (corresponding to one week of the target wellbore), expand the width of the ring as the height of the rectangular image (corresponding to the height of the target wellbore), and the observation point is \(a'\). By expanding the transformation, the vertical view image can be transformed into a front view image.

### 3.3. Image Mosaic

The expanded rectangular image was registered and fused together, as shown in Fig. 6, to generate a complete front view rectangular image of the wellbore, so as to facilitate the quantitative evaluation of wellbore detection.
4. Image Mosaic Method

4.1. Image Registration Method

Image registration is a process to obtain two or more images with overlapping areas at different times and on different platforms for optimal matching [5]. Image matching includes geometric distortion correction, unification of different spatial coordinates, etc. [6]. Image registration is completed by translation, rotation, scaling and other processes. In the early stage of wellbore image, eccentricity correction, expansion transformation and correction have been carried out. At this time, image registration only needs translation transformation. In this paper, the method of template matching will be selected to achieve image registration.

Template matching refers to cutting out a rectangular area in the overlapping zone of the image as a template, comparing the template with the area of the same size in the searched image, and determining the best matching position according to the degree of similarity, so as to determine the overlapping zone scope of the two images [7]. Schematic diagram of template matching is shown in Figure 7:

For convenience of representation, we assume that m and n are odd integers, and the operation results $C(x,y)$ of function $w(x,y)$ and function $f(x,y)$ can be expressed as:

$$C(x,y) = \sum_{s=a}^{a} \sum_{t=b}^{b} w(s,t) f(x+s,y+t)$$  \hspace{1cm} (3)

The constants a and b are given as $a = (m - 1)/2$ and $b = (n - 1)/2$. For any given position $(x,y)$, the value $C(x,y)$ can be calculated by Formula (3). All values $C(x,y)$ can be calculated as x and y vary. The maximum value of $C(x,y)$ indicates the best match position $w(x,y)$ in $f(x,y)$. For specific calculation, normalized correlation coefficient [8] can be used to calculate the following:

$$\gamma(x,y) = \frac{\sum_{s=a}^{a} \sum_{t=b}^{b} [w(s,t) - \bar{w}] [f(x+s,y+t) - \bar{f}(x,y)]}{\sqrt{\sum_{s=a}^{a} \sum_{t=b}^{b} [w(s,t) - \bar{w}]^2} \sqrt{\sum_{s=a}^{a} \sum_{t=b}^{b} [f(x+s,y+t) - \bar{f}(x,y)]^2}}$$  \hspace{1cm} (4)

Where, $\bar{w}$ is the mean of the template $w(x,y)$, and $\bar{f}(x,y)$ is the mean of the corresponding region in the image $f(x,y)$ and $w(x,y)$.
4.2. Image Fusion Method

After obtaining the spatial transformation relation of the image to be registered by correlation method, it is necessary to select the appropriate image fusion strategy to realize the smooth and seamless mosaic of the image through fusion. Generally speaking, image fusion can be divided into pixel-level fusion, feature-level fusion and decision-level fusion [9]. Pixel-level fusion is the most basic fusion method, and this paper will use the fade-in and fade-out of the pixel-level fusion method to achieve image fusion.

The weight of the pixel in the overlapping zone of the fade-in and fade-out method is related to the boundary distance between the pixel point and the overlapping zone. Supposing that $g$ represents the fused image, $g_1$ and $g_2$ represents the image to be spliced respectively, then $g$ can be expressed as [10]:

$$
g(x,y) = \begin{cases} 
g_1(x,y) & (x,y) \in g_1 \\
d_1 g_1(x,y) + d_2 g_2(x,y) & (x,y) \in (g_1 \cap g_2) \\
g_2(x,y) & (x,y) \in g_2 \end{cases}$$

(5)

Where $d_1$ and $d_2$ represents the weight value, and satisfies $d_1 + d_2 = 1$, $0 < d_1 < 1$ and $0 < d_2 < 1$. It goes from 1 to 0 in the overlap zone $d_1$, and 0 to 1 in the overlap zone $d_2$. Thus, smooth transition of overlapping zones can be achieved, and the change of weight value is shown in Figure 8.

![Figure 8](image)

Figure 8 Different variations of weight value in image fusion

5. Image Mosaic Results

5.1. Image Mosaic Process

The image mosaic process is shown in Figure 9. Firstly, two adjacent images are extracted. Then eccentricity correction and expansion transformation are carried out and the image relationship is used to transform the vertical view image into a rectangular image. Then the registration template is selected and the registration coordinates are obtained by using the normalized correlation method. Finally, the method of fade-in and fade-out is used to carry out pixel-fusion in the overlapping zone to complete the image mosaic.
5.2. **Stitching Results**

According to the splicing process in Figure 9, the results are shown in Figure 10- Figure 14.

Figure 10 is the original video image. The white ring in the image is the imaging result of the wellbore collar. The boundary of the image to be processed is estimated according to the shape of the collar, so as to facilitate the subsequent image processing. The images selected in Fig. 10 were intercepted and eccentricity correction was carried out according to the principle in Section 3.1 to obtain the results shown in Fig. 11. After the eccentricity correction, the image is transformed using the principle described in Section 3.2 to obtain the expanded rectangular graph, as shown in Fig 12. The registration image and template image were selected, and the normalized correlation coefficient is calculated as shown in Fig. 13. The peak value of the correlation coefficient is the registration coordinate position, that is, the moving coordinate of the image is obtained, and then the image fusion was carried out using the fade-in and fade-out method, with the fusion result shown in Fig. 14. The Fig. 14 is a panoramic image of tubing detection in a production well. This panoramic image is used in combination with other logging methods to provide quantitative interpretation of tubing.
6. Conclusion
Wellbore visual detection is a new engineering detection technology. The obtained detection image is intuitive, efficient and easy to interpret. The key technologies of downhole video (image) processing include camera eccentricity correction, image expansion transformation, and image mosaic. Through the
processing of the detection image, its panoramic front view image is obtained, which lays a foundation for the next visual quantitative detection.

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