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A Novel Video Logging Method Based on the Self-Focus Lens Array

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Abstract

At present, down-hole video logging method is used to observe the bottom and lateral well wall image, which places video camera on the bottom of logging instrument. This method can acquire the bottom image clearly. It's difficult to obtain lateral image because optic axis of lenses is placed along with the well axis, and it's impossible to place an existing camera along the radial direction because of restriction of borehole diameter or pipe diameter and object distance of camera, etc. A method and instrument for acquiring lateral image is presented on this paper, multiple self-focus lenses are placed along radial direction, used special relay lens transmitting the multiple imaging to an image sensor, and formed one image, then transmitted the image to ground. In order to use optic spectral properties, light cone circling the self-focus lenses is used to transfer the image, the minimum overlap radius for measurement boreholethe is analyzed,the seal problem for the optical system is designed.The lateral well wall image is acquired through researching the method of lateral multiple lens, then the phase correction method is used to fuse the image from different angles of lateral well wall. The video well logging instrument is developed using the above method, which can real-timely display the crack opening , filling substance, porosity and rock component of down-hole casing and borehole.So this method can provide an interpretation tools for the pipe internal or downhole phenomena.

Key words: Lateral video logging; Image acquisition; Self-focus lens array; Circular light source; Phase correction method; Image fusion

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INTRODUCTION

The downhole video logging method commonly used in the logging instrument, which was placed on the bottom, used to observe the bottom and lateral images, to collect the image at the bottom of borehole[1-3]. When used for lateral imaging, due to the optical axis of the lens along the borehole axis direction, it's hard to obtain the lateral well wall image, because of the hole diameter or pipe diameter and the existing camera distance limit, radial direction place an existing camera is impossible. The main reason is that these instruments designed based on the normal camera technology ,the diameters of normal lens is very large, place the camera in the bottom of well, which try to acquire the image on the bottom, but can not obtain the lateral well wall image. Since this proposal placed the main light source and imaging lens optical axis parallel to the axis of the borehole wall and sleeve through the plane at the bottom of the instrument (or convex) window irradiation bottom of the well, and received the reflected light. Obviously, such a scheme for identifying wells whereabouts matter, auxiliary salvage contributed. Since, near the reflection light in the viewing angle range, and distant reflection less attenuation of light and, in principle, cannot be placed to meet the direction of the well axis, and the well logging interpretation require for lateral imaging. The normal optical system just like the human eye, looking straight ahead, to see the front of the image, for the lateral can only get fuzzy and unclear images. In order to get a clear lateral borehole image, it's needed to disposit the lens facing to the lateral sidewall[4-5].

Our group study with Self-Focus Lens Array (SFLA) as objective lens, which placed in the lateral multiple objective lens, light cone is used to transfer image device, light source uses circular one, the light strength of which can be controlled by light source controller. Lateral multi-lens imaging system can overcome the deficiencies of the vertical camera difficult to get a clear image of the lateral borehole wall. Using the proposal, and compared to the previous proposal, image distortion can be eliminated. Also using the image mosaic method can form a complete image of a sectional lateral without the need for the mechanism rotates, the other can be avoided due to the lens movement appears "ghosting"[6-7].

1. DESIGN PRINCIPLE FOR VIDEO LOGGING INSTRUMENT

1.1 Basic Principle of Video Logging Instrument

The block diagram of Video logging instrument is shown in the Figure 1, which consist of two parts: downhole and ground part.

The downhole consist of power module, Light Source Control Module, Light source, Optical system, DSP control module, CCD and modulation module.

(1) Light source control module is used to adjust light strength. Light source is used to supply the light for Optical system. Light source is designed as circular one, and the LED is distributed around the light source board, the light strength is controlled by the digital potentiometer based on the I^2C bus.

(2) CCD is used to convert the light signal to electronic one, which transfer the borehole image to DSP control module, which is used to convert the differential LVDS signal to the TTL/CMOS one, and then transfer to the modulation module by the cameralink interface[8-9].

(3) Modulation module realizes the following functions: convert the cameralink interface to the normal well information coding format. Demodulation module realizes the functions of converting the normal well information coding format to the USB data format.

(4) Power module is used to supply the power to light source control module and CCD. Which can supply the ±5V, ±3.3V to CCD,light source control module and modulation module.

(5) DSP is used to realize the image compression because if sending the original image to ground, it will occupy the cable transmission bandwidth, simultaneously it can be used to control the light source strength of light source.

(6) Optical system is the core of this system. The image is clear or not decides it. The composition block diagram is shown in the Figure 2.

(7) Software is used to display the underground image, Interpret the crack opening , filling substance, porosity and rock component of down-hole casing. Which is realized by the graphical display software LabVIEW 8.6.

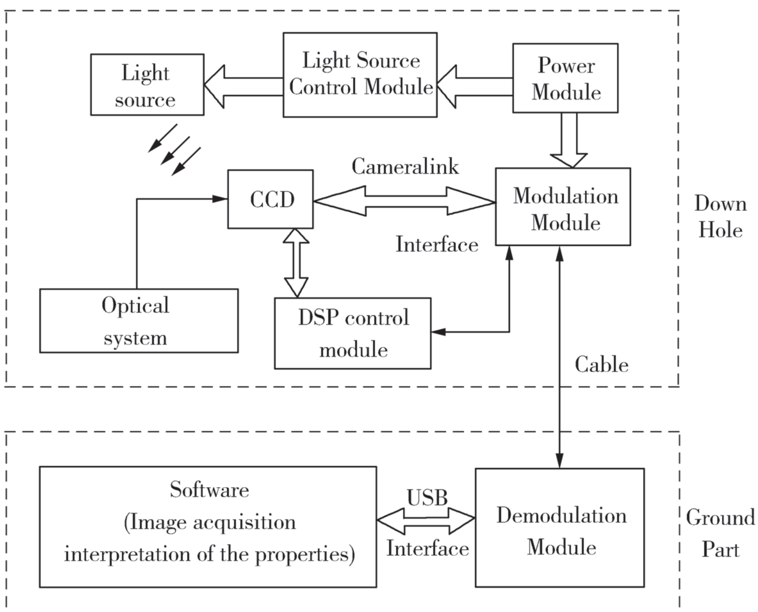


Figure 1
Basic Diagram for Video Logging Instrument

1.2 Design of Optical System

SFLA is the most important component of Optical system, and the most important properties of it is smallness, the diameter of it is very small. Light cones is used to transfer light. In the laterally placed some SFLA, in the well axis placed only one self-focus lens.

Optical system is divided into two cavities, the above cavity set two light cone fixed plates, which placed up and down, and the center of which place one light cone parallel to the well axis, it can be defined as Horizontal Light Cone (HLC), and 90 degree bending light cone around the LCFP, it can be defined as Vertical Light Cone (VLC) and the small side of which coupled to SFLA, the side of SFLA face to the tested well wall through the hole on the shell of optical system (SPS). The small end of HLC is coupled to self-focus lens, the other side of self-focus lens face to the bottom of the borehole.VLC face the well wall, can obtain the image of well wall. The two Light cone fixed plate (LCFP) is sheathed on the outer shell of the optical system. And the Circular Glass Shell (CGS) is used to isolate the optical system from the outside well environment.

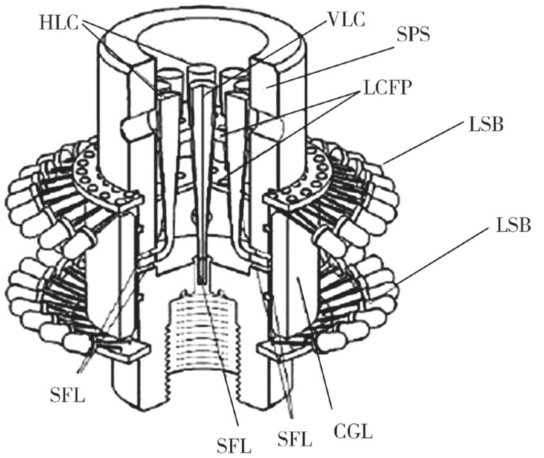
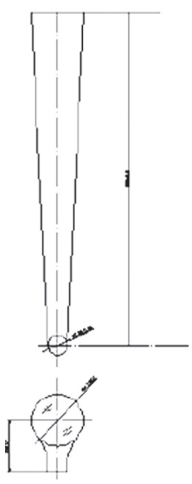


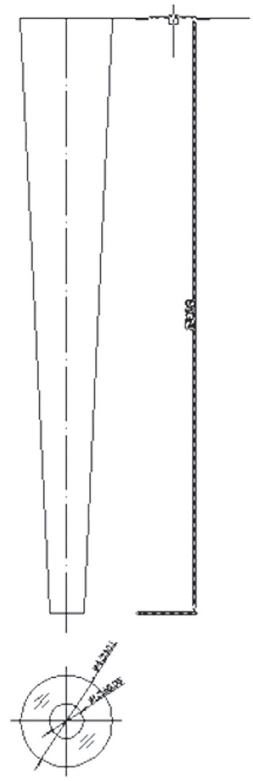
Figure 2
Front View of Video Logging Instrument

The most important part for single lens imaging system is coupling and image transfer. Light cones are used to transfer light. It's very difficult to mechanical processing. The orthographic views of 90 degree bending

Light cones is shown in Figure 3.



(a) The Orthographic Views of HLC



(b) The Orthographic Views of VLC

Figure 3
Orthographic Views of Light Cone

1.3 Minimum Overlap Radius for Measurement Borehole

SFLA is used to obtain the whole information of borehole, so it will cause the overlap between the two self-focus lens. With the increase of numerical aperture, can see the scale will be bigger, but the gradient refractive index lens edge will appear serious fuzzy phenomenon, caused very big effect on imaging, and so select the appropriate gradient refractive index lens is particularly important. The method for computation of minimum overlap radius is as follows:

The eight self-focus lens is equally distributed on the SPS, so the angle among each eight self-focus lens are 45°.The radius of SPS is d, θ is the field angle of self-focus lens, R2 is the distance from the edge of self-focus lens to sidewall, r1 is the radius of well. θ_1 is the angel between axial direction of self-focus lens and, is 22.5°. r_1 value is obtained according to the cosine theorem.there will compute under three cases, the result is shown in the Table 1.

Seen from the table.1, when the parameter of d is determined, the numerical aperture $N_A = \sin(\theta)$ is larger, the overlapping radius is small, so obtained image information is much. With the increase of the numerical aperture N_A, so the range of seen information is large, but the edge of self-focus lens is fuzzy, it influences the imaging, so it's important to select the right self-focus lens[10].

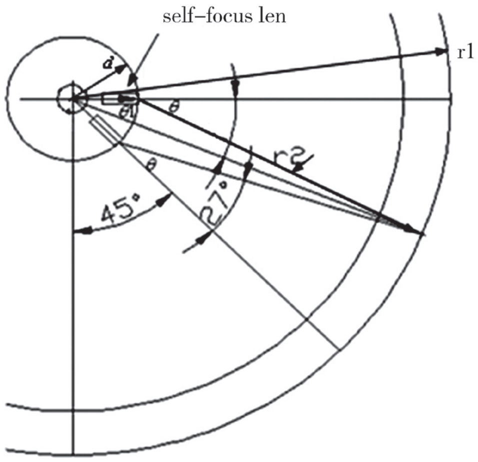


Figure 4
Schematic Diagram of Computation the Minimum Overlapping Radius

Table 1
r_1 Value Under Different Cases

d (mm)	sin(θ)	r_1(mm)
	0.46	72.2613
10	0.552	41.5204
	0.6	34.9051
	0.46	86.7136
12	0.552	49.8245
	0.6	41.8861
	0.46	101.1659
14	0.552	58.1286
	0.6	48.8672

1.4 Seal Design for Optical System

It needs to consider the seal problem because the logging instrument is placed in the downhole, there will have muds or other materials that can pollute the lens, the circular ring glass window is designed to avoid the lens to be polluted. The mechanical structure is shown in the Figure 5.The field angle of one self-focus lens is 2θ .

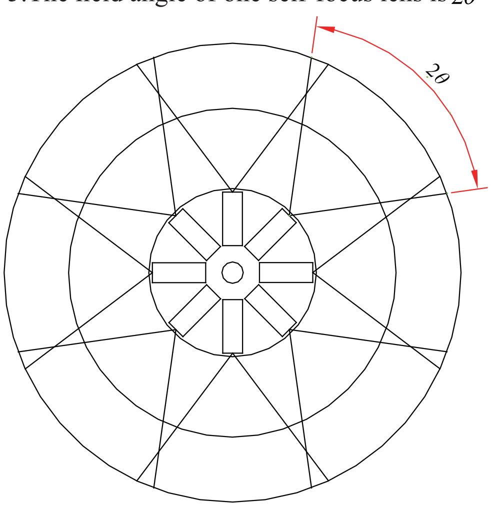


Figure 5
Distruibued Relation of VLC

Image region of single lens on the CCD area is shown in the Figure 6. Seen from Figure 6, there are nine Imaging region, In which the center of the circular region for the well axis is the direction of the imaging area, other eight ones is the lateral bearing imaging area, all the images come from the self-focus lens through the light cones.

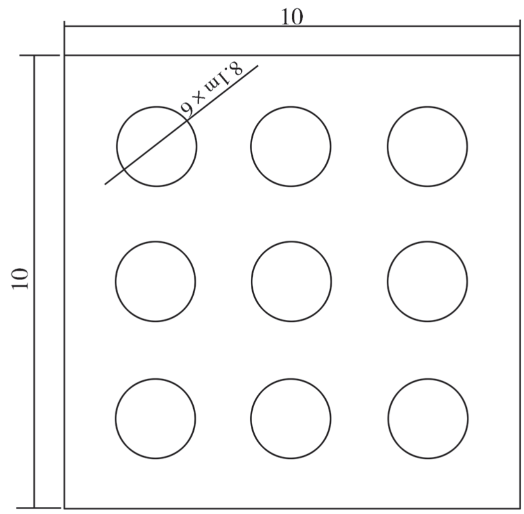


Figure 6
Nine Imaging Region of CCD

2. IMAGE PROCESSING AND INFORMATION INTERPRETATION

2.1 The Borehole Image Processing Principle

Seen from Figure 5, the borehole image from the different angles has some overlap, in order to cut the overlap part, and form the registration image for well wall. Then it's needed to process the image from the SFLA. In order to realize image registration, it's needed to realize image translation, rotation and scaling. The process is shown in the Figure 7. Downhole Image from the CCD is firstly needed to registration, Panoramic and fusion; finally form the GIS map for the downhole.

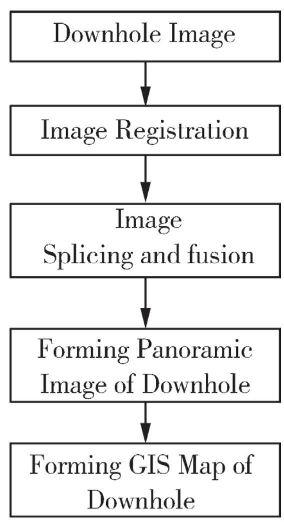


Figure 7
Flow Diagram of Image Fusion

2.2 Process of Image Translation

Assumption the two images: $f_1(x,y)$, $f_2(x,y)$, and there are only translation relation between the two image, and the translation amount is (x_0, y_0).

$$f_1(x,y) = f_2(x\text{-}x_0, y\text{-}y_0) \quad (1)$$

According to the translation property of Fourier transform, there are such relations:

$$F_2(u,v) = e^{-j(ux_0+vy_0)} F_1(u,v) \quad (2)$$

Where $F_1(u,v)$ and $F_2(u,v)$ are the Fourier transform of $f_1(x,y)$ and $f_2(x,y)$ respectively.

The cross spectrum of them is as follows:

$$\frac{F_1(u,v)F_2^*(u,v)}{\left|F_1(u,v)F_2^*(u,v)\right|} = e^{-j(ux_0+vy_0)} \quad 3)$$

Where $F^*_2(u,v)$ is the complex conjugate of $F_2(u,v)$, the fourier transform of $e^{-j(ux_0+vy_0)}$ is a two-dimensional pulse function, the function name is $\delta(x\text{-}x_0, y\text{-}y_0)$. And phase correlation is to get the inverse fourier transform of equation (3), then search the peak value ,to decide the registration parameter(x_0,y_0).

The step of image translation is as follows:

(1) Acquire images contained with the different angels through the optical system;

(2) Execute the FFT algorithm to the acquired images;

$$\mathrm{A} = fft(f_1 x,y)\mathrm{B} = fft(f_2 x,y)) \quad (4)$$

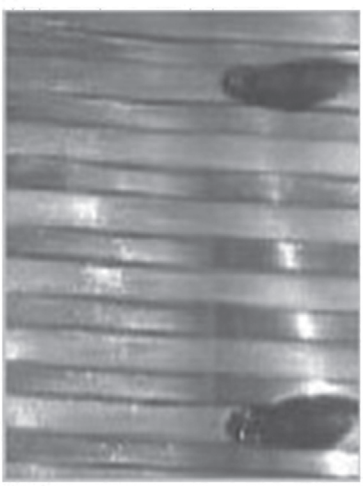
(3) Compute the cross power spectrum of images;

(4) Compute the inverse cross power spectrum aiming at the step (3);

$$C = A.{*}conj(B)/norm(A.{*}conj(\mathrm{B})) \quad (5)$$

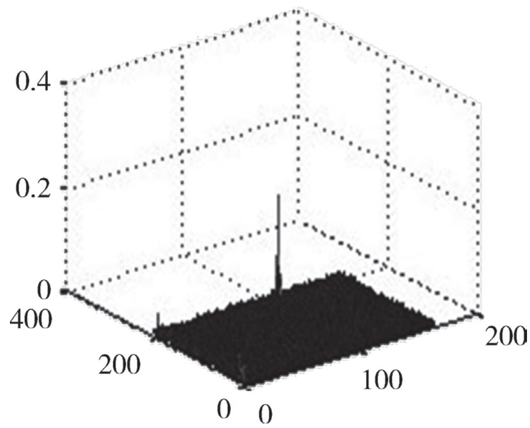
(5) Search the maximum amplitude, then which is the translation amount.

Figure 8 is result of estimating the parameters through the phase correlation method. Figure 8(a) is the reference image, Figure 8(b) is registration Image, Figure 8(c) is Fourier Transform of Cross Power Spectrum, Figure 8(d) is splicing image.

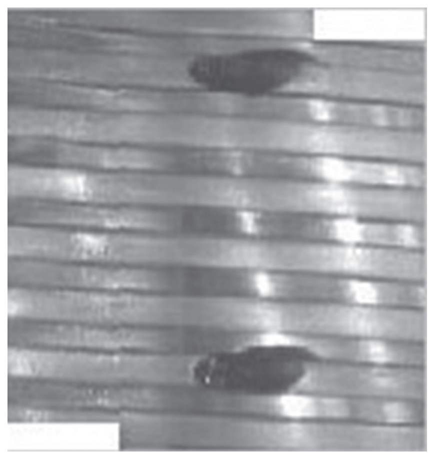


(a) Reference Image

(b) Registration Image



(c) Fourier Transform of Cross Power Spectrum



(d) Splicing Image

Figure 8
Stimation of Registration Parameter Using Phase Correlation Method

2.3 Process of Image Rotation

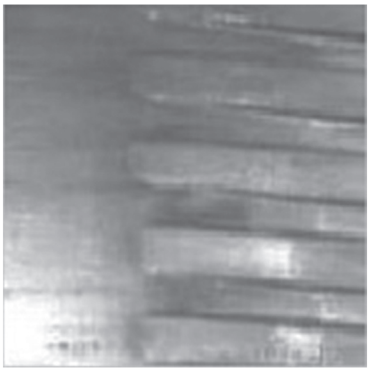
The steps of image rotation and scaling is as follows:

Assumption the two images: $f_1(x,y)$ and $f_2(x,y)$, is obtained from $f_1(x,y)$ to scale the image with λ parameters and rotate one with θ_0 counterclockwise, and meets:

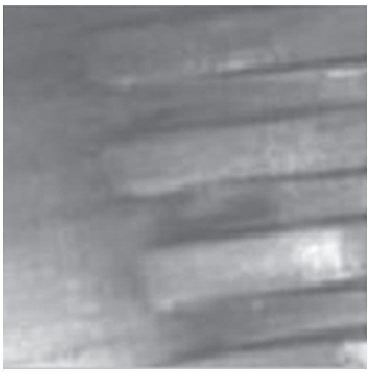
$$f_2(x,y) = f_1[\lambda^{-1}(x\cos\theta_0 + y\sin\theta_0), \lambda^{-1}(-\sin\theta_0 + y\cos\theta_0)] \quad (6)$$

After logarithmic polar coordinate transformation, then

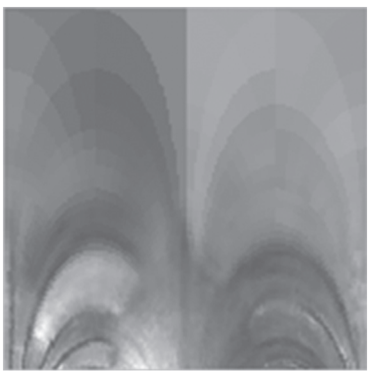
$$f_2(\ln\rho,\theta) = f_1(\ln\rho - \ln\lambda, \theta - \theta_0) \quad (7)$$



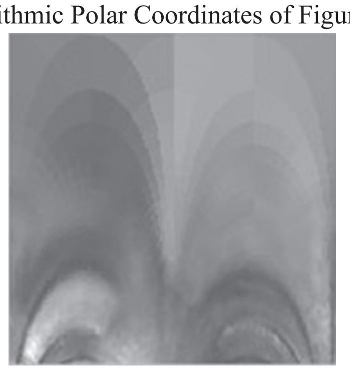
(a) Raw Image



(b) Zoom and Rotation Image



(c) Logarithmic Polar Coordinates of Figure (a)



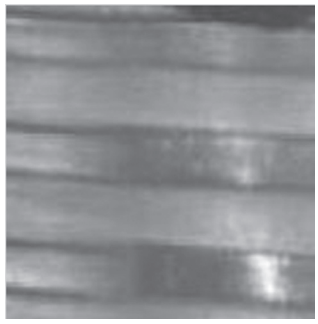
(d) Logarithmic Polar Coordinates of Figure (b)

Figure 9
Mosaic Effect Diagram After Registration

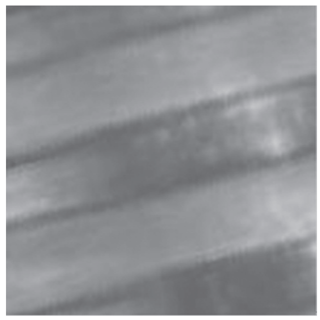
Image Descartes coordinate rotation and scaling has been converted to the logarithmic polar coordinate on the translation relation, in the log polar coordinate system using phase correction method.

Figure 9 realizes the image registration, Figure 9(b) is the registration image after Figure 9(a) rotates 17.36°, and zooms 1.37 times, at the same time which cut in the center at the same size, realize the image registration using the phase correction method.

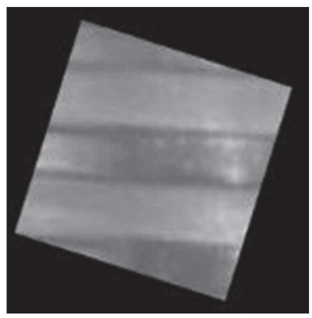
2.4 Mosaic Image After Registration



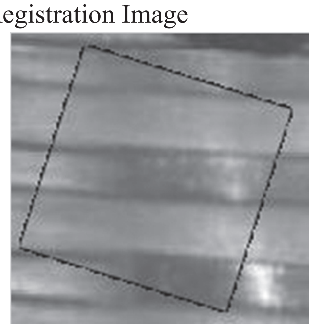
(a) Reference Image



(b) Registration Image



(c) After Registration Image



(d) Mosaic Image

Figure 10
Mosaic Image After Registration

Figure 10 is the mosaic image for the two downhole image. Figure 10(a) is the reference image, Figure 10(b) is registration Image, Figure 10(c) is the image after registration, and Figure 10(d) is mosaic image.

2.5 Fusion Image Using Phase Corection Method

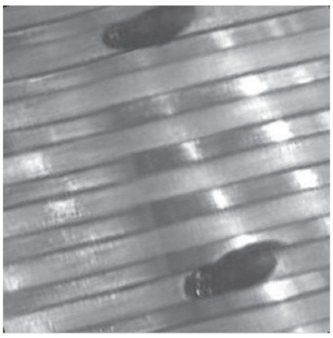
Image fuses using the pixel maximum method, assumption that the size of two images is m×n, the image after fusion is f, then aiming at the pixel Gray scale value ,choose the maximum one to execute the image fusion, the equation is:

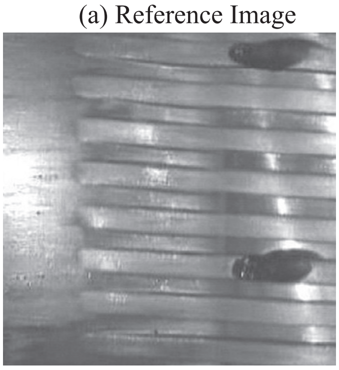
$$f(m,n) = \max\{A(m,n),B(m,n)\} \tag{8}$$

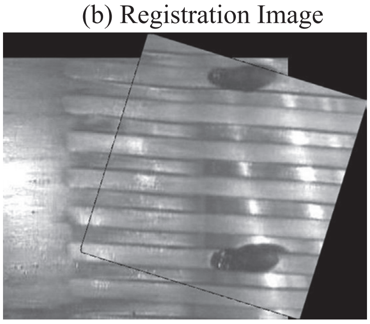
m,n is the row and column of image .when fusion is executed, comparison of the size of pixel value corresponding place in the raw image, and taken the maximum of pixel value as pixel value in the position (*m*,*n*) of image *F*. Taken the radial 8 self-focus lens images for image registration.

The difference between downhole 1 and downhole 2 is diameter of borehole.

Figure 11 is Mosaic Experimental Result of downhole 1. Figure 11(a) is the reference image, Figure 11(b) is registration image, Figure 11(c) is a Mosaic image, Figure 11(d) is the fusion image.


(a) Reference Image


(b) Registration Image


(c) Mosaic Image

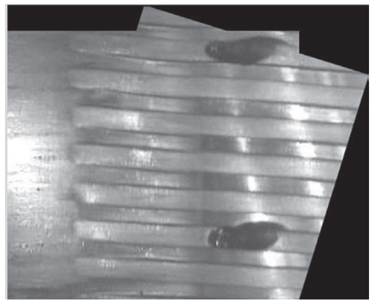
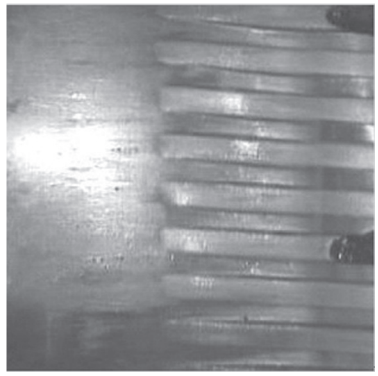
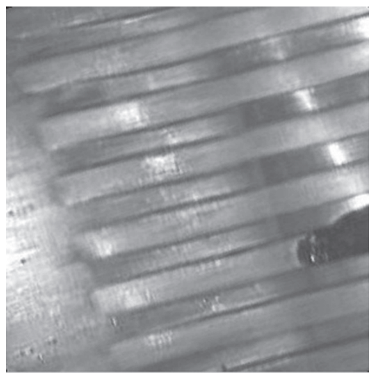
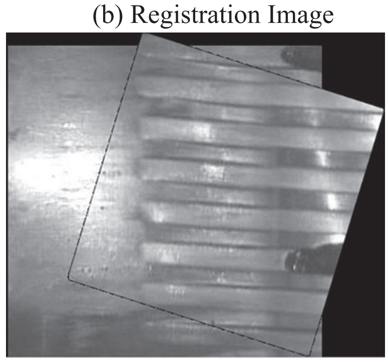

(d) Fusion Image

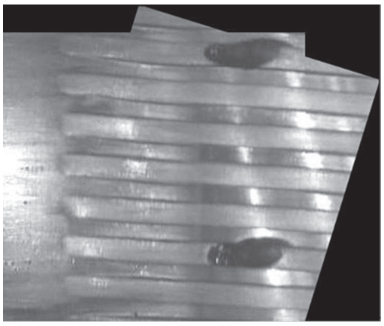
Figure 11
Mosaic Experimental Result of Downhole 1

Figure 12 is Mosaic Experimental Result of downhole 2. Figure 12(a) is the reference image, Figure 12(b) is registration Image, and Figure 12(c) is a Mosaic image, Figure 12(d) is the fusion image.


(a) Reference Image


(b) Registration Image


(c) Mosaic Image



(d) Fusion Image

Figure 12
Mosaic Experimental Result of Downhole 2

Seen from Table 2, it shows the Estimated Parameters for downhole 1 and downhole 2. Using this parameters can make the image from different angles to one GIS map, which can display the information directly, which provide a novel method for well logging such as crack opening, filling substance, porosity and rock component of down-hole casing, or casing casing damage inspection.

Table 2
Two Experimental Result

Image	Estimated Parameters [$x_0, y_0, \theta_0, \lambda$]
downhole 1	[113,37,17.27,1.336]
downhole 2	[80,18,17.31,1.346]

CONCLUSIONS

This paper researches to use the SFLA to acquire the signals in the process of well logging instrument design, using this method can obtain the image of well wall. The main work of this paper is below:

(1) Because the size of SFLA is about 1.5 mm.it is very suitable for acquiring the well wall information, because the diameter of borehole is about the 77 mm.

(2) Using circular light source provides a new light principle for downhole image acquiring. Through test, circular light source has good effect on the acquiring the well wall image information, and improve the definition of well wall image.

(3) Because the image is obtained from different angles and the acquired image has overlap. In order to form the whole well wall information map, phase correction method is used to realize image fusion, and get the good result.

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