Measurement System for Liquid Level based on Laser Triangulation and Angular Tracking

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***Abstract*—This paper introduces a kind of measurement method of the displacement for the liquid level by the use of the laser triangulation and the angular displacement tracking. Based on the principle of the laser reflection and the principle of the source synchronous tracking, according to the triangulation method and the optoelectronic matrix imaging technology, it realize the corresponding relationship between the liquid displacement and the light imaging. Thus to obtain the actual data of the height of liquid level. This method can be used for a large number of-way, high-precision measurement of the liquid displacement of Newton, and to overcome the existing the difficulties and problems in the non-contact measurement for the height of by ultrasound.**

***Index Terms*—Laser, Trigonometry, Angular displacement, Liquid level, Tracking**

I. INTRODUCTION

The liquid level measurement has a broad application in the economic production and the scientific research, a typical method of measuring liquid level is usually achieved using ultrasonic distance measurement principle. but it exists the following questions: First, by the non-uniform temperature field effects; Secondly, is subject to medium density non-uniform effects; Thirdly, measurements blind spots exist, as well as there are certain requirements on the probe position.

The above deficiencies of liquid level measurement can be overcome by the use of the laser technology and of the photoelectricity scanning technology, and of the array type Charge Coupled Device (CCD)[1]. Namely, according to the physical characteristics of the laser and light reflection principle, when the light source fixed and irradiated surface, the normal of the laser incidence angle will produce a horizontal movement along with the vertical movement of liquid level, then the reflected light image also will be change on the detection surface, and thus we can know the amount of liquid surface displacement; At the same time in a wide range of measurement, we can take the angular displacement synchronization tracking method. Namely, when the liquid level is changed on large scale, to change the incident angle of the light source. according to changes in the amount of angular displacement, we can also be achieve the amount of liquid displacement. This method of system provides another new option. for non-contact measurement[2].

Ⅱ. COMPONENT OF THE SYSTEM

The level photoelectric measurement system shown in Fig.1, Where, there is the whereabouts of the liquid Q, there is the laser generator A, there is the CCD photoelectric detection receiver B. We can see from the diagram, when the light source to the measured surface, the part of the light will result in refraction into the liquid, while the other part of the liquid will produce the surface reflection; and the incoming light and reflected light are located on opposite sides of surface normal, and the reflected light will be Launched into the photoelectric detector. If the measured liquid level take placing changes down, under the conditions which the location of the light source and the location of the photoelectric detectors are fixed, Then the position of the reflected light spots at the receiver will take place displacement. According to the principles of trigonometry, we can to know the relationship between the displacement of the reflected light points and measured surface landing[3][4].

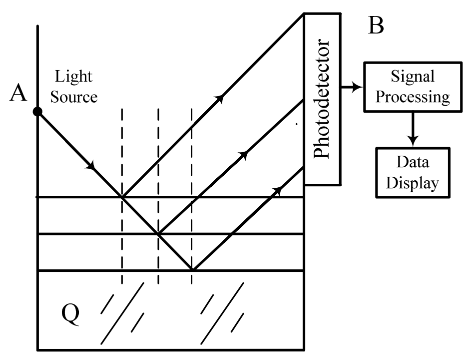

Fig.1 Liquid level measurement diagram

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III. SELECTION OF THE SCHEME

The use of electronic technology and computer technology, combined with transmission characteristics of laser, there can are variety of options at the measurement system of the liquid-surface displacement[5][6].

A. Oblique Triangulation System

The principle of the laser triangulation measurement shown in Fig.2. The laser beam from the light source, That is collimated by the lens and will be formed spotlight, which is projected onto the surface of the liquid under test; And the reflected laser beam from the liquid surface is imaging at the surface of the photoelectric detector through the lens. When the liquid surface height changes, the image point of the receive surface will take place the displacement too. According to principles of optical imaging, we can obtain the image to zoom in and out ,in the surface of detection.

In accordance with the structure shown in Fig.2, There is a angle (the incident angle)θ_1 between incident light ray axis and the measured surface normal; and the θ_2 is the reflection angle, the θ_3 is the reflection angle between the detector surface and the imaging optical axis. The θ_1, θ_2, and the θ_3 to meet the Scheimpflug condition [7][8], that is,

$$\tan(\theta_1+\theta_2)=\kappa\tan\theta_3 \quad (1)$$

Where the κ is lateral magnification.

Under these conditions, the measured points within the range of certain depth can focus imaging in the detection of surface, thus to ensure the measurement accuracy. If the movement distance of the light image at the detector surface of the receive is x', To apply the relationship of the similar triangles, Then the displacement distance of the liquid's surface along the normal direction as follows:

$$x=\frac{ax'\sin\theta_3\mathrm{con}\theta_1}{b\sin(\theta_1+\theta_2)-x'\sin(\theta_1+\theta_2+\theta_3)} \quad (2)$$

Where the a is the distance between the reflective optical axis intersection at the liquid surface and the front of the receiving lens, And the b is the distance from the back of the receiver lens to the array surface.

B. Normal Translation Measurement System

Normal translation measurement system shown in Fig. 3. In the figure, the point A is a fixed laser light source; the emitted light constitute the α angle with the side face of the container. The A'–B location is the photoelectric detector imaging plane, and the A'–B perpendicular to liquid surface. The C-C' and the E-E' respectively are two plane positions in the process of the liquid displacement. The O–O' and the M–M' respectively are two normal of the light incident point; the O–A' and the M'–B respectively are two reflected light of the incident light; the point P is export of the liquid-outflow. When the container side face perpendicular to liquid surface, then the incidence angle between light and normal is α also. We can see from the diagram, when the light source is transmit to the measured liquid surface, the reflected light will be emitted to the photoelectric detector, if the measured liquid surface is produces change in surface displacement, the location of normal will be also moves to left or right at the horizontal direction of liquid surface. If the incident light source and the surface of photoelectric detection is fixed, in the liquid surface is moving up and down, the normal change does not cause the changes in incidence angle, so all of the reflected light of the incident light ray will remain parallel to each other. The reflected light will be form a image as consistent with the liquid displacement at the surface the photoelectric detector. The optical signal processing by computer will be shown in data at the monitor, that we can be directly obtain the displacement from the liquid surface.

In the measurement system of the normal translation, we can see from Fig. 3, in the photodetector and the liquid surface perpendicular to the conditions, when the distance of displacement is X, then the image by the reflected light point formed in the light receiving surface is A'–B. So that $\overline{A'B}=\varDelta L$, under the principle of reflected light, and the parallel lines of different cross-cutting nature and the triangle method, the available distance from the liquid surface displacement is:

$$X=(1/2)\bullet\varDelta L \quad (3)$$

If the plane of photodetector and the incident light are parallel lines, then the distance of liquid surface displacement X is defined by the relation：

$$X=\varDelta L'\cos\alpha \quad (4)$$

C. Angular Displacement Tracking Measurement System

Unilateral tracking test system shown in Fig. 4. The

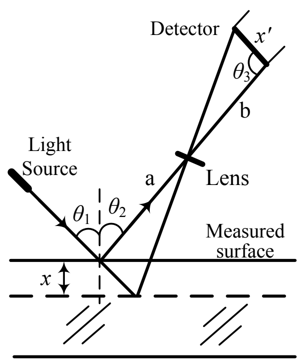

Fig.2 Oblique triangulation measurement diagram

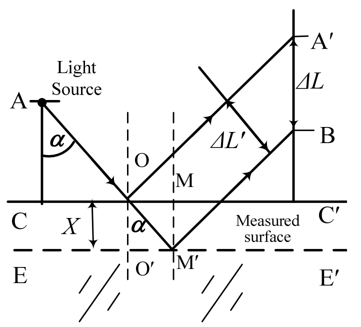

Fig. 3. Normal translation measurement diagram

point A is light generator, which is installed at the walls of the container and the wall perpendicular to the liquid surface; through the servo unit, the light source can be around the point A for 0°~ 90° angular displacement of rotation; the point B is the reflected light receiver focusing lens; the B'–A' is the imaging of x for displacement distance, it is in detection plane of the optical-electrical detector; detection plane is consisted of the CCD photoelectric conversion unit matrices, and with the vertical liquid surface; the point A and the point A' is in the same horizontal plane, the O–O' is the normal to the midpoint of liquid surface; According to the reflective properties of light, we can know that α is the initial incidence angle of light(beam) and that β is the tracking incidence angle of light after the liquid surface displacement; the C–C' and the E–E' is represented different locations of the liquid surface, for the vertical container, then there are the line segment $\overline{CC'} = \overline{EE'}$ and $\overline{OC'} = \overline{OE'}$. When there is the cylindrical container, then line segment $\overline{OC'}$ is represented the radius. This system features is that need a long focal length lens, and the launching light sources unilaterally tracking

In the unilateral track measurement system, we can see from Fig. 4, when the detection surface and the liquid surface perpendicular, and the liquid level move down through the C-C' position, focusing the reflected light of the light source A is projected onto the point A' by the focusing lens. At the same time, through the corresponding signal processing circuit to start the computer timing and tracing procedures. If the known values of the initial incident angle α, then the liquid surface the C–C' of the initial position as follows:

$$L_1 = \overline{OC'} \bullet \cot\alpha \tag{5}$$

Along with the liquid level drop, when the receiving lens is fixed, the reflected light in receiver will left from the point A', this time, by a real-time tracking procedures to adjust the incident angle of launch light, to let the reflected light back to the detection surface, and track this again.

When the liquid level down to E–E' location, the reflected light is projected to the point B' by the lens, thereupon, in the vertical detection surface to obtain the image m of the liquid surface displacement, through the optical element matrix testing, we can see the value of m in length. If the angle β is known, according to the triangle theory, the location E–E' of the liquid surface as follows

$$L_2 = \overline{O'E'} \bullet \cot\beta \tag{6}$$

While $\overline{OC'} = \overline{O'E'}$, so there are:

$$L_2 = \overline{OC'} \bullet \cot\beta \tag{7}$$

Then the amount X of the liquid surface displacement as follows:

$$X = L_2 - L_1 - m = \overline{OC'}(\cot\beta - \cot\alpha) - m \tag{8}$$

If the object focus a and imaging focus b is known in the initial lens, by the triangle theory, we can also achieve the displacement $X = (a/b) \bullet m$, then the average velocity of liquid surface displacement can be expressed as $\bar{v} = x/t$.

D. Multi- light Source Measurement System

Multi-light source sub-fixed measurement system shown in fig. 5. In figure, the point A and B are the light source generator; the point A' and B' is the corresponding reflected light receiver; two sets of transmitter and receiver devices the point A and A ', the point B and B' are located at two line of levels. α and β are the two incidence angle of light sources. Their characteristics are that transmitter and receiver are mounted on the top from the vertical liquid surface with fixed angle and fixed distance, when the liquid level move down through the two tested reflective surface C–C 'and E–E' which are set in the test device, you can detect the liquid surface displacement distance and average speed.

In a multi-light source sub-fixed measurement system, we can see from Fig. 5, when the measured liquid level moves down through the position C–C', then the reflected light from A is received to the A', this time to start the timing process. If the fixed angle α and the fixed location A' are known, by the triangulation principle to know the initial location of the liquid surface as follows:

$$L_1 = \overline{OC'} \bullet \cot\alpha + \overline{A'B'} \tag{9}$$

When the liquid level fall down to location E–E', then the reflected light from B is received to the B'. If the fixed angle β and the fixed location of B' are known, by the triangulation principle to know the location of liquid at this time as follows:

$$L_2 = \overline{O'E'} \bullet \cot\beta \tag{10}$$

Liquid surface displacement as follows:

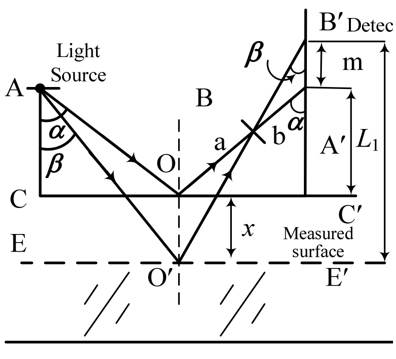

Fig. 4. One-sided track measurement diagram

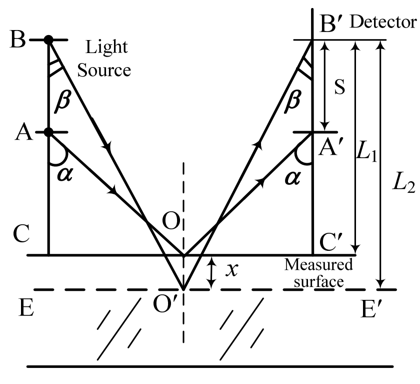

Fig. 5. Multi-light source measurement diagram

$$X = L_2 - L_1 = \overline{OC'}(\cot\beta - \cot\alpha) - \overline{A'B'} \qquad (11)$$

Ⅳ. EXPERIMENTAL ANALYSIS OF SYSTEM

A. Experimental Methods

The system method to measure the liquid level change with the laser triangulation method and the angular displacement tracking, both it can be used in the situation for liquid level changed greatly and for precision is not too high, but also can be used in the instance for liquid level changes in smaller and for measurement accuracy require a higher precision.

In the experimental system uses a wavelength of 730nm red laser as light source, by the 30°angle to launch to the liquid surface. The photovoltaic conversion to be realized using PIN line at the optical receiver module, and the detection signal by the encoding is send to the microcontroller for processing and output, and to shown the displacement distance of the liquid surface by the LED. This system selected distance from the liquid surface to the receiving lens is 1.5 times the lens focal length, and the incident light is perpendicular to the array.

B. Analysis of the Experimental Error

From experimental research, after lens focusing, the light point projected onto the photovoltaic arrays just has a small displacement, the control of displacement measurement accuracy primarily is decided to tracking the angle and front distance a and back distance b; after lens focusing, the facula size of the receiver is also directly the important factors of affecting the measurement accuracy. In addition, to select the smaller array element spacing detector is also one of effective way for improving the accuracy.

The analysis shows that the error of the experimental results sources are as follows:

a. The angle offset error

When there is the offset angle of 0.1°, light source away the surface 0.5 meter, the offset error is about:

$$\frac{0.1° \times 3.14}{180°} \times 500\text{mm} \approx 0.87\text{mm}$$

b. Facula error

The different incidence angle of the light source will cause the change of laser spot, thus affecting the adjacent photosensitive devices to take place induction.

c. Systematic errors

Systematic errors are generally the photosensitive device and liquid surface fluctuation and mechanical vibrations caused.

Ⅴ. CONCLUSION

The system uses optoelectronic and computer technology, combined with angular displacement tracking method to realize non-contact liquid level measurement. In the displacement detection that is a more advanced detection method, to achieve the availability of more desirable result. With the emergence of new types of sensors and the continuous advancement of technology, this test method will has a wide range of application foreground in the machine perspective, automatic processing, line detection, biology and medical simulation field.

Ⅵ. ACKNOWLEDGMENT

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