

A High-precision Hand-held Face Detection System

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Abstract—This paper aims at portable high-precision surface defect detection equipment designed based on laser non-contact measurement, though a CCD camera and dual wave line semiconductor lasers can achieve the measurement of small surface in a close distance. Resultant data is sent to PC via wireless transmission mode to achieve the separation of detection module with terminal display processing module. The detection system with a small-volume structure which can achieve fast and accurate scanning can be used to achieve the device workpiece surface defect measurement under various complex occasions. It is able to achieve real-time display of the measurement results through MATLAB graphical user interface. High measuring accuracy and reliability of the system is verified by experiments, and the depth measurement accuracy can reach $40\mu\text{m}$. The results provide an important basis for the detection of surface blemish and improve product design and processing quality.

Index Terms—Face detection, Three-dimensional reconstruction, Laser scanning, Machine vision, High-accuracy measurement

I. INTRODUCTION

With the rapid development of science and technology, surface accuracy requirements of the precision instruments become more and more important. The measurement accuracy directly impact on the practical performance of instruments, however, some of very small cracks and bumps can not be discovered in time, which will cause serious consequences [1]. At present, the application of such detection equipment is mainly based on contact measurement, with low accuracy and poor stability. A small part of the non-contact laser measurement is mainly used for the detection of designated flatness detection and its bulk can not be achieved online portable measurement [2-5]. Today, with the increasing demand of surface high-precision detection, it is of great significance for equipment online operation monitoring, analysis of surface defects generation and development mechanism, and structural improvements to develop high-precision portable laser scanning online surface detector.

In order to meet the instruments surface detection requirements, this article has designed a high precision defect detection device based on laser triangulation measurement. It uses dual-beam measurement and wireless data transmission mode to achieve the data

transmission between detection module and terminal processing display module. Except for reducing the volume, it also reduces the complexity of the post-date processing. The application of valid stripes proposed method to complete the measured information extraction is easier than the traditional two-camera measurement 3D stitching and reconstruction in three-dimensional information of the late match. The basis requirement of measurement depth range is 100cm, besides; the use of the extended structural design can not only accomplish close-range measurement, but also can get long distance and larger-scale measurement by replacing the lens and change the laser angle.

The key design requirements for the scanner are that it shall be small and fast, portable and reliable with high accuracy measurement results while the cost of measurement is reduced. The small 3D scanning device will be placed over the target to be detected, and the laser scans the area for flaws, and then sends the resultant data to PC via wireless transmission and high-resolution 3D surface maps are shown by measurement software. The measured surface defects' location, size and other parameters can be calculated by the analysis software. It can adapt to a variety of different environment measurement requirements and measurement results with high precision. The depth error is within $40\mu\text{m}$, the equipment has good practical value.

II. SYSTEM OVERVIEW

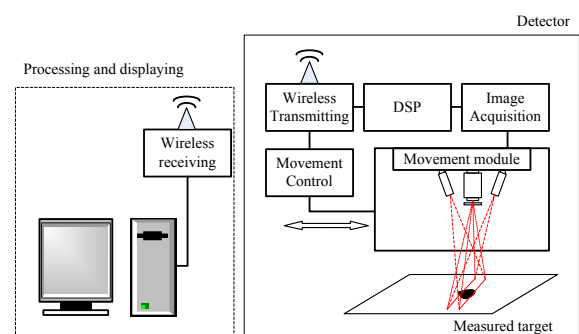


Figure 1. Framework Diagram of System

Laser triangulation is used as the basic measurement principle in this device. Laser scans the testing targets and gets the laser image by CCD camera, and then we can deduce the spatial coordinates of the measurement

target by analysis of the laser stripe position in image. Combined with practical application and direction development of the instrument, the following requirements are proposed: miniaturization and portable, low cost, high resolution and accurate measurement results. The designed system framework is shown in Figure 1:

The system consists of four parts: control system, image capture and processing, wireless transmission, and data analysis and display. Laser and CCD camera are placed in small connection board, and the board is fixed in small electronic control displacement platform. The control system controls CCD camera for image acquisition and synchronously movement electronic control displacement platform. After a high-speed digital processing chip DSP, we obtain information of the laser stripe by scanned images. Wireless transmission module will take processed stripe information to the PC terminal. After processing software, three-dimensional coordinate image of the measured surface will be real-time displayed.

In order to obtain three-dimensional spatial coordinates of the surface measured, it is required to establish spatial three-dimensional coordinate system with the center of the lens as coordinate origin. Any point of the laser stripe position (x, y, z) can be calculated by the point imaging in the CCD plane's position (x', y', f).

The geometric relationship between object points and image points can be expressed in the following formula 1 [6-8]:

$$\begin{cases} x = \frac{bx'}{f \cot \theta - x'} \\ y = \frac{by'}{f \cot \theta - x'} \\ z = \frac{bf}{f \cot \theta - x'} \end{cases} \quad (1)$$

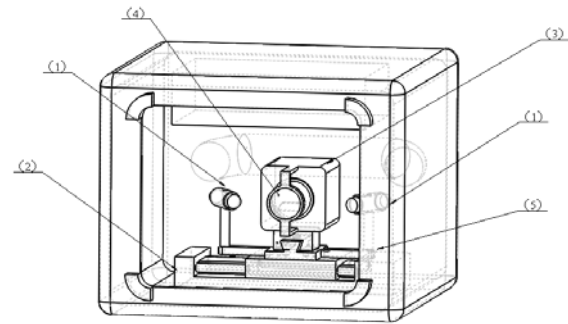
where f is focal length, b is baseline, θ is laser beam angle.

III. PROPOSED SCHEME

For rapid measurement of the test surface, multi-beam or coded light projection measurement methods are often used today. The entire surface measurement of the target can be achieved in one-time projection. This method not only can achieve rapid measurement, but also may increase the maximum utilization efficiency of CCD imaging plane. But this method have higher requirements for measurement environment, thus it is only applicable to the measurement of a continuous smooth surface and can't be used in the measuring complex and undulating surface. With a relatively high cost, the projection equipment also makes the volume too large, and can not adapt to different occasions and different accurate measurement requirements.

To avoid the drawbacks of the measurement method above-mentioned, dual-beam horizontal scan mode is used in this paper, with the measuring end structure as

shown below:



1- Word lines semiconductor laser, 2- High-precision electronic control displacement platform, 3-CCD camera, 4-650nm narrowband filter, 5- Small connection board

Figure 2. Detection Device

In the system, two 650nm small word line lasers are placed in both sides of the CCD camera, and emission power is 5 ~ 15mw adjustable and line width is less than 1mm in 180mm measuring distance. The semiconductor lasers and CCD camera can achieve close-surface information measurement through a simple combination method. It not only reduces the size and cost of measurement device, but also can carry out an effective treatment for visual blind spot phenomenon generated by the propagation characteristics of light in the measurement process. Accurate extraction of the measured surface information by quickly and efficiently stripe extraction algorithm, makes it easier to achieve a three-dimensional stitching and reconstruction in the latter part of the three-dimensional information stitching than the traditional dual camera measurement. Because the measurement is carried out by use of two lasers and will get two 3-D maps. At any time, it can be drawn via equation 1 that two laser lines are in the same coordinate system with the center of the lens; for this, it is only required to insert the second image point coordinates in the first image coordinate system in 3D point cloud fusion to compensate respective vision dead angle. Because of the two lasers' different scanning position, it is able to further increase horizontal and vertical resolution of the scanner and increase the scanning area by this method.

In order to achieve 50mm × 50mm area face detection with 10cm distance, a monochrome CCD camera shall be chosen as optical receiver; the image plane resolution is 795 (horizontal) × 596 (vertical) pixels, with image acquisition speed of 50 frames/s and 5mm focal length of the lens. As measured simultaneously with a dual stripe, if the measurement surface is too large ups and downs, streaks may intersect with each other, which will interfere with the accuracy of the measurement results. In order to eliminate mutual interference between the stripes, combined with the overall design requirements of the instrument, it is required to select the semiconductor laser and camera lens whose center distance b (baseline) has a length of 45mm and the lens axis angle at laser direction is 30°. By above structure design, it is 80mm length from the lens center; the two laser stripes coincide

together in the optical axis of the lens. As the distance increases, the stripes gradually deviate on both sides, with imaging on both sides of CCD image plane. The front instrument housing is designed with a length of 130mm from the center of the lens, so as to achieve 80mm-180mm of depth measurement. To achieve their stripes information extraction only need to have an image separation process for the left and right 397 pixels. Camera and laser are uniformly fixed in small electronic control displacement platform; platform uses a ball screw with a positioning accuracy of less than 10 μ m and can achieve the fastest speed 40mm/s lateral movement. The size of entire instrument is 230mm $\times$ 230mm $\times$ 250mm can meet the requirements of the portable measuring.

In the actual measurements, in order to meet different needs of different target measurement requirements, we need to extend the measurement distance range. As shown in Figure 3, the design follows structure to connect CCD camera and semiconductor lasers together. It can achieve CCD camera forward and backward movement and rotation of the laser. Adjusting the CCD camera position can bring baseline changes within a certain range, and the laser and optical axis angle's change can change detection range expansion. With the choice of appropriate focal length lens, it is able to complete measurements under different fields of view. In order to rapidly obtain the new system parameters value, the system shall achieve precise calibration of the new parameters by a set of the rapid calibration apparatus in a very short time. The instrument fixed in the long-distance displacement of the table or placed in the pipeline can achieve a larger area and real-time three-dimensional detect.

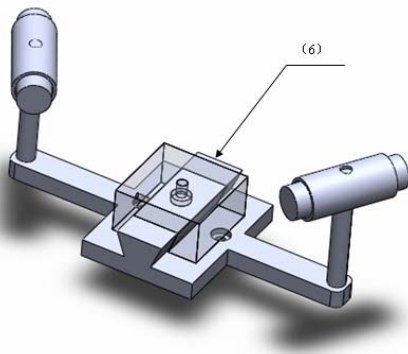


Figure 3. The Measurement Connection Frame

It can be found through large experiments that the light unevenly distributed in environment will bring more environmental elements inside, as shown in Figure 4(a). Due to the influence of ambient light, the laser stripe information extraction can not be obtained accurately. In order to eliminate the influence of ambient light on the imaging result, a 650nm narrowband filter is placed in front of imaging lens to reduce the interference caused by ambient light. As shown in Figure 4(b), the narrowband filter effectively filters out of the surrounding environment interference [9].

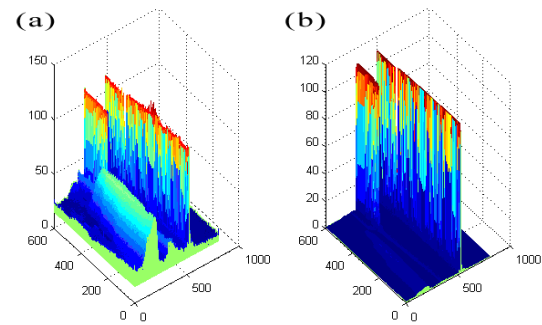


Figure 4. (a) Gray Surface with No Filter (b) Gray Surface Chart with Filter

The work process of scan processing module is shown in Figure 5.

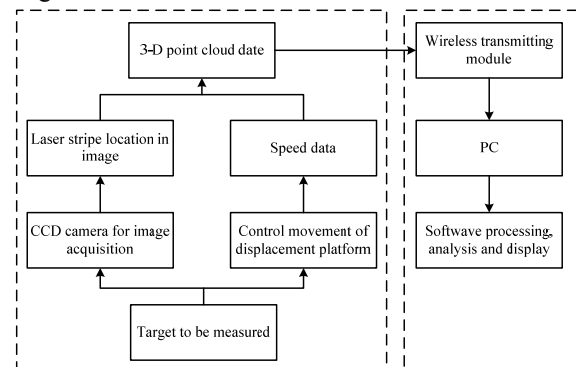


Figure 5. The Detection Device Work Flow Chart

Electronic control displacement platform carries camera and laser to scan the surface to be measured with the demand speed, and gets real-time image of the laser stripe by CCD camera. After this, we choose DSP as image processing chip to extract laser stripe position [10-11].

Firstly, we need to do filtering for images. The use of sensitive optoelectronic components in the system is susceptible to the interference of external factor and photosensitive element CCD will generate lots of noise by the factor of reflected light and stray light. In the laser stripe extraction process, if the image noise is too large, it will bring many errors to the laser stripe center extraction.

Wiener filter is to find an estimate f' so that the statistical error function (equation 2) minimum.

$$e^2 = E\{(f - f')^2\} \quad (2)$$

The expression can be expressed in the following formula 3 in the frequency domain:

$$F(u, v) = G(u, v) \left[\frac{1}{H(u, v)} \cdot \frac{|H(u, v)|^2}{|H(u, v)|^2 + S_\eta(u, v) / S_\eta(u, v)} \right] \quad (3)$$

where $H(u, v)$ is degraded function.

$$H(u, v)^2 = H^*(u, v)H(u, v) \quad (4)$$

where $H^*(u, v)$ is the complex conjugate of $H(u, v)$,

$S_n(u, v) = |N(u, v)|^2$ is the power spectrum of noise.

Select the 5×5 template to do wiener filter for scanned image. After processing, image noise gets a better inhibition and obvious edge of stripe.

Secondly, we need one picture to take a rough calculation of laser stripe gray threshold and remove the pixels outside the threshold. The image gray average G_e and mean-square deviation σ can be calculated by all image pixels gray value. Take q as the summation of pixels' gray value; gray value is greater than S and S can be calculated by the following formula:

$$S = [G_e + (5 \times \sigma) / 6] \quad (5)$$

The laser stripe threshold T can be calculated by this equation:

$$T = q / q' \quad (6)$$

where q' is the total number of those pixels. Empty the pixels that gray value is less than T , and extract the laser line position roughly. Using the image threshold processing to get the result as shown in figure 6 below:

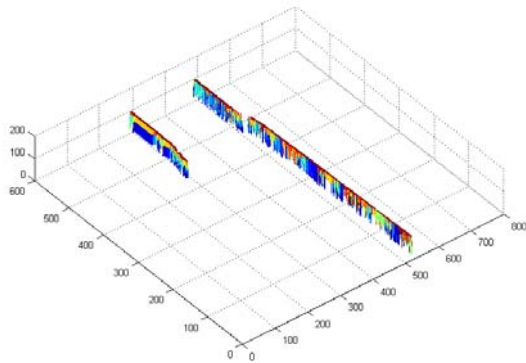


Figure 6. Extraction of Laser Light with Light Threshold Analysis

Finally, a least square fitting is used to calculate sub-pixel position of the laser stripe center. Least square method is to find the best function matching by summing the error of square. Based on given data point (x_i, y_i) , $i=1, 2, \dots, n$, assume the fitting function form as equation 7:

$$p(x) = \sum_{k=0}^m a_k \phi_k(x) \quad (7)$$

where $\{\phi_k(x)\}_{k=0}^m$ is a known linear independence function, solve the coefficient $a_0, a_1, \dots, a_m$ make the value of equation 8 minimum, $P(x)$ is considered as a fitting function.

$$\begin{aligned} \phi(a_0, a_1, \dots, a_m) = \\ \sum_{i=1}^n [p(x_i) - y_i]^2 = \\ \sum_{i=1}^n \left[\sum_{k=0}^m a_k \phi_k(x_i) - y_i \right]^2 \end{aligned} \quad (8)$$

By a least square fitting, it is able to get the minimum error curve of the discrete points [12] and the extreme point measurement accuracy can reach to 0.1pixels. The fitting curve for a line is shown below:

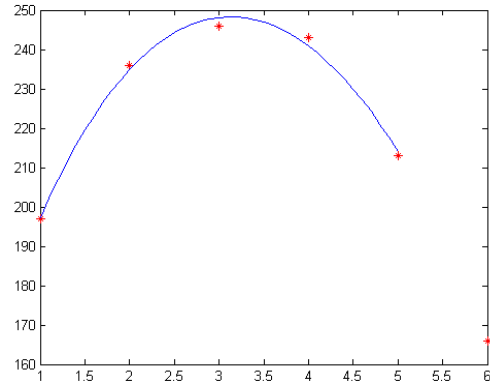


Figure 7. Laser Pixel Curve Fitting

The results of stripe center position data is transferred to PC by wireless transmission module and then the surface three-dimensional information is displayed by processing software. Through processing and analysis by data processing software MATLAB, it is able to achieve calculation and evaluation of the surface measured.

IV. EXPERIMENTAL RESULTS

The measurement requirements of instrument design are to meet a small area of measurement within a close range of 80mm to 180mm depth; testing equipment can be placed on the front of the tested surface. Upon running equipment, we can directly achieve the acquisition and processing of the measuring surface, as shown in figure 8.

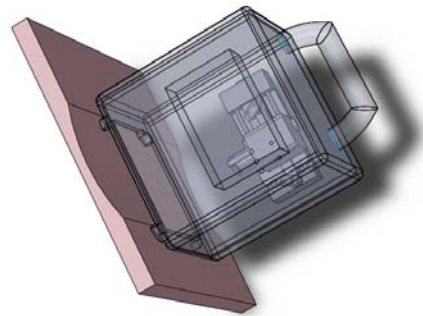


Figure 8. Target Detection

In order to verify the reliability of the equipment in actual work process, we do the following test experiment:

A. Partial Surface of Microscope Scanning Imaging

The partial surface of microscope shell is selected to do scan imaging. Through DSP image processing system, sub-pixel level of laser stripe position accuracy can be attained, and wireless transceiver module transmits data to PC.

In order to facilitate observation and analysis, GUI graphical user interface in MATLAB is used as the display interface for real-time data processing. The laser stripe position information and system parameters value after calibrated are taken into the formula 1 to obtain the spatial coordinate of laser stripe. The 3-D surface image will be displayed in the interface, with the measurement results shown in Figure 9:

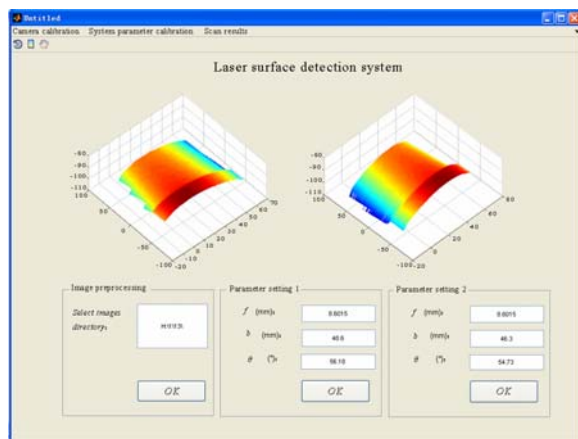


Figure 9. The Face Detection Device GUI Interface

Due to the use of two lasers measurement, we will get two different type scan images, as shown above. Analysis of the two images, target information on the left can be collected more full by the left laser imaging stripe, and the right side laser imaging stripe, just opposite. Integrate stack all data of two laser scanning information can well compensate for each other's lack of information caused by vision dead angle and a more comprehensive point cloud data can be obtained.

B. Plaster Mold Scanning Imaging and Data Fusion

Sometimes, we want to directly observe the surface properties of the measured target. For this purpose, the two images are fused into one image and get a complete 3D view. In this system, two three-dimensional maps have the same coordinate system can easily achieve the three-dimensional image fusion though MATLAB software. Finally, we will get a more complete three-dimensional information graph through a data fitting. The measured surface's micro-structural information is more directly reflected.

Select dome plaster mold as a target to be detected which high of 50mm. We get two three-dimensional maps through two different lasers which are shown in figure 10(a) and figure 10(b), their fusion result is shown in figure 10(c):

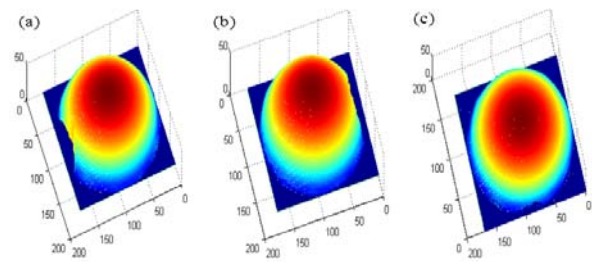


Figure 10. (a) The left laser scanning results (b) The left laser scanning results (c) Images fusion result

Though their fusion result we can get the dome plaster mold surface information directly and full-scale. The mold's volume and height can be accurately calculated.

C. Surface Analysis

For 3D data points of measuring surface, through MATLAB processing and analysis can quickly access information of the tested surface, judge the hollow position, and show its mark in the user interface. Select a tile which has defects as measured target and get measurement results as shown in Figure.11, through processing and analysis can quickly realize the surface defect and the visual dead angle due to the propagation characteristics of the light can be maximum eliminated.

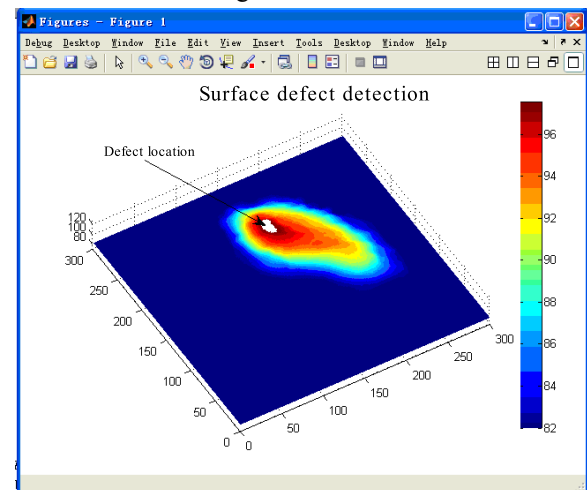


Figure 11. Detection For Ceramic

After a number of micro-movement measurement experiment and analysis can get the scanner uncertainty of measurement is 0.4 pixels. From the differential for equation 1, we can draw the factors affect the measurement accuracy [13-15]:

$$\delta z \approx \frac{z^2}{fb} \delta x' \quad (9)$$

System accuracy can be drawn from the equation above. System accuracy δz is proportional to f , b and inversely proportional to z^2 and $\delta x'$. Lens focal length and baseline length value is at a certain value when parameters were selected. Take system calibration parameters value into formula 2, we can get the device measurement accuracy can reach $40\mu\text{m}$, the horizontal resolution can up to $10\mu\text{m}$ and vertical resolution up to

15 μ m. It meets to the accuracy requirements of engineering applications.

V. CONCLUSIONS

In this article, a small laser defect detection system was designed. It used a simple way to achieve high-precision measurement of the target surface. The system has the advantage of low-cost, portable measurement and can be adapted to a variety of complex measurement environment online- measurement. Through the device, the process of surface defects change will be recorded and the experiments also show its effectiveness.

In the measurement, the selection of CCD camera and line structured light generation have a direct impact on the image quality and will affect accuracy of measurement results. The more accurately the light source and CCD camera is useful to improve the measurement accuracy.

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