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A conoscopic holography-based 3D measurement system for analyzing defects in steel plate surface

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Abstract: A conoscopic holography-based 3D measurement system for analyzing the defects on the surface of steel plates was introduced in this paper. The hardware, which is automated through software, performs sampling of the steel plate surface. Through the software interface, point-cloud data of the steel plate surface are obtained and reconstructed to form a 3D image of the steel plate surface. The software allows automatic analysis of steel plate surface defects through identification of the bulges and depressions. In addition, the software can also automatically calculate the defect information, such as the deepest point, volume, opening area, opening length, and so on, thereby determining the defect size. The results determined by this 3D measurement system were found to be in good agreement with the actual values.

Key words: 3D measurement; surface defect; conoscopic holography

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1 Introduction

Machine vision inspection technology is the production line monitoring technique that is being prevalently used to inspect defects in the surface of steel plates during the manufacturing process. However, this technology focuses only on the 2D features of the defects. Unfortunately, there is no standard technology to detect the 3D features of the defects. In many cases, the 3D information of the defects in the surface of the steel plate plays an important role in determining its quality. Therefore, it is of critical need to develop a viable 3D measurement technology to detect the defects in the steel plate surface [1].

In this paper, we present a 3D measurement system based on the conoscopic holography technology, for precisely capturing the defects in the steel plate surface. The system is designed to automatically measure the size of the defects. Using this system, we successfully acquired the 3D information of defects in the steel plate surface.

2 Detection principle

The traditional holographic technology typically uses coherent light to establish interference between the object beam and the reference beam. In such a case, the speed of both the object and the reference beams are the same, while their travel paths are different. On the other hand, in conoscopic holography, a beam of light is passed through the polarizer and the uniaxial crystal, so as to produce the ordinary and extraordinary rays. These two rays generate an interference pattern. In other terms, the hologram is obtained by interference of the ordinary and extraordinary rays, without any coherent light. This facilitates accurate measurement of the object [2-5]. Fig. 1 schematically illustrates the operating principle of the sensor.

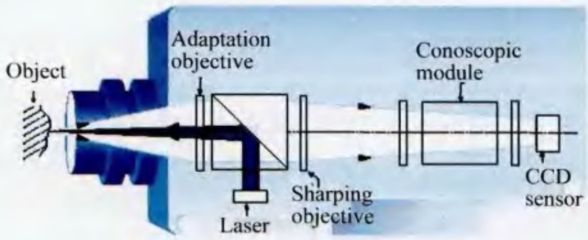

Fig. 1 Operating principle of the sensor

3 Architecture and design of the system

From the interference pattern, the 3D shape of the steel plate surface can be reconstructed by the point-cloud data. Furthermore, the system automatically analyzes the defects in the steel plate surface, as characterized by bulges or depressions. In this way, a user can observe the morphology of the steel plate surface from all directions in the three-dimensional space. According to the requirement of the user, the system can select a specific location for cutting, and the user can obtain a section. By using this section, the user can separately observe the selected surface.

The 3D measurement system used for detecting the defects in the steel plate surface has six function modules, including switchyard, analysis and processing after three months, 3D operation, database manipulation,

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print, and setup.

Using these functions, the system allows control of hardware operation, observation and analysis, and storage of defect information. The hardware operation has three steps. First, it initializes the mobile platform, the probe position and the camera conditions. Second, it begins to send instructions to the equipment for measuring. Third, upon completion of the measurement, the results, which are displayed on the main interface, can be obtained from the equipment.

The second functionality, observation and analysis, forms the core of the software. This allows the user to observe the morphology of steel plate surface from all directions in the three-dimensional space. Moreover, the user can also select a specific location for cutting and obtain a section, so as to accurately understand the defect information in a particular section. Fig. 2 shows the main interface of the system.

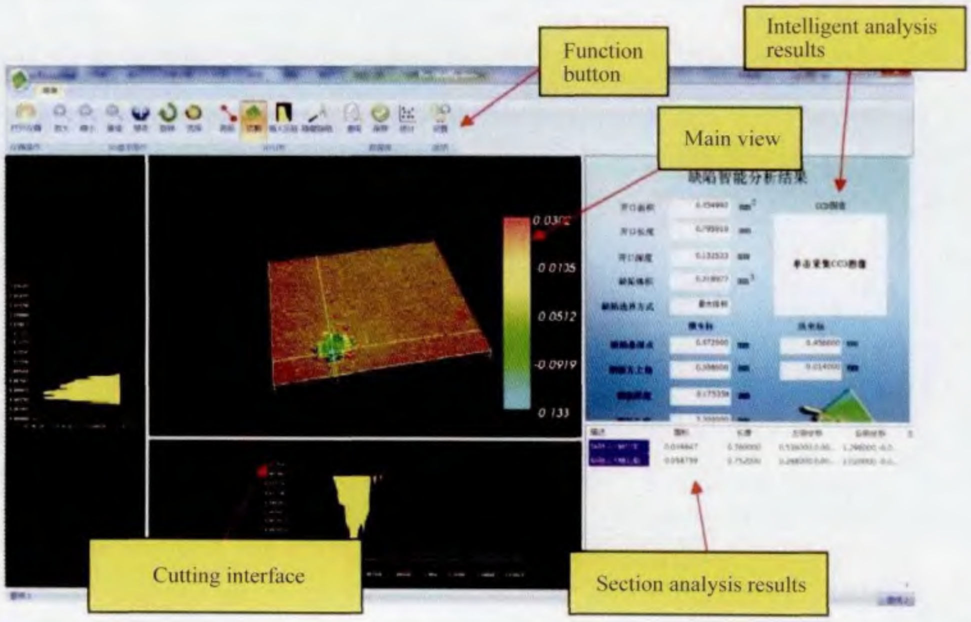

Fig. 2 Main interface of the system

The interface provides 4 different ways to query, namely, name query, ID query, parameter query, and materials query. Upon completion of the query, information about the steel plate is displayed to the user. The information includes defect ID, classification of defects, steel plate ID, steel plate name, steel plate thickness, steel plate reel number, unit number, class number, surveyor number, defect opening area, defect opening diameter, defect volume, defect depth, and measuring time. Fig. 3 shows the typical query interface.

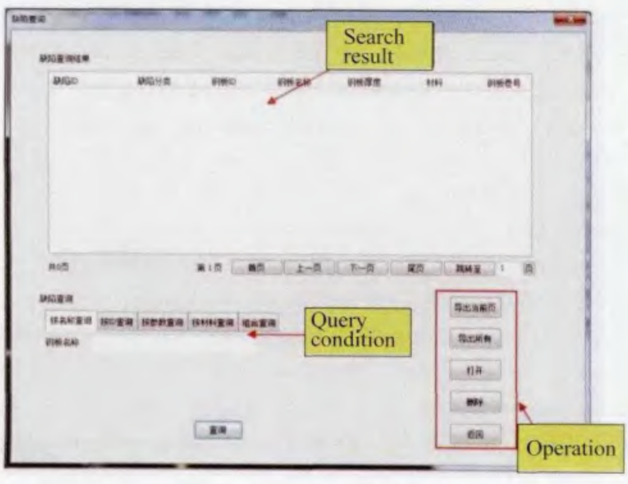

Fig. 3 The query interface

The user can also save this information by choosing the save option in the main interface. The user can input necessary information to the database. Accordingly, the software automatically calculates the detailed information of the defects. Fig. 4 shows the information preservation interface.

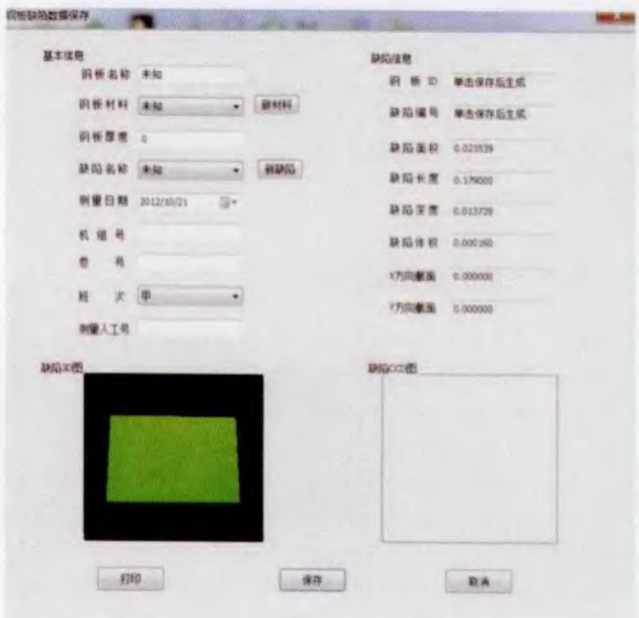

Fig. 4 The information preservation interface

In addition, the statistical function is often used to understand the distribution of defect opening diameter or defect depth in a month. Fig. 5 shows the statistical interface and Fig. 6 shows the print interface.

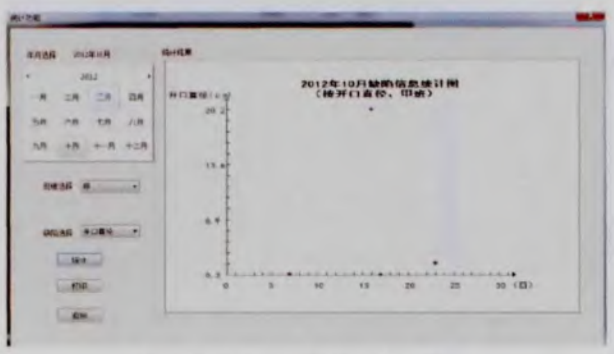

Fig. 5 The statistical interface

Fig. 6 The print interface

The system setup mainly includes standards for measuring defects, data pre-processing options and detector parameters. Fig. 7 shows the typical system setup interface.

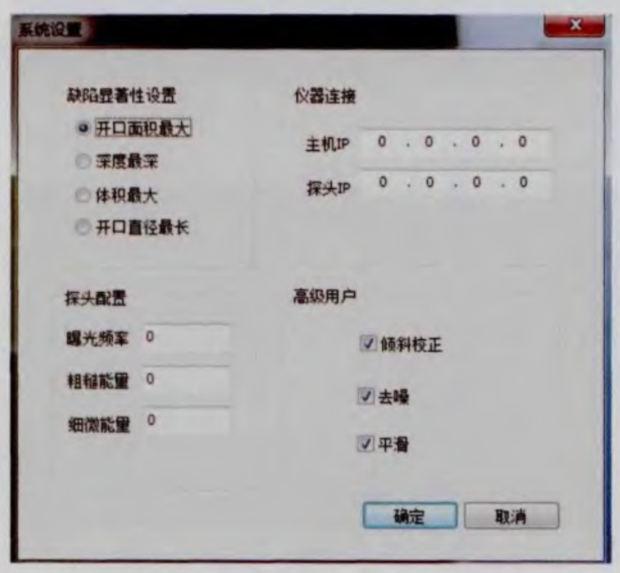

Fig. 7 The system setup interface

4 3D reconstruction and display of steel plate surface

3D reconstruction implies the mathematical modeling of the 3D object, suitable for computer representation and processing. It forms the basis for processing and analyzing the properties of the steel plate using the computer. In this system, the point-cloud data can be provided by the laser and the mobile platform. Several 3D coordinate points can be obtained from these point-cloud data, which in turn are analyzed by the system to identify the defects in the steel plate. Subsequently, the system measures different properties of the steel plate, including the depth, volume and opening length of the defects.

In this system, the point-cloud data are converted into dot matrix data via interpolation. Here, each of the elements in the matrix corresponds to the surface depth of the steel plate obtained by laser detection. The dot matrix data are subsequently converted into 3D data for further display. Fig. 8 shows the data processing flow.

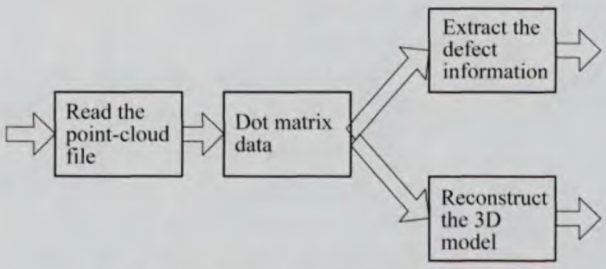

Fig. 8 The data processing flow

5 Defect detection and test

Defects refer to larger areas deviating from the datum. Therefore, it is important that the system first analyzes the datum of the steel surface. Following that, the distance of each point to the datum can be calculated. If the calculated distance is greater than the threshold value, that point is considered to be a defect.

(1) Determination of the threshold

To comply with the dot matrix data of different scales, the threshold has to be determined dynamically. If m is assumed to be the average distance of all points to the datum, the threshold is taken as "m times k" in the algorithm. In this system, the threshold can be adjusted by using the visual interface.

(2) Defect location

From step (1), a binary image can be obtained. Here, 1 signifies a defect, and 0 indicates the datum. Subsequently, expansive working can be used to correct the defect margin, and the property of the defect can be estimated. The location of the defect can be determined by a pre-defined selection method.

(3) Calculation of the defect area

The area of a defect is calculated as follows:

counting the total number of the grids that are marked as defect; and then multiplying the number by the size of each grid. The accuracy of the area determined by this method depends on the step length of the mobile platform along the *x*-axis and the *y*-axis.

(4) Calculation of the defect volume

The volume of a defect is calculated as follows: calculating the total depth of all the grids that are marked as defect; and then multiplying the depth by the size of each grid. The accuracy of the volume determined by this method depends on the precision of the probe and the step length of the mobile platform along the *x*-axis and the *y*-axis.

(5) Opening length

The distance between any two points of the defect on the edge is calculated, and the longest distance is taken as the opening length of the defect.

(6) Defect selection

The system offers 4 ways to select a defect, including the maximum depth, biggest area, maximum opening length and maximum volume. A defect can be selected from all the defects in the previous steps, according to a pre-defined selection method.

(7) Application and test

Two groups of pitting samples were selected and each group was tested 10 times. The testing results suggest that the numerical test depth changes within 0.5 μm. Fig. 9 shows the pitting test object. The micro test image of Pitting 1 is shown in Fig. 10, while Fig. 11 shows the corresponding 3D reconstructed image. Similarly, Fig. 12 shows the micro test image of Pitting 2, and the corresponding 3D reconstructed image is shown in Fig. 13.

Fig. 9　Pitting test object

Fig. 10　Micro test image of Pitting 1

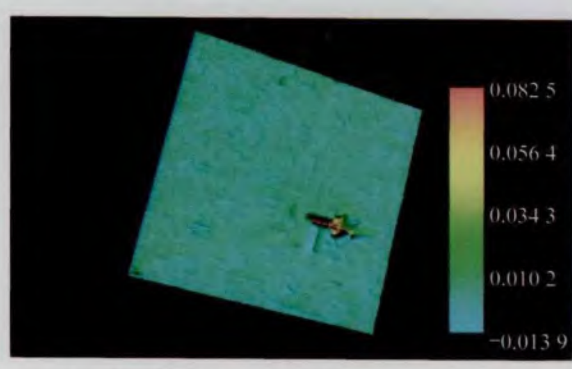

Fig. 11　3D reconstructed image of Pitting 1

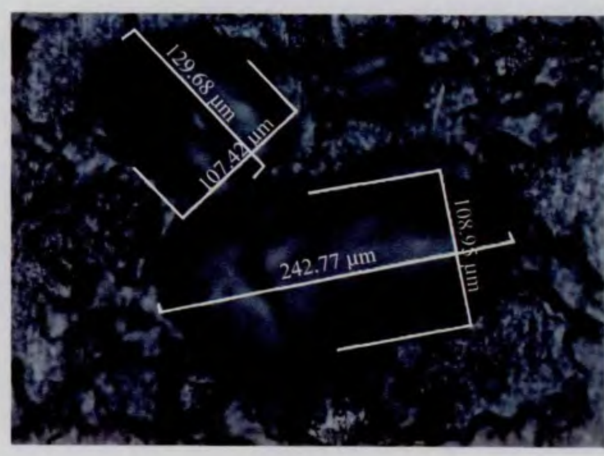

Fig. 12　Micro test image of Pitting 2

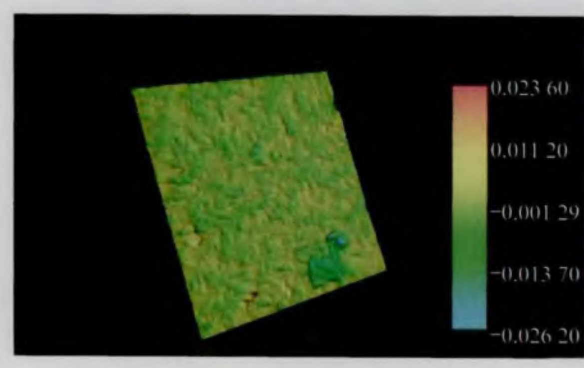

Fig. 13　3D reconstructed image of Pitting 2

6 Conclusion

In summary, we have presented a 3D measurement system based on the conoscopic holography technology to identify the defects on the surface of steel plates. The system is supported with the appropriate software to facilitate automatic analysis of the defects in the steel plate surface through identification of bulges or depressions. In addition, the software can also automatically calculate the defect information, such as the deepest point, volume, opening area, opening length, and so on, allowing automatic measurement of the defect size. The system has obtained good results under laboratory conditions.

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