

# An Intelligent Nondestructive Testing System of Ultrasonic Infrared Thermal Imaging Based on Embedded Linux

Hao Mi, Ming Yang, Tian-yue Yang

**Abstract**—Ultrasonic infrared nondestructive testing is a kind of testing method with high speed, accuracy and localization. However, there are still some problems, such as the detection requires manual real-time field judgment, the methods of result storage and viewing are still primitive. An intelligent non-destructive detection system based on embedded linux is put forward in this paper. The hardware part of the detection system is based on the ARM (Advanced Reduced Instruction Set Computer Machine) core and an embedded linux system is built to realize image processing and defect detection of thermal images. The CLAHE algorithm and the Butterworth filter are used to process the thermal image, and then the boa server and CGI (Common Gateway Interface) technology are used to transmit the test results to the display terminal through the network for real-time monitoring and remote monitoring. The system also liberates labor and eliminates the obstacle of manual judgment. According to the experiment result, the system provides a convenient and quick solution for industrial non-destructive testing.

**Keywords**—Remote monitoring, non-destructive testing, embedded linux system, image processing.

## I. INTRODUCTION

As a means of detection, non-destructive testing is widely used because it can maintain the integrity of the detection object. Non-destructive testing can be used in all stages of production, including structural design, material selection, material processing, factory inspection, and post-repair. Non-destructive testing is important for the checking the reliability of product quality and cost control.

In the 1970s, some scholars proposed a method of vibration thermal image detection, which became the prototype of ultrasonic infrared heat wave detection technology [1]. Ultrasonic excitation infrared non-destructive testing uses the energy of ultrasonic waves to excite the vibration of the device under test. In the defect area, the friction around causes the temperature to rise and infrared thermal imaging is used to detect the temperature variation. This detection technology has the advantages of high speed, high accuracy, easiness in locating and has a wide range of objects to be measured. However, the detection requires manual real-time field judgment, the result cannot be saved, the viewing mode is

primitive, with low integration and low intelligence, thus limiting the application scenario [2].

In view of the above situation, this research implements an intelligent non-destructive detection system based on embedded linux. An image recognition algorithm is realized on the ARM core. And an embedded linux system is built on the ARM core. So the whole system can detect the defect itself and send the result through internet by the boa web server and CGI technology. Compared with the traditional system, this system is smarter and it realizes remote monitor.

## II. THEORY OF ULTRASONIC INFRARED DETECTION

It is generally accepted that the ultrasonic wave causes the object to vibrate when the device is under test. The vibration state of the contact surfaces on both sides of the defect is inconsistent, resulting in mutual friction and collision. The energy is converted into heat, which can be analyzed by kinetic methods.

The finite element method is used to analyze the induced heat generation at the defect of the tested part. For a certain unit  $e$ , the following elastic dynamic equations are satisfied:

$$M_e \ddot{\delta} + C_e \dot{\delta} + K_e \delta = f_o + f_u \quad (1)$$

where  $\delta$  is the node displacement matrix of element  $e$ ;  $M_e$  is the mass matrix of the element,  $C_e$  is the damping matrix of the element,  $K_e$  is the stiffness matrix of the element,  $f_o$  is the external load matrix, and  $f_u$  is the collision contact force matrix. If the whole is analyzed, the collision contact force on the contact boundary changes with the deformation, then the finite element motion control equation of the measured part is:

$$M\ddot{U} + C\dot{U} + KU = F_s(U) + F_{s0} \quad (2)$$

where  $U$  is the nodal displacement matrix;  $M$  is the mass matrix,  $C$  is the damping matrix,  $K$  is the stiffness matrix,  $F_s$  is the contact force matrix, and is related to contact deformation,  $F_{s0}$  is the loading force.

During ultrasonic excitation, due to the dynamic friction between the crack defect interfaces, the mechanical energy is converted into thermal energy, and the heat flux density of the generated heat is:

$$q(t) = \left[ \mu_d + (\mu_s - \mu_d)e^{-c|v(t)|} \right] F_N(t) v_r(t) \quad (3)$$

Hao Mi is a master's student with the Department of Instrument in Shanghai Jiao Tong University, China (e-mail: mhsjtu@sjtu.edu.cn).

Ming Yang is professor and doctoral supervisor of Shanghai Jiao Tong University (e-mail: myang@sjtu.edu.cn).

Tian-yue Yang is PhD candidate in Shanghai Jiao Tong University (e-mail: thomas-yang@sjtu.edu.cn).

$\mu_d$  is the dynamic friction coefficient of the contact surface,  $F_N$  is the normal contact force,  $v(t)$  is the relative velocity of the contact point,  $v_t(t)$  is the relative tangential velocity of the contact point, and  $\mu_s$  is the static friction coefficient of the contact surface,  $c$  is the speed coefficient of static friction converted to dynamic friction.

The heat is generated and the temperature rises around the defect area. Therefore, the device to be tested is detected with an infrared thermal imaging device, the position and heat of the defect can be found in the infrared image [3].

### III. SYSTEM STRUCTURE

The detection system consists of an ultrasonic power supply, a detection object, an infrared thermal imaging device, an ARM

core, and a display terminal. The excitation device of the system is a high-power ultrasonic power source for generating ultrasonic excitation, and the excitation power is the resonance frequency of the object to be detected. The thermal images can be transmitted to the ARM core via USB. The ARM core is used to implement image processing algorithms and networking functions. Image processing is performed on-chip to realize defect recognition and positioning, and then connected to the route through the LAN network. The infrared thermal image and detection result data of the display terminal can be viewed on a computer or mobile phone with networking function, after accessing an IP address. The system facilitates data uploading, archiving and real-time viewing. The structure of the system is shown as Fig. 1.

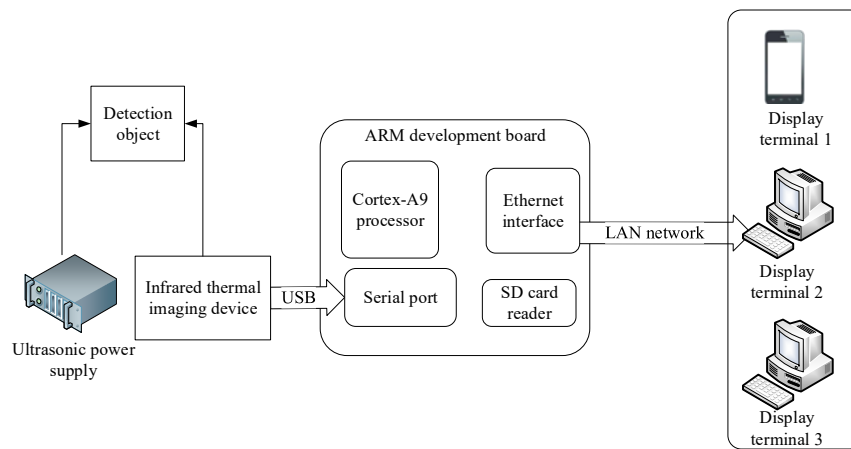


Fig. 1 The structure of the system

### IV. SOFTWARE AND ALGORITHMS

In terms of image processing algorithms, the system adopts CLAHE algorithm to enhance the contrast of the image, and uses Butterworth bandpass filter to reduce the noise. In terms of networking functions, the system adopts the embedded linux operating system, and the linux system kernel is tailored and optimized according to requirements. Then the system is compiled and transplanted into the ARM core, and then an embedded web server is built to realize dynamic web page through CGI technology.

#### A. Embedded Web Server

In embedded linux, this paper chooses embedded web server technology as a solution to access the Internet. The embedded Web server means that importing Web server technology in traditional embedded devices, and embedding some protocols in the TCP/IP network protocol as a new communication protocol. Implemented in the client browser via the Internet, it enables remote online management and monitoring of embedded devices [4].

In the embedded linux system, httpd, boa and tthttpd are widely used Web Servers. Httpd only supports static pages, does not support CGI, and is not suitable for advanced applications. Both tthttpd and boa support CGI and the functions provided are similar, but tthttpd requires larger resources than

boa. Boa can use simultaneously all ongoing HTTP server, rather than by calling 'fork' to generate a child process to handle multiple connections simultaneously. Boa performs 'fork' calls only for CGI programs, automatic directory generation, and file compression. To a large extent, boa server approach can reduce the demand on system resources, it is very important because these are relatively limited storage and computing resources on embedded devices [5]. Therefore, boa is chosen as the web server in this paper.

#### B. Implementation of Dynamic Web Pages under Linux

CGI is an interface standard or specification for exchanging information between a server and a host application. A web server can activate an application while passing user-submitted data to the program through CGI, and then returning the program's response (output) to the browser. In linux system, CGI technology is commonly used to display dynamic pages. This server-side technology can realize the interaction between the browser and the server [6].

The workflow of CGI is as follows: The client sends a page request to the web server through a web browser. After receiving the request, the web server starts the CGI program and sends a browser request. Then the result is input to the web browser, and the web browser sends the results to the display terminal over the network.

### C. Image Processing Algorithm

Since the temperature of the normal area of the device under test is similar, the color tone of the thermal image is relatively simple. After being converted into a grayscale image, the gray histogram is concentrated and the contrast is low. At the same time, due to the uneven temperature distribution in the thermal image, there will be a lot of speckle noise, and the temperature diffusion in the defect area causes the blur of the edge, which is an obstacle to the subsequent defect analysis. Therefore, this algorithm should enhance the contrast of the image and filter the noise.

This paper chooses the Contrast Limited Adaptive Histogram Equalization (CLAHE). Compared with the adaptive histogram equalization and the histogram equalization, the CLAHE algorithm has a good effect, which can broaden the distribution of the gray histogram of the thermal image and enhance the gray level difference between the normal region and the defect region. At the same time, it can effectively suppress the enhancement of the noise region and prevent excessive enhancement.

The low frequency part of the thermal image is a region with slow temperature change or stable temperature. It is the normal region and has little influence on the extraction of the defect profile. The Butterworth bandpass filter can attenuate the low frequency part and suppress high frequency noise. It has high precision, stability and flexibility, which can retain important information for subsequent image defect detection. Therefore, Butterworth bandpass filter is chosen for enhancement.

The Butterworth bandpass filter can be thought as a series connection of a Butterworth high-pass filter and a Butterworth low-pass filter with different cutoff frequencies. The  $n$ -th order Butterworth high-pass filter transfer function can be expressed by:

$$H(u,v) = \frac{1}{1 + \left(\frac{D(u,v)}{D_H}\right)^{2n}} \times \frac{1}{1 + \left(\frac{D_L}{D(u,v)}\right)^{2n}} \quad (4)$$

### D. Defect Identification and Location

After image enhancement, the defect area and the normal area have been distinguished, and the color distribution of the defect area is not uniform. Therefore, the local variance is chosen as the basis for distinguishing the defects in the image. The specific plan is as follows:

- G component of the RGB color image is divided into  $3 \times 3$  image part a total of 9, sub-picture length or width is not an integer is rounded down;
- The standard deviation of the gray value for each sub-image is calculated, denoted as  $i=1\sim9$ ;
- The range  $D$  of 9 standard deviations is calculated. If  $D > D_0$ , judge that this image is defective. Otherwise, it is judged to be a normal test piece.  $D_0$  is the threshold.

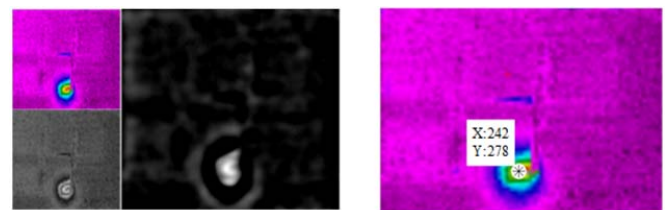
To locate a defective center for defect detection, firstly, a closed operation is performed to eliminate the influence of noise around the defect. Then we select the maximum connected domain center as the defect center. Finally, the

identification and location of the defect are achieved.

## V. EXPERIMENTS AND RESULTS

In order to verify the processing algorithm and the effect of remote monitoring, ultrasonic power is used to vibrate the defective workpiece, and thermal images are collected with infrared thermal imaging. After the image information is processed by the algorithm, the result is uploaded to the local area network and can be viewed at the display terminal.

Fig. 2 (a) shows the comparison between the original thermal image, the grayscale image, and the image after processing. It can be seen that the edge of the defect is clearer, the background and the measured object are distinct than before. Fig. 2 (b) shows the results of detection.



(a) Image enhancement

(b) Defect location

Fig. 2 Image processing effect

The mobile phone or PC used for displaying is connected to the local area network, where the detection system is located, and input the fixed URL to view the fever condition of the detected object, the detection result can be seen. Fig. 3 shows the detection results viewed by the mobile phone accessing URL. From the above results, it has been proved that the system implements intelligent non-destructive testing.

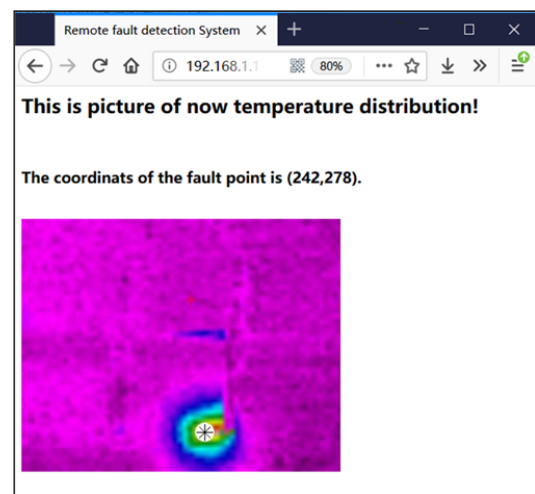


Fig. 3 System operating results

## VI. CONCLUSION

An intelligent non-destructive testing system based on ultrasonic infrared thermal imaging is showed in this research. Remote monitoring and intelligent detection is implemented on

the system. The image algorithm running on the chip replaces the judgment of the staff and improves the efficiency and accuracy of the detection. The browser/server structure is adopted. Through the boa server and CGI technology, the functions of networking and dynamic pages are realized. So the detection information can be released in real time through the network. The intelligent system provides a solution for the automation and intelligentization of non-destructive testing for industrial production.

#### ACKNOWLEDGMENT

The work is supported by the National Science Foundation of China (Grant No. 81571831, Grant No. 51275287), the Precision Medical Instruments and Ultrasonic Technology Laboratory, Shanghai Jiao Tong University-China.

#### REFERENCES

- [1] E G. Henneke, et al. "Thermography-an NDT method for damage detection." *J Metals*. 31(9), p.11-15,1979.
- [2] X. Han, "Finite Element Modeling of the Heating of Cracks During Sonic Infrared Imaging," *J. Appl. Phys.* 99(7), p. 074905, 2006
- [3] Solodov, Igor, et al. "Noncontact Sonic NDE and Defect Imaging Via Local Defect Resonance." *J Nondestruct Eval*. Vol.3, pp. 1-8,2016.
- [4] Sonali, "An approach for de-noising and contrast enhancement of retinal fundus image using CLAHE." *Opt Laser Technol* 2018, to be published
- [5] S.-Q, "Disturbance rejection control for vibration suppression of smart beams and plates under a high frequency excitation," *J Sound Vib*, vol. 353, pp. 19-37, 2015.
- [6] S. Kapuria, "A nonlinear efficient layerwise finite element model for smart piezolaminated composites under strong applied electric field," *Smart Mater Struct*, vol. 22, p. 055021, 2013.

**Hao Mi** a master's student at Shanghai Jiao Tong University in China. The main research direction is image processing and defect detection. Her major is measure and control technology and instrument. She got the bachelor's degree in Harbin Institute of Technology in 2016.