Design and Analysis of On-line Casting Surface Defect Detection System

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Abstract. In order to solve the problem of surface defects on line detection in the production of cast iron castings, this paper describe an on-line detection system for casting surface defects based on PMAC motion control card, moreover, it analyzes the factors affecting the acquisition of high quality images, studies on the effects of motion velocity, exposure time, the angle between the light source and the camera on the image acquisition in detail and optimizes the impact parameters. Online experiments show that the control system has stable operation, good robustness, high control precision and stable image acquisition, which can meet the requirements of the actual engineering.

Introduction

The engine casting of cylinder block and head is the key components of the engine, also is one of the most complex castings in automobile casting production[1].Cylinder Block and Head embodies the core technology of manufacturing, its quality plays a decisive role in the performance of engine power and fuel consumption, and its complete manufacturing equipment and manufacturing level is one of the important factors that affect the performance of the engine[2].Casting in casting production process will appear empty, sand drop, cracks and sarcoma surface defects, etc. These defects not only restricts the casting mechanical properties, density, corrosion resistance and anti crack performance, but also affect the appearance and roughness of the casting surface.

At present, Cylinder Block and Head casting foundry is still used manual detection. The manual detection not only has low detection efficiency, also is prone to error. With the development of science and technology, a large number of visual inspection system is applied to the detection of auto parts, such as the Engine cylinder surface detector developed by German TOPOMETER company and the cylinder head system introduction of Shanghai Volkswagen can c be in the corner of the casting, overlap and other areas for a simple, comprehensive testing. But our country is still relying on manual detection or off-line detection method to detect engine casting of cylinder block and head. At the same time, the casting surface shaps is not suitable for magnetic flux leakage detection and eddy current detection technology because of its complexing surface shape[3-5]. Infrared detecting equipment is seriously disturbed by electromagnetic and signal in the bad casting environment[6]. Laser scanning detection cannot detect the cracks in the vertical direction of the beam and poor stability[7], which is not suitable for the detection of the casting.

Aiming at this problem, in order to realize the online casting surface defect detection, this paper studied the machine vision defect detection principle, and according to the characteristics of the engine casting of cylinder block and head, analyzed the detection performance and function of the casting line, and according to the actual needs, chose the visual defect detection for the camera and the light source, focused on the distortion calibration linear array CCD camera and error correction method, developed the cylinder casting surface defect detection system based on machine vision.

System Structure

Casting quality of cylinder block and head detection system is based on machine vision, laser ranging, motion control technology, and combine with computer, intelligence and pattern recognition and distributed control and other techniques of the detection system. Among them, obtaining high quality images continuously and high precision data affect the reliability and stability of the surface defect detection, so the visual acquisition system must be able to meet the complex working environment and has strong anti-interference ability. According to the functional requirements of the application and characteristics of the design of online casting surface defect detection system, the system architecture is shown in figure 1. The whole system includes image and data processing system, equipment control system, image acquisition system, mechanical movement mechanism and peripheral equipment.

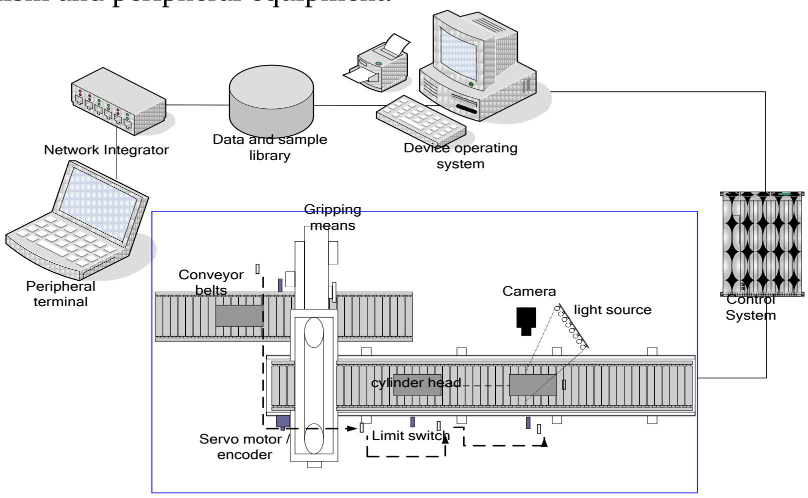

Fig. 1 Schematic diagram of detection system of casti.

Control System Design

The device control system is used to control the motion of each actuator of the machine, and to send and receive the command of the host computer to control the subsystem, so as to assist the implementation of the mechanism to complete the operation. In order to realize automatic surface defect detection system of cylinder block and head casting,we designed the core control unit with IPC and motion control system based on PMAC card ,the system structure diagram is shown in figure 2.

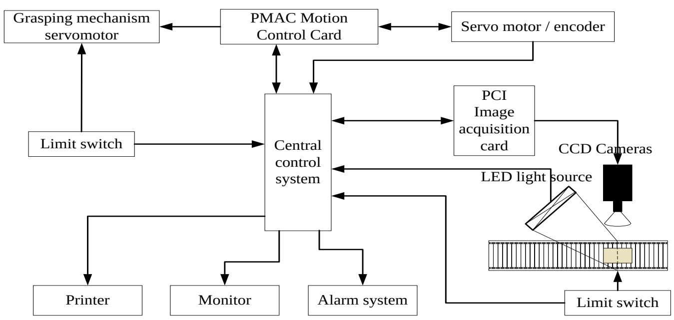

Fig. 2 General structure of the system.

The system consists of motion control subsystem and data processing subsystem. The motion control system is realized by the PMAC motion control card in the real time to control the servo motor, photoelectric switch, limit switch, indicator light alarm and other parts.IPC collect the casting surface image acquisition, processing, communication and control.Servo motor provide motion power for the movement of each axis and servo motor with encoder signal feedback to the IPC,then the acquisition speed of the camera is controlled by line-scan digital camera according to the feedback signal of the encoder. The different actuators equipped with a limit switch for tracking the position of the casting.

High quality image acquisition

The relationship between the speed and image quality. Application scan image does not produce distortion or motion interpolation for image distortion to restore movement, while the camera image acquisition have maintained uniform transfer movement. In order to ensure that the image is not compressed and stretch, must ensure that the resolution of the image is equal to the longitudinal, online array camera scanning image. First of all, defined Variable as following, the line number of linear array camera per line H_c (pixel), the target width *WD* (m), the target speed V_0 (m/s), linear array camera line scanning rate V_c(m/s), the target run time of scanning a frame image T_0(s), linear array camera scan time for scanning a frame image of T_c(s). Above all, vertical resolution is equal to the lateral resolution, as in Eq.(1).

$$\frac{WD}{H_C}=\frac{V_0\times T_0}{V_C\times T_C}; \tag{1}$$

Based on T_0=T_C, the camera line can be scanning rate of, as in Eq.(2).

$$V_0=\frac{V_C\times WD}{H_C} \tag{2}$$

This article has chosen the line-scan digital camera DALSA PC - 30-04 k80 , which the highest line frequency of 17.6 kHz, maximum scanning objects running speed of 1.72 m/s. According to the scene of the work environment and the demand with the device itself, the casting speed is about 0.2 m/s, then high speed will result in equipment vibration of stability increasing the cost of the design of the equipment and the collection of high frequency will have produced too large amount of data increasing the operation time of the algorithm.

Therefore, it chooses the right cylinder head speed, on the premise of meet the requirements. Running speed and the relationship between the image distortion have been determined, when calibration plate surface image has been scanning circle, on the premise of the line frequency of 2.5 kHz, 40cm width, cylinder head speed of 0.1m/s, 0.2m/s, 0.3m/s, 0.4m/s and 0.5m/s. The stoma round size has been determined by circular degree of calibration plate surface, which has been used in the image binary progress. And the circularity has been designed as in Eq.(3).

$$C=\frac{4\pi\times S}{A^2} \tag{3}$$

In Eq. (3), S is the circle area, A is the circumference, and the circularity is 1. The smaller circular degree is, the more irregular the graphics is, and the greater the gap of circular is. As shown in Fig 3, through the collection and send the casting surface image extraction, has determined the relationship between the round hole circularity and the speed. In Fig. 3, when the sampling frequency of 2.5 kHz, speed in the round hole circularity is 0.85, with the increase of movement, round hole circular degree has been increasing. When the acquisition speed is 0.2 m/s, the circularity is largest.

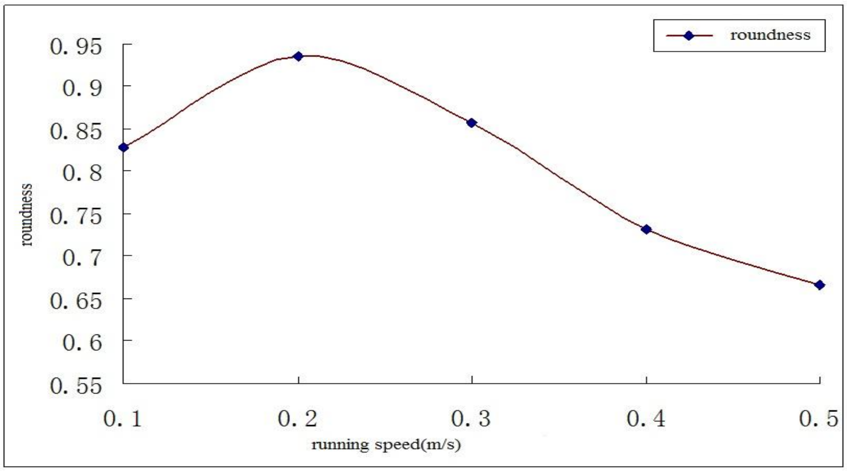

Fig. 3 The casting head and casting head pore roundness speed diagram.

Velocity scanning calibration plate has been divided into ten levels in 0.1 ~ 0.3 about (0.1,0.13,0.16,…,0.3).After binary image,while the motion platform speed has been 0.22m/s in Fig. 3, stomata circularity has been 0.983. In order to improve the precision of image scanning, the diameter of movement direction and the direction of the chip have been calculated, by means of scanning image interpolation correction, round hole image binary processing, search up and down, right and left for four points[8]. By the pixel number of movement direction diameter N_1, the pixel number of chip direction N_2, the linear interpolation has been modified by movement .Then the correction factor is as in Eq.(4).

$$f = \frac{N_2}{N_1} \tag{4}$$

The whole image is expressed as $f(i,j)$, and after interpolation image represented as $f(m,n)$.Based on the linear array camera without the distortion of the horizontal axis, according to the interpolation coefficient on the direction of the pixel interpolation calculation. It can be expressed as in Eq.(5).

$$\begin{cases} i + u = m / f \\ j = n \end{cases} \tag{5}$$

In the above formula, u is representative of the interpolation coefficient. According Eq. (5), original image coordinates are obtained by target coordinates reverse transform to get the corresponding original image coordinates. The value of the target image is expressed as in Eq.(6).

$$f(m,n) = (1-u) f(i,j) + uf(i+1,j) \tag{6}$$

By extracting the hole circularity and interpolation correction, the hole circularity has been up to 0.989, as shown in Fig 4.

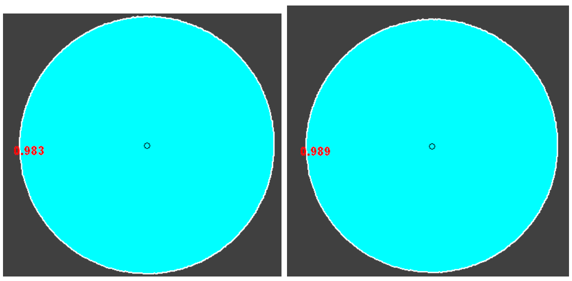

Fig.4 Comparison of roundness of circular hole before and after calibration.

The relationship between exposure time and image quality. Better to highlight the characteristics of measured object surface area and background,we need to adjust the exposure time of camera, to make better edge features of scan image and better inhibition of background.A single pixel of theory of linear CCD camera charge calculation formula has been as follow.

$$f(m,n)=(1-u)f(i,j)+uf(i+1,j) \quad (7)$$

As in Eq.(7),there are the electric charge of pixel Qin,photoelectric conversion efficiencyη,electronic chargeδ,pixel area *S*, Planck's constant *h*, the incident optical radiation frequency *v*,exposure time *t*, and pixel irradiance received Ee.In Ep.(7),the exposure time *t* is very small.All CCD surface irradiance is a constant value in the integration process,there for,Qin[9-12] is:

$$Q_{in}=g_z E_e t \quad (8)$$

As in Eq.(8), gzis photoelectric conversion coefficient. The relationship between Er or t and image grey value G, is shown as:

$$E_r=\frac{1}{tg_v}G \quad (9)$$

As in Eq.(9),in certain cases of gain value gv, relative irradiance of sensor E_r and image grey value *G* is inversely proportional to the relationship, and is proportional to the exposure time *t*.If scanning image grey value may set 170, exposure time *t* and irradiance relations E_r will be written as in Eq.(10).

$$t=\frac{170}{E_r g_v} \quad (10)$$

In Eq.(10), the gain value g_v can be obtained by the manufacturers.The change curve is shown in Fig.5,between the exposure time *t* or image SNR and image contrast. In Fig. 5,while the exposure time *t* is increasing, the image SNR is decreasing,but the image contrast is rising and after falling.When the exposure time is 230μs,the image contrast comes to the maximum,and then declines. At this time,the image signal-to-noise ratio also shows a sharp decline.

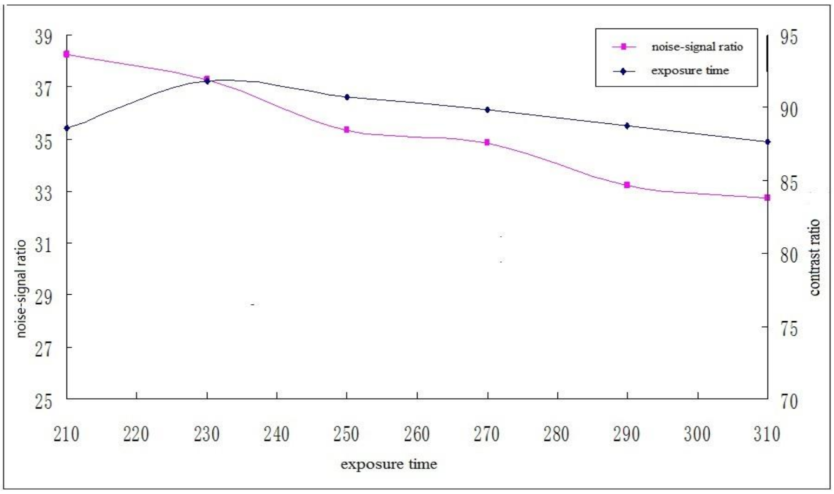

Fig.5 Relationship between exposure time or contrast and signal to noise ratio.

The relationship between the angle of light source and image quality. The casting will be considered a reflection light source in the image scanning, and line array camera is placed directly above the surface of the casting.The illumination $E_{A'}$ can be shown as:

$$E_{A'}=\frac{L_r\cdot\tau\cdot\pi\cdot\cos^4\alpha}{4F^2{}_1(B+1)^2} \quad (11)$$

In Eq. (11),there are the included angle of the optical axis α,the scanning area in the direction of the light brightness L_r,lens transmission ratio τ,The lens magnification B and Lens aperture F.If the incoming light is stronger,the image edge pixel is darker than near the center of the pixel.The smaller F means the larger the lens aperture and the relative aperture is bigger,so the more light is into the lens and the smaller the depth of field.

Through the above analysis, in order to obtain high quality images of the surface of the cylinder head,camera light irradiation Angle to scan images in detail on the influence law of the research.When the light incident Angle of surface of the cylinder head is more than 60 degrees,reflectivity will decrease obviously[13]. In this paper, we set the exposure time of 230μs,cylinder head speed of 0.2 m/s,the camera line frequency of 2.5 kHz,the incidence angles of the camera light source between 10 ° and 60 °,The relationship between the angle of light source and image quality is shown in Fig.6.

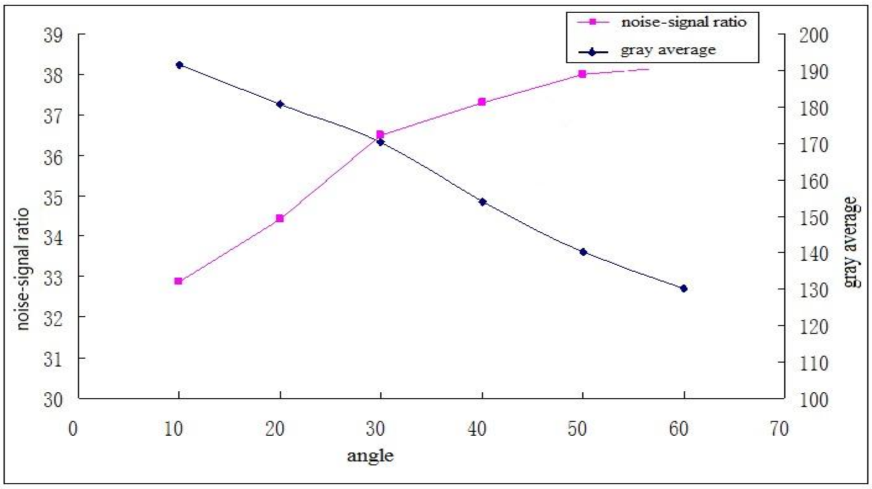

Fig. 6 Ra The relationship between the angle of light source and image quality.

(mage SNR and gray average)

Through Fig. 6, the angle between the light source and the camera is better 30 °.Equations should be centered and numbered consecutively, as in *Eq*. (12).

$$I\left(\left(P-k_i\right)^2, m_i^2, M\right)=\frac{1}{(2\pi)^5}\int\frac{d^3k_i}{2\omega_i}\delta^4\left(P-k_i\right). \qquad (12)$$

Punctuation marks are used at the end of equations as if they appeared directly in the text.

Conclusion

This paper designed the motion control system of defect detection based on PMAC card ,analyzed the influencing factors of obtaining high quality images and given image and movement speed, exposure time and light angle parameter values.from the field environmentthe and actual demand of detection of surface defects of casting. Online verification shows that the defect detection system has good function and can meet the needs of the field engineering.

Acknowledgment

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References

[1] WU Dian-jie.Developing Tendendy of Automotive Engine Cylinder Block Casting Production Technology in China [J]. Modern Cast Iron,2012,S2:23-30.

[2] WANG Xin-jie.Research and Application of Lost Foam Process Technique in Enging Cylinder Block & Cylinder Head Casting [J].Foundry Engineering,2007,01:35-52.

[3] HG Ramos,AL Ribeiro. Present and Future Impact of Magnetic Sensors in NDE.Procedia Engineering. 2014,86:406-419.

[4] Experience using magnetic flux leakage technique for internal inspection of in-service pipelines: NDE: The Next Decade and Beyond. 19–23 Mar. 1990. pp. 130–132.

[5] Lokendra Kumar, B.S. Manjunath, R.J. Patel,etc. Prabhu, Experimental investigations on melting of lead in a cuboid with constant heat flux boundary condition using thermal neutron radiography, International Journal of Thermal Sciences, November 2012, 61:15-27.

[6] P Gardner,SA Arnold,F Brown,R Carr,A Nordon. Investigating the feasibility of mid infrared spectroscopy for monitoring an industrial de-racemization biotransformation process.Analytica Chimica Acta. 2013,779(10):50-55.

[7] James S Duncan, Nicholas Ayache. Medical image analysis:progress over two decades and the challenges ahead [J]. Transactions on Pattern and Machine Intelligence, 2000, 22(1): 85-108.

[8] Qin Li, Dong Lili ,Xu Wenhai,Wu Houde. Method for conversion calibration between CCD image gray value and illumination[J]. Chinese Journal of Scientific Instrument,2015,03:639-644.

[9] Jingbang Chen,Dezhen Song,Rihong Zhu et al.Large aperture-high accuracy phase-shifting digital flat interferometer. Optical Engineering.1996.

[10] Yan Xueying,Study on Despecking and Segmentation Methods of SAR ImageSAR [D]. Xidian University,2013.

[11] Liu Yuanjiong. Research on Imaging Optimization and Depth Information Extraction of Steel Plate Surface Defects Based on Image Processing [D]. Wuhan University of Science and Technology,2011.

[12] LI Zhi-jie,PANG Ye-chi,YU Zhao-yang,MU Ming,OUYANG Yu-jie.Effectsof Illumination Source on Image Quality Captured by Linear Array Camera [J].China Printing and Packaging Study,2014,03:25-30.

[13] Tsai R Y. A versatile camera calibration technique for high-accuracy 3D machine vision metrology using off the shelf TV cameras and lenses[J].IEEE Journal of Robotics and Automation RA, 1987, 3(4):323-344.