International Journal of Research Studies in Science, Engineering and Technology
Volume 10, Issue 1, 2023, PP 13-19
ISSN : 2349-476X
DOI: https://doi.org/10.22259/2349-476X.1001003

Research and Application of Online Intelligent Detection Technology for Continuous Casting Billet Rhombohedral Deformation

Han De-fei[1*], Shi Lei[1], Jin Sha[2], Xie Yu[3], Mo Ying-ze[1], Kang Xin-lei[3], Zhang Li-qiang[3]

[1]Jiangsu Yonggang Group Co.,Ltd.,Zhang'jiagangJiangSu, 215628 China.

[2]Wuhan Yoseen Infrared Technology Co.,Ltd.,Wuhan HuBei,430000； China.

[3]School of Metallurgical Engineering, Anhui University of Technology, Ma'anshan, Anhui, 243002 China.

***Corresponding Author:** Han De-fei, Jiangsu Yonggang Group Co., Ltd., Zhang'jiagangJiangSu, 215628, China.*

Abstract

At present, all the major steel mills at home and abroad use visual or manual measurement methods to control the rhombohedral deformation of small billets, which is difficult to measure manually due to the fast pulling speed of the small billet continuous casting machine, and there are large safety risks. Therefore, it is particularly necessary to develop an online identification system for the billet rhombohedral deformation to achieve accurate measurement and control of each billet and to eliminate the rolling process of the billet rhombohedral deformation. This paper briefly describes the principle of the automatic billet rhombohedral deformation identification system developed by Jiangsu Yonggang Group in cooperation with Wuhan Yoseen Infrared Technology Co.

Keywords: *rhombohedral deformation; image analysis; industrial camera; automatic identification*

Introduction

Rhombohedral deformation, commonly known as de-squared, usually occurs in small and rectangular billets and refers to a super poor defect characteristic of a billet or rectangular billet due to the four corners not being 90° and the rectangular cross-section of the billet evolving into a parallelogram, trapezoid or diamond shape, with the two diagonals of the cross-section not being of equal length, rhombohedral deformation is a common way of determining whether a small billet is internally defective or not. When the internal cracks induced by rhombus exceed the capacity of the billet, the rolling mill will cause the steel to be rolled, resulting in an accident in the rolling line, so the rhombus test is a particularly important basis for determining whether the billet meets the standard in the steel mill.

In order to ensure that the billet shape of the continuous casting machine rhombohedral deformation are found in time, the diagonal length of the billet cross-section is controlled by the major steel mills at home and abroad, based on the danger of the billet rhombohedral deformation, which are currently measured visually or manually, and the billets are disposed of according to the visual or manual measurement results. As the billet continuous casting machine has a fast pulling speed, the billet temperature is still high after passing through the fire cutter, and frequent manual inspection in the high temperature area is a high work intensity, manual measurement is more difficult and there is a greater safety risk, so manual measurement cannot achieve accurate monitoring of each billet rhombohedral deformation, and there is a risk that the billet with excessive rhombohedral deformation will be sent to the rolling process. Therefore, it is necessary to develop an online billet rhombohedral deformation detection technology, using visual imaging analysis technology instead of manual billet inspection, remote, real-time, accurate detection and analysis results, to achieve accurate measurement and control of each billet, to prevent rhombohedral deformation billets from being sent to the rolling process.

Overview of Technology Selection and Research Approach

"Machine vision" is a method of measurement and judgment using machines instead of visual inspection: a machine vision product (image acquisition device) converts the object under test into an image signal and transmits it to a dedicated image processing system, which converts the image information into a digital signal based on pixel distribution, brightness, colour and other information, and performs various operations on these signals to extract target characteristics and perform corresponding actions based on the results of the judgment[6-8]. This technology is used as a pre-research project to install an infrared thermal camera, a high-definition visible camera and an industrial camera on the pass line, respectively, and install them underneath the corridor using a lifting method, looking slightly down on the steel roller conveyor with the lens facing the direction of the steel outlet of the continuous casting machine, to make a real-time recording of the production situation on site and observe the billet cross-section one by one. A machine vision algorithm engineer performs in-depth analysis and design of the image and conducts algorithm testing to realise that the system automatically identifies the billet and calculates the diamond change rate. When abnormal rhombohedral deformation of the billet is detected, real-time alarm notification is provided to reject unqualified billets in time to guarantee the quality of steel output and improve production efficiency.

Traditional products use manual visual inspection methods to detect defects on the surface of the product, the manual visual inspection method is relatively crude, especially in the metallurgical industry, manual contact with accurate detection is more difficult, detection activities are point inspection method, more random and discontinuous, there is a lot of uncertainty, and detection data is difficult to save. With the continuous development of science and technology, especially the development of computer technology, machine vision technology began to be used in industry on a large scale. Combined with computer image processing and pattern recognition, machine vision technology integrates relevant knowledge from different fields such as computer technology and software engineering to quickly and accurately detect product quality and complete inspection tasks that cannot be done manually. The application flow chart of intelligent manufacturing equipment is shown in figure 1.

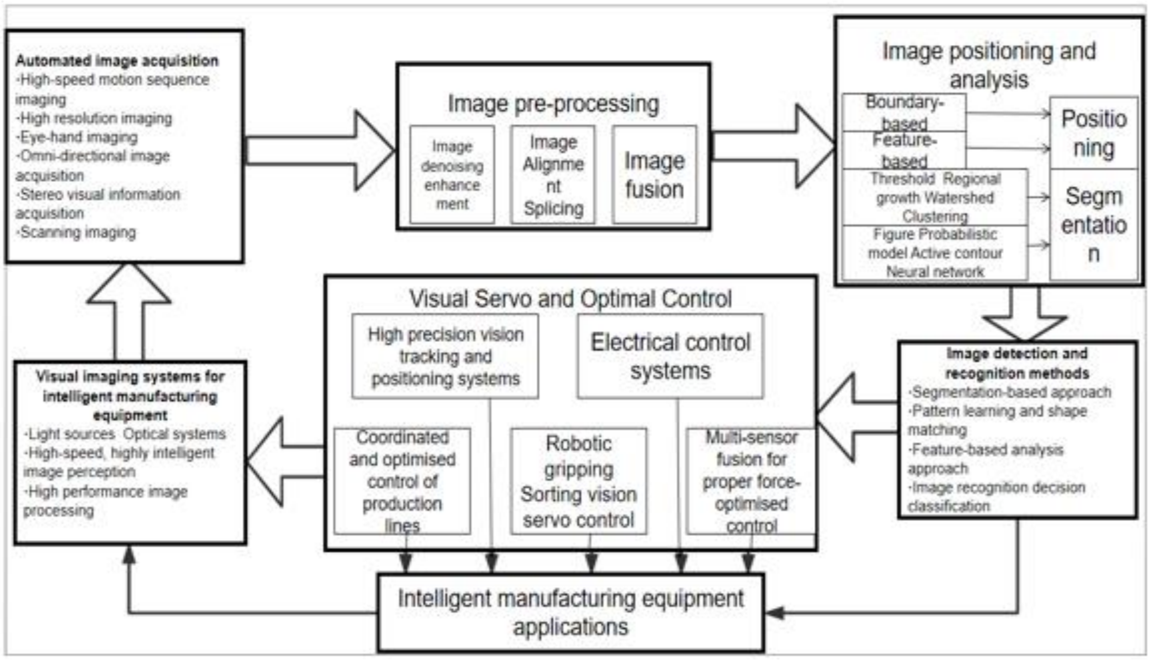

Figure1. *Application flow chart of intelligent manufacturing equipment*

This project takes continuous casting billet rhombohedral deformation detection as an entry point, surveys stable inspection points and identifies continuous casting billet rhombohedral deformation data through machine vision. An industrial camera was installed at the 7# continuous casting shop in Yonggang's third steelmaking shop at the steel turning point, with the lens facing the direction of the billet cross section and with one of the billet cross sections facing the centre of the screen [1]. After observation, the billet cutting surface is visually analysed for rhombohedral deformation, if there are problems such as shear drag, craters and slagging on the cutting surface, these will affect the results of rhombohedral deformation detection on the billet cutting surface; the billet is transported out of the flame cutting machine to the cold frame inspection point and the billet temperature is measured to be between 500-700°C. Due to the high temperature of the billet, the high bright light produced is well separated from the background and the camera then takes a real-time picture of the production situation on site, looking at the billet sections one by one. A machine vision algorithm engineer analyses the image in depth and conducts an algorithm test to automatically recognise the billet and calculate the rhomboidity ratio, and when an abnormal rhombohedral deformation is detected, a pop-up warning screen is immediately issued to remind the site personnel to review the abnormal billet and reject the unqualified billet in time to ensure the quality of the output billet, thus avoiding the inflow of unqualified billet into the next process and eliminating the impact of unqualified billet on the subsequent rolling process.

System Hardware Design

The project study uses gige industrial cameras for real-time acquisition of each other's billet production screen, first of all, industrial cameras have native image data acquisition capabilities, with excellent 2592*2048 screen resolution and stable more than 22fps high frame rate, while the body size 45*15cm long and wide is relatively small, easy to install in the field to provide the original accurate data for machine vision algorithms. The second choice of gige vision interface is based on site deployment considerations, due to the harsh conditions of the site, the production process for a long time in a high temperature environment, gige industrial cameras using IPX6 waterproof and dustproof level process, the use of water-cooled line mode to protect the camera stable work, while having a long-distance reliable gigabit level high-speed image transmission mode. 2006, the American Automation Imaging Association (AIA) launched the GigE Vision standard, the biggest feature of the standard is based on Gigabit Ethernet communication protocol development, compared to USB and camera link two machine vision common communication methods, to achieve up to 125M / s long-distance high-speed image transmission rate, can quickly through the Gigabit Ethernet transmission of large images, fully in 8 machine 8 stream continuous casting machine to ensure Information transmission is stable and can be adapted to the application of this scenario.

In terms of engineering structure, in order to ensure that when the industrial camera is installed, the lens is facing the direction of the billet cross-section of each runner and that the billet cross-section is facing the centre of the screen, so that the industrial camera can take real-time pictures of the production situation on site and obtain ideal infrared images. The cameras are positioned in front of the billets coming out of one runner to ensure that the output billets are in the same position in each runner; the machine vision method is used to determine the shape of the high temperature billets in the infrared image, and when the billets reach the right position, the four corners of the billet section are positioned and the distance between the two points of the diagonal is automatically measured to calculate the rhomboidity ratio. The system supports the setting of a threshold value for the rhomboidity ratio of change and automatically alerts screenshots when the detection data exceeds the threshold value. The system also supports real-time temperature measurement of the billet surface, reflecting the advantages of the red outside array inspection.

System Software and Algorithm Function Design

The system software is fully programmed and developed by Wuhan Yoseen Infrared Technology Co., Ltd. After the system software gets the real-time billet screen transmitted by the front-end camera, it determines the shape of the highlighted billet in the visible screen in real time through the image feature capture algorithm, identifies and confirms the billet when it reaches the appropriate position, and automatically measures the distance between the two diagonal points, and then calculates the rhomboidity ratio and other section parameters. The system supports the setting of a threshold value for the rhomboidity ratio, and automatically alerts the staff to screenshots when the detection data exceeds the threshold value, and sends out an alarm signal to remind them to deal with the problem in time. The billet visual image detection algorithm is designed to fit the actual image by correcting the actual measurement value, automatically capturing the target features, correcting the screen effect, identifying the target features and outputting the results of the detection calculation. Based on this data, data such as rhomboidity ratio, diagonal length, edge length and area of the area are calculated and visually rendered on the screen for easy retrieval.

Using the advantages of high resolution industrial cameras, machine vision data is analysed to determine the shape of the highlighted billet in the visible image in real time. When the billet reaches the right position, the corners of the billet section are positioned and the distance between the two points of the diagonal is automatically measured to calculate the rhomboidity ratio of change. The system supports the setting of a threshold value for the rhomboidity ratio, and automatically alerts the site personnel to review the abnormal billets when the detection data exceeds the threshold value, so as to reject unqualified billets in time to ensure the quality of the steel output and thus avoid the danger of unqualified billets to the subsequent rolling process. In terms of software system implementation, we established differential equations to be solved using computer programming and developed a new software system that has the advantages of a friendly interface, fast execution, good real-time and easy maintenance, while having strong drawing, calculation and visualization functions.

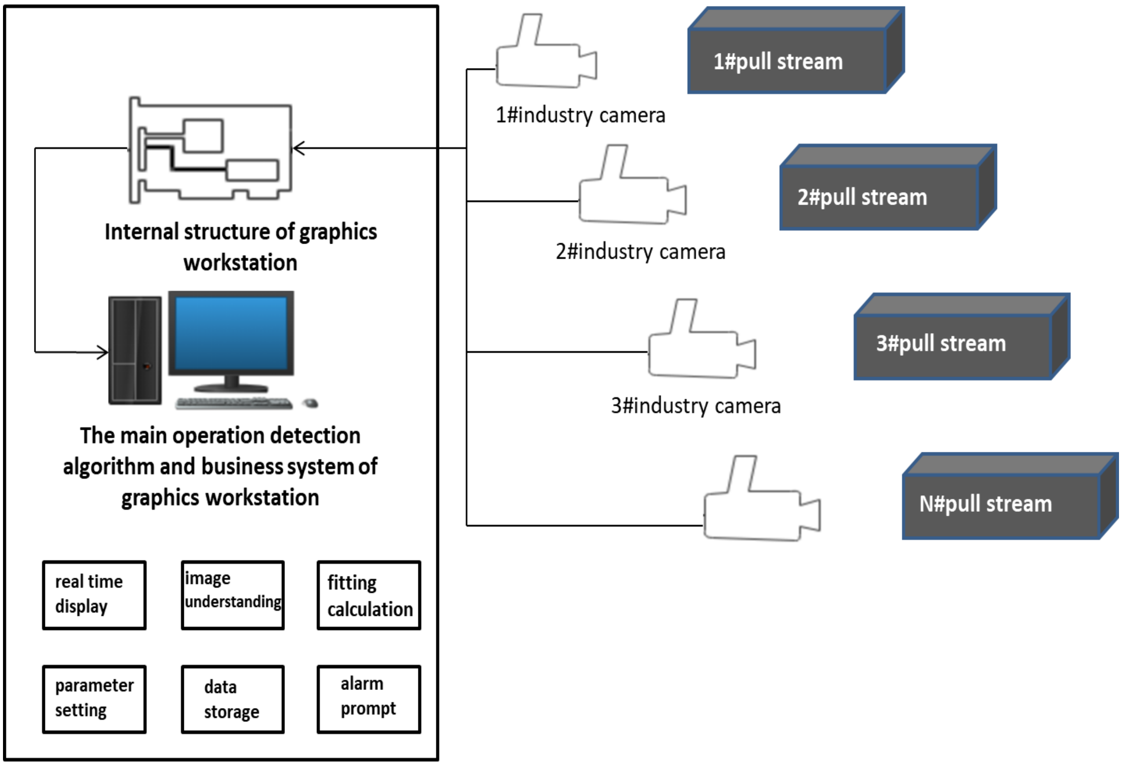

Figure2. *Software system structure diagram.*

The most central technology in the image algorithm part is good image understanding, which is to make data descriptions of image features and thus recognition [2]. The specific tasks of image understanding include target detection, feature extraction and target recognition. In order to shave off the interference factor of ambient light and give the algorithm an input grayscale image with a relatively fine demarcation between the billet and the background, a black and white imaging industrial camera is used, while the image processed by the camera base is still a grayscale image, which needs to be further binarised. Binarisation is the process of assigning a grey value of 1 to pixels greater than or equal to the threshold value and 0 to pixels less than the threshold value, resulting in a black and white image with only 0 and 1 grey values, according to a given threshold value. The binarised image effectively distinguishes the background from the target and quickly and accurately extracts the pixel points at the boundary of the target area.

Based on the binarisation process, the image is more clearly segmented into regions that do not overlap each other, which facilitates the algorithm to fit the edge cut to the square blanks that appear on the screen, and finally the detection result is derived by mathematical conversion and the rhombohedral deformation formula.

The diagonal difference D is expressed using the metric, as shown in equation (1):

$$D = |d1 - d2| \quad (1)$$

d1and d2 denote the diagonal lengths respectively.

Using a more scientific approach to calculating the rhomboidity ratio of change R, the diagonal lengths of the small square billets are compared and the formula for the rhomboidity ratio of change is derived, see equation (2):

$$R = \frac{|d1 - d2|}{0.5(d1 + d2)} * 100\% \quad (2)$$

In this project, the customer produced a billet with a square cross-section of 160 mm and the standard is that the absolute value of the difference between the two pairs of legs does not exceed 7 mm and the billet is considered to be qualified if the rhomboidity ratio R ≤ 3%.

The rhombohedral deformation detection system can be put into operation 24 hours a day and is convenient and efficient. It can automatically measure the billets one by one and store, report and communicate remotely the measured data. The diagonal difference value will be displayed in a curve chart for storage; the data report can be exported and calculated by the process personnel, and the data report can be used as an important basis for big data analysis, so that it is easy for the site personnel, line supervisors and research engineers to review and analyse the data subsequently; the remote communication can communicate with the local area network in real time, and the secondary screen will be available to the staff of the back channel and the section. The company's intranet three-tier system can be called remotely for collection and analysis, and monthly analysis reports can be formed according to the set data report format, which can be analysed and exported according to the set time period for quality management personnel to download and query; the rhombohedral deformation inspection system provides effective transitions between the two processes in the steelmaking and rolling mills based on automatic monitoring and judgment of the key quality of small billets.

Validation of Software Applications and Analysis of Results

In order to verify the practical application of the rhombohedral deformation detection solution, the industrial camera equipment for rhombohedral deformation detection was installed in the 7# continuous casting machine of the steelmaking plant, one industrial camera was installed in each stream, and the algorithm software application program was prepared by the research team according to the requirements; during the use of the cold frame billets, the billets were turned steadily and reached the set position, and the rhombohedral deformation difference and rhomboidity ratio were calculated for each billet, and no billets were found to have been missed during the on-site tracking; Through the comparison between manual measurement and industrial camera measurement, due to high temperature on site the data of 18 billets are tracked and checked as shown in the following table1.

The maximum difference between manual measurement and automatic measurements is within ±1mm, and the measurement data meet the requirements of online continuous production inspection. Fig.3 is the detection image taken by industrial camera.

Table1. *Automatic / Manual Measurement Comparison*.

serial number	Automatic industrial camera measurement				Manual manual measurement				Measurement Deviation (mm)
	Left diagonal length (mm)	Right diagonal length (mm)	Differentials (mm)	rhomboidity ratio (%)	Left diagonal length (mm)	Right diagonal length (mm)	Differentials (mm)	rhomboidity ratio (%)	
01	227.8	229.5	1.7	0.74%	227.2	228.7	1.5	0.66%	0.2
02	227.6	230.0	2.4	1.05%	227.5	229.6	2.1	0.92%	0.3
03	227.8	232.2	4.4	1.91%	227.2	231.8	4.6	2.00%	-0.2
04	229.6	230.2	0.4	0.17%	229.1	230.0	0.1	0.04%	0.3
05	226.1	232.2	6.1	2.66%	225.8	231.7	5.9	2.58%	0.2
06	231.4	228.6	2.8	1.22%	230.9	227.9	3	1.31%	-0.2
07	229.6	230.8	1.2	0.52%	229.1	230.0	0.9	0.39%	0.3
08	230.0	226.3	3.7	1.62%	229.7	225.5	4.2	1.85%	0.5
09	231.8	226.8	5	2.18%	231.7	225.9	5.8	2.53%	0.8
10	228.8	228.4	0.4	0.17%	228.1	227.9	0.2	0.09%	0.2
11	227.7	230.9	3.2	1.40%	227.6	229.9	2.3	1.01%	0.9
12	229.2	229.7	0.5	0.22%	229.1	229.3	0.2	0.09%	0.3
13	230.3	229.6	0.7	0.30%	230.2	229.5	0.7	0.30%	0
14	228.1	231.4	3.3	1.44%	227.4	230.4	3	1.31%	0.3
15	227.7	229.4	1.7	0.74%	227.1	229.0	1.9	0.83%	-0.2
16	231.9	231.8	0.1	0.04%	231.2	231.0	0.2	0.09%	-0.1
17	227.9	229.1	1.2	0.53%	227.4	228.4	1	0.44%	0.2
18	229.2	228.5	0.7	0.31%	228.3	227.6	0.7	0.31%	0

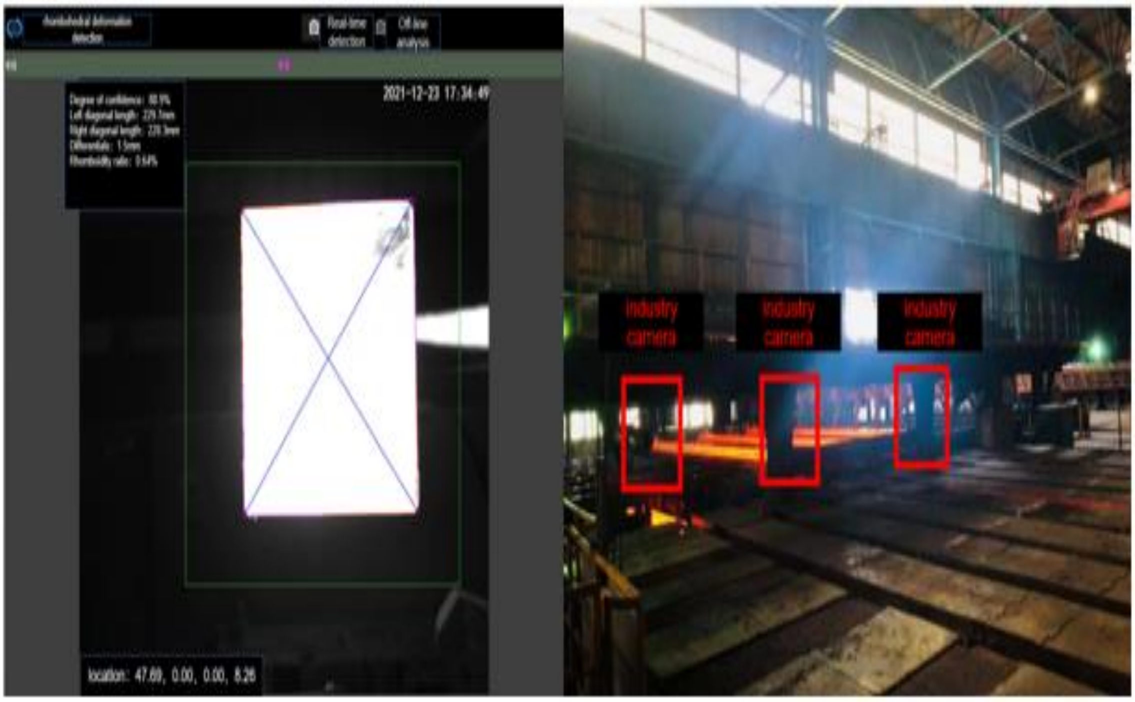

Figure3. *Detection diagram of industrial camera*

CONCLUSION

In modern automated production processes, machine vision systems are used extensively in the fields of condition monitoring, finished product inspection and quality control. Machine vision systems are characterized by increased flexibility and automation in production.

Based on the system architecture presented in this paper, the results of the online intelligent inspection tests of the continuous casting billet rhombohedral deformation have verified that the method used is feasible, the system has been followed up for up to three months in the field, the process personnel and the technical staff exchange continuously revised detection algorithms, the technology has reached a mature stage, by the relevant technical personnel on-site comparison, the billet cross-section detection value and manual measurement value deviation control within ± 1mm.With the successful development of this technology and its online operation, it will eventually be applied to the entire production line for production quality inspection, which will greatly reduce the workload of operators and improve inspection efficiency.

REFERENCE

[1] Zhao Guosheng., Yu Zuopeng, Li Wenhu. Quality control of continuous casting rectangular billets [J]. Hebei Metallurgy, 2009 (04):42.

[2] Li Yuxiang, Fang Zhi, Yue Zhenhua. Measures to improve the shape quality of small billets [C]//. Proceedings of the 17th (2013) National Steelmaking Academic Conference (Vol. B). [Publisher unknown], 2013:436.

[3] Kong Qingfu, Zhou Xiaohong, Liu Jianhua, Cao Xiaoming. Analysis of the causes and countermeasures of diamond change in 45 steel [J]. Hebei Metallurgy, 2003(03):31.

[4] Chen Zhikun, TianLiping, Tang Ruiyin. Online inspection method of continuous casting slab profile [J]. Journal of Hebei Institute of Technology, 2003(01):17.

[5] Cao Guangchou. The use and equipment improvement of the small billet continuous casting machine introduced from Demark in China [J]. Hebei Metallurgy, 1986(01):43.

[6] Zhang Pengyuan. Practical application of machine vision technology in machinery manufacturing automation [J]. Fluid Measurement and Control, 2022, 3(02):1.

[7] Xu Yang, Liu Lei." Machine vision intelligent robot nondestructive inspection system exploration." Computer Knowledge and Technology 18.08(2022):76.

[8] Liu Kaidi. Research on the application of machine vision technology in intelligent steelmaking. 2021. Anhui University.

[9] Zhang Xinglan, Ouyang Qi, Zhao Liming. Image clarity control algorithm for continuous casting hot billet surface defects[J]. Journal of Chongqing University, 2010, 33(05):89.

[10] Chen Haiping. Development and research of part inspection system based on Open CV and USB industrial camera [D]. Guangxi University, 2012.

[11] Zhang Xinglan, Ouyang Qi, Zhao Liming. Image clarity control algorithm for continuous casting hot billet surface defects [J]. Journal of Chongqing University, 2010, 33(05):89.

[12] Yin Chengtian, Liu Guoping, Hu Ronghua. An improved image enhancement algorithm and its application in image enhancement of cast billets[J]. Journal of Iron and Steel Research, 2010, 22(09):58.

[13] Qi Xin, Chen Jianfeng, LuoWeilin. FPGA implementation of image preprocessing algorithm[J]. Foreign electronic measurement technology, 2021, 40(02):102.

Citation: *Han De-fei, Shi Lei, Jin Sha, Xie Yu, Mo Ying-ze, Kang Xin-lei, Zhang Li-qiang, "Research and Application of Online Intelligent Detection Technology for Continuous Casting Billet Rhombohedral Deformation", International Journal of Research Studies in Science, Engineering and Technology, vol. 10, no.1, pp. 13-19, 2023.*