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The Development of Cold Optical Surface Inspection System for Billet Surface Defect Detection

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The goal of this study is to develop the analytical system and the Billet Automatic Surface Inspection System (Billet ASIS) to avoid machine damage caused by defects on the cold billet surface, especially sponge, during the billet rolling in the follow-up workflow. With the capturing of billet surface images, development of pre and post-processing algorithms, utilization of a deep learning technique, and the introduction of an alarm system, the proposed system can localize the potential defects, guarantee tolerance to defect variance, and ensure all the detected defects can be found at the examination station. During the online test, the overall detection rate and over-detection were 91.3% and 8.6%, respectively, which can further guarantee the quality of the billet product.

Keywords: Deep Learning, Defect Detection, Defect Localization

1. INTRODUCTION

As an integrated steel plant, the manufacturing procedures in Chinese Steel Corporation (CSC) consist of several procedures, and the billet is one of the most important semi-products within these procedures. The completeness of the billet manufacturing is highly related to the performance of the following procedure, thus eliminating the incomplete products is necessary to ensure the overall manufacturing performance.

Magnetic particle testing (MPT), an inspecting technique by observing the distribution of the magnetic particle powder that is magnetically attracted on the magnified metal surface in a dark room, is one of the most reliable methods for billet surface inspection[1-2], which has been well utilized in CSC. To examine a 12-meter-long standard billet takes more than three technicians at least 1 minute. Figure 1 shows two qualified billets with extremely different particle expressions, which implies MPT is a highly experienced-dependence skill.

To not only boost the performance of billet inspection but also quantify the billet surface quality, this study proposed a Billet Automatic Surface Inspection System (Billet ASIS)" to collect all necessary information and do data analysis before billet arrival at the MPT inspecting station. The Billet ASIS consists of a Monitoring Module, Brightness Triggering Module, AI Module, and

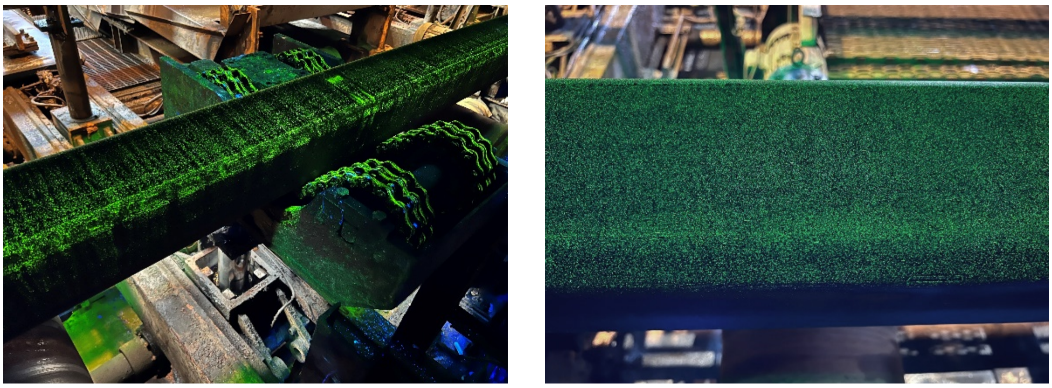

Fig.1. Two different particle distributions on the billet with smooth surfaces.

Defect Localizing Module, which aims to fulfill the purpose of doing data collection at the right timing, analyzing the collected data, and alarming rapidly/properly at MPT inspecting station. Further descriptions of Billet ASIS manufacturing, performance evaluation, and discussion will be mentioned in the following sections.

2. EXPERIMENTAL METHOD

The Billet ASIS is designed to capture and analyze the incoming billet surface image. To clarify, the online workflow of Billet ASIS can be visualized in Figure 2 and listed in six steps:

1. Wait for a billet go through the checkpoint
2. Trigger the record system
3. Record the consecutive billet surface images
4. Archive the recorded image data
5. Analyze with AI
6. Alarm and localize the detected defects

2.1 Monitoring Module

The motorized system has been well utilized for product and semi-product of billet transporting in CSC, and to ensure the Billet ASIS can be integrated with the existing structure, we designed an arch-like gate, the "Monitoring Module" which is located in between the motors, to inspect the whole billet. Four Basler ace acA1920-40gm industrial cameras, covered by customized protectors, are used to capture billet surface images. The air flow goes through the cameras while Billet ASIS working to cool down the camera and remove the manufacturing dust. The LED lights ensure a consistent brightness of the billet surface. The illustration of the Billet ASIS inspecting structure and its location on the CSC transporting system is shown in Figure 3. Finally, the billet usually takes 4 minutes to transport from the "Monitoring Module" to the billet inspecting station, which is sufficient for AI Module processing and will be mentioned later.

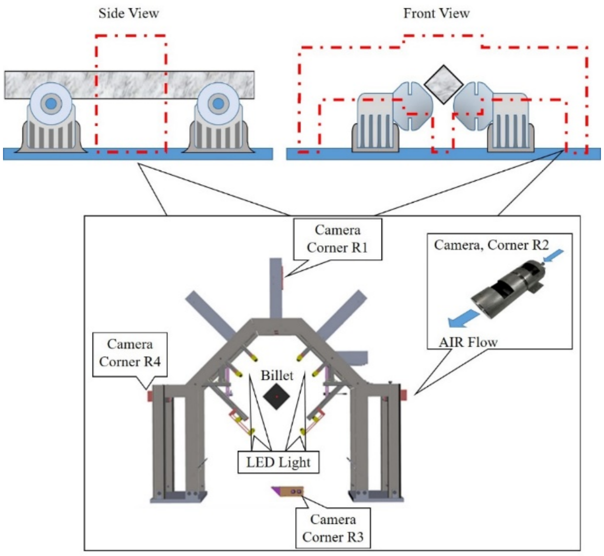

Fig.3. Monitoring module of Billet ASIS

2.2 Brightness Triggering Module

To avoid the negative effects of the manufacturing environment, such as duct accumulation in front of the camera lens, the manufacturing/transporting vibration, and electrical instability.

The Brightness Triggering Module helps Billet ASIS to determine when to trigger the monitoring module by the brightness of the images, instead of using

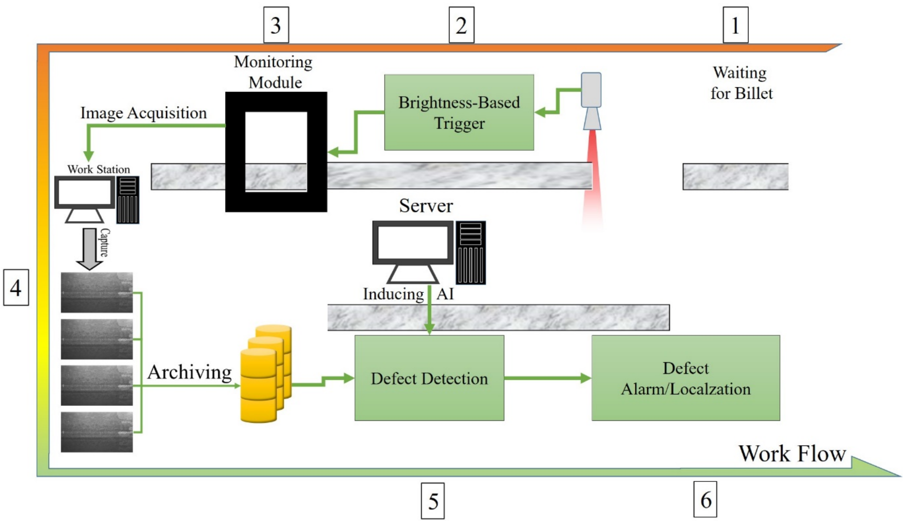

Fig.2. Visualizing the overall workflow of Billet ASIS.

a laser sensor. In this study, the trigger level of brightness is an intensity of =50, and the comparison between Background and Billet images is shown in Figure 4.

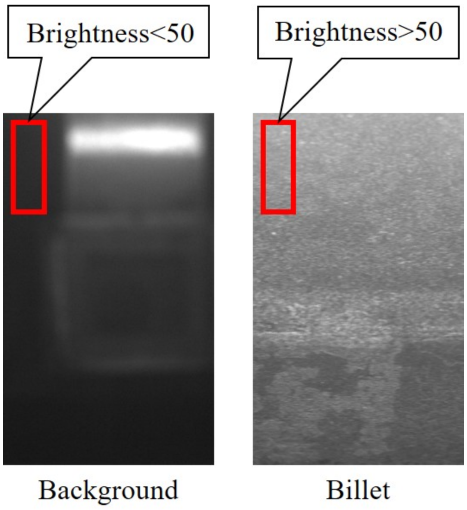

Fig.4. Brightness comparison between background and billet.

2.3 AI Module

While developing the Billet ASIS system, the AI module, based on i7-10700, 32G ram, and RTX 3060, is designed for defect detection. The fourth version of the model You Only Look Once (YOLOv4), which well balances the model performance and resource consumption in early 2020[3-4] was utilized for defect detection. More than 600 image samples, labeled by Labeling[5], are collected for AI model training. Vertical/Horizontal flipping and rotating can effectively increase the training database (Figure 5)[6]. The built-in learning rate tuning method, Cosine Annealing LR[3], helps YOLOv4 to improve the training performance, and Figure 6 compares the training loss in between with and without Cosine Annealing LR learning rate adjustment. To evaluate the performance of the AI module, not only the conventional accuracy and loss, provided by YOLOv4, will be considered, but the statics of Billet ASIS alarming status, mentioned in a later section, will be considered.

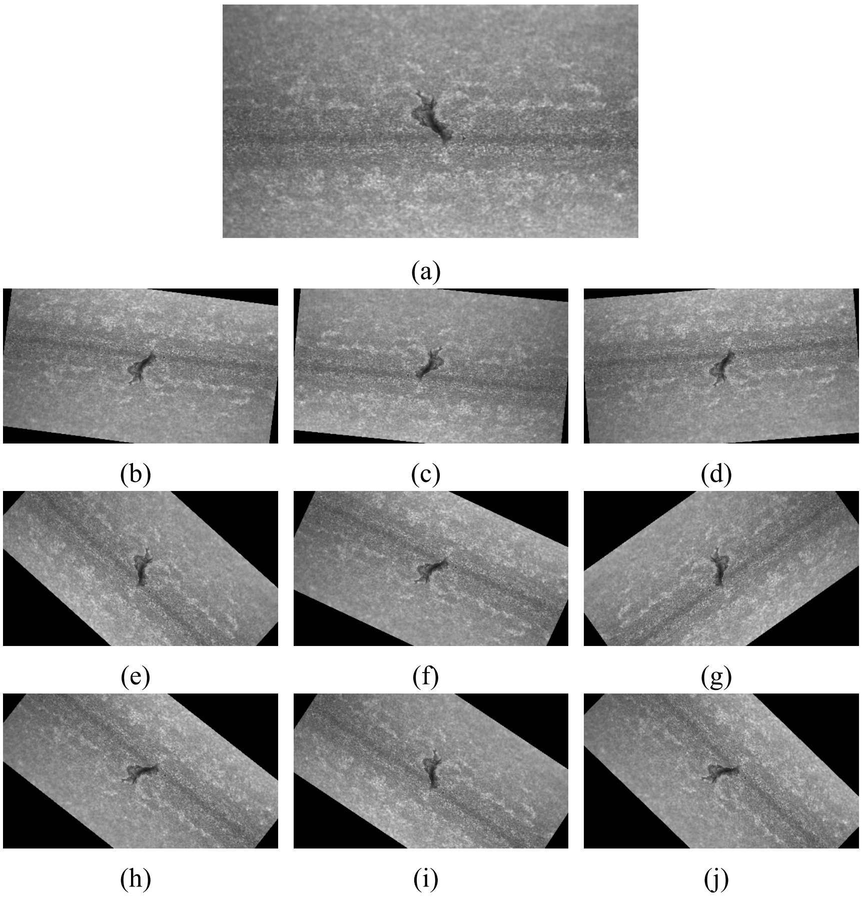

Fig.5. Data argumentation.

(a) (b)

Fig.6. The training history of YOLOv4 (a) without Cosine Annealing LR, (b) with Cosine Annealing LR.

2.4 Defect Localizing Module

The low-light environment (darkroom) of the billet surface inspecting stations in CSC is designed for MPT. To achieve alarm and avoid over-lighting, we designed a "Defect Localizing Module" which deployed the low-light indicators equally along the billet length directly in the inspecting stations (2m in between each indicator) to rapidly localize the detected defects. The idea of "Defect Localizing Module" is shown in Figure 7. To evaluate the overall performance of Billet ASIS, the detection ratio (true-positive, as high as possible) and false-detection ratio (true-negative, as low as possible), which are the most common evaluations in CSC, were utilized.

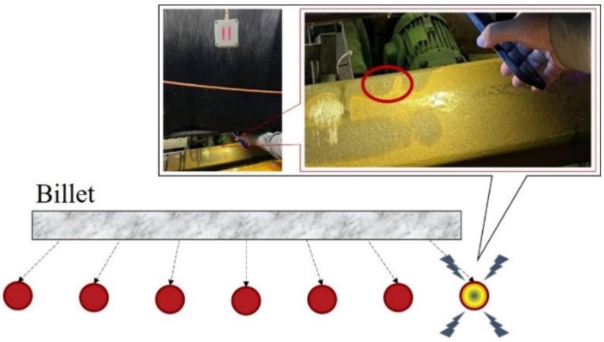

Fig.7. Defect Localizing Module of Billet ASIS.

3. RESULTS AND DISCUSSION

The YOLOv4 was trained and validated by the collected 600 samples in the ratio of 9:1 with data argumentation and epoch 100. Training with Cosine Annealing LR helps YOLOv4 improve the training/validated loss from 7.121 / 7.445 to 2.067 / 3.095 respectively (Figure 6). The 20 billets online inspecting test, which evaluates the overall performance of Billet ASIS, achieves a 91.3% detected and an 8.6% false-detected rate. The "Monitoring Module" usually records 600 images for each billet, and the "AI Module" takes 60 seconds on average to analyze and each billet has 4 minutes to arrive at the MPT inspecting station, which means there is sufficient time for data analyzing.

4. CONCLUSIONS

This study investigates a Billet Automatic Surface Inspection System(Billet ASIS), which is consisted of a monitoring Module", "Brightness Triggering Module", a YOLOv4 based "AI Module" and a "Defect Localizing Module" that is designed for billet surface inspection. By training with 600 defect samples with argumentation and the training/validated loss of YOLOv4 is 2.067 / 3.095, and the Billet ASIS achieves a 91.3% detection rate and 8.6% false-detection rate in 20 billets of online inspect testing. The billet usually takes more than 4 minutes to arrive at the MPT inspecting station which is sufficient time for the AI analysis. The performance of Billet ASIS, including detection rate, processing time, and alarm method, more than meets the billet inspecting requirement in CSC.

5. REFERENCES

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