Retraction Notice

The Editor-in-Chief and the publisher have retracted this article, which was submitted as part of a guest-edited special section. An investigation uncovered evidence of systematic manipulation of the publication process, including compromised peer review. The Editor and publisher no longer have confidence in the results and conclusions of the article.

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Research on intelligent transportation and logistics tracking of long billet based on machine vision

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Abstract We solve the problems in the iron and steel industry of identifying the quantity, length, and position of billets in complex industrial environments by studying and applying machine vision algorithms, such as billet image segmentation based on optimal threshold method and billet image post-processing based on morphology. Compared with the existing technologies that rely on various sensors to realize the automatic transportation of billets or the physical marking of billets one by one to realize the billet logistics tracking, the scheme proposed here has a low one-time investment cost, especially for the billet logistics tracking of follow-up production control and quality traceability. Because the hot delivery billets only carry out virtual marking, there is no consumption cost of consumables, i.e., the higher the hot delivery rate, the lower the average marking cost of billets. Moreover, due to the non-contact of machine vision, the system failure probability is also lower. The machine vision algorithm and solution proposed here achieve the goal of intelligent transportation and logistics tracking of long billets with lower investment cost, lower consumption of consumables, fewer faults, and higher efficiency. © *2022 SPIE and IS&T* [DOI: 10.1117/1.JEI.31.6.062004]

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1 Introduction

In the iron and steel industry, to improve the production efficiency, reduce the production cost, control and trace the product production quality, tracking the billets from continuous caster to heating furnace is an important link. How to improve the automation level of billet transportation and reduce the workload of manual input, especially to realize the logistics tracking of high-temperature red billet with low cost and high efficiency, is a research hotspot.[1,2] In terms of automatic billet transportation, at present, it can be realized by adding sensors such as weight, length, and position; in terms of billet logistics tracking, at present, the billet identity can be identified through high-temperature coating code spraying and subsequent machine vision before entering the heating furnace, so as to realize logistics tracking and subsequent production control and quality traceability.[3] The one-time investment cost of the above solutions is high, and so too is the use-cost of single consumables. In addition, the failure rate is also high due to the large number of sensing devices in contact with the harsh environment at the site. Moreover, in the construction of a long billet with a fast production rhythm, the production rhythm may be affected by waiting for code spraying of billets one by one.

In view of the shortcomings of the existing methods, this paper studies and proposes to use machine vision to realize the intelligent transportation and logistics tracking of billets and achieve the goals of lower investment cost, lower consumption of consumables, fewer failures, higher efficiency, and so on. The core of this scheme is to apply an appropriate machine vision

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algorithm to identify the number, length, and position of billets in complex industrial environments.[4,5]

2 Methods

2.1 *Judgment of Steel Moving Machine Based on Image Segmentation and Recognition*

The billet pushing action of the steel-moving machine is driven by the number of billets on the current cooling bed. Generally, when the number of billets on the cooling bed reaches more than a certain number (such as 4), it is necessary to send a signal command to drive the action of the steel-moving machine. We have installed a camera for identification and a constant light source system on site to ensure the image quality of obtaining the billet state of the cooling bed. On the one hand, it ensures that the image is within a reasonable image capture range, and on the other hand, it ensures less image interference. In this paper, the method of image segmentation is proposed. First, the billet on the cooling bed is segmented, and then the number of connected areas is obtained by morphological annotation method, so as to obtain the current numbers of billet on the cooling bed.

2.1.1 *Billet image segmentation method based on optimal threshold method*

Because billet and background belong to typical binary image segmentation, the common method is to divide the image gray into different levels, and then set the gray threshold to determine the meaningful area or the boundary of the segmented object.[6] In the process of image segmentation, if the threshold is too large, the redundant part of the image will be extracted. If the threshold is too small, the required part will be lost. Therefore, the selection of threshold plays a very important role in image segmentation.

When the brightness difference between the target billet and the background object in the image is relatively small, the bimodal characteristics of the gray histogram of the image observed from the histogram are not obvious, so it is not easy to determine an appropriate threshold directly using the histogram. Therefore, the following discriminant analysis method can be used for processing.

The principle of determining the best threshold by discriminant analysis is that after threshold processing, the inter class variance between the separated pixel classes is the largest. Discriminant analysis needs to calculate the zero-order matrix and first-order matrix of histogram. It is a common method to automatically determine the threshold in image thresholding.

Assuming that the total number of pixels of the image is N and the number of pixels with gray value of i, the zero-order matrix and first-order matrix of gray distribution with gray level of K are defined as follows respectively.

The zero-order matrix is:

$$\omega(k) = \sum_{i=0}^{k} \frac{N_i}{N}. \tag{1}$$

The first-order matrix is:

$$\omega(k) = \sum_{i=0}^{k} \frac{iN_i}{N}. \tag{2}$$

When $K = L - 1$, $\omega(L-1) = 1$; $\mu(L-1) = \mu_A$, where μ_A is the average gray value of the image.

Set the $M - 1$ thresholds of the image as $0 \le k_1 \le k_2 \le \ldots \le k_{M-1} \le L - 1$, divide the image into M gray value classes C_j, and

$$C_j \in [k_{j-1}+1, \ldots, k_j] k_0 = 0, k_M = L, j = 1,2,3, \ldots, M. \tag{3}$$

Then the probability of occurrence of each type C_j is:

$$\omega_j = \omega(k_j) - w(k_{j-1}). \tag{4}$$

The corresponding average probability is:

$$\mu_j = \frac{\mu(k_j) - \mu(k_{j-1})}{\omega(k_j) - \omega(k_{j-1})}, \tag{5}$$

where $\omega(0) = 0, \mu(0) = 0$.

Therefore, it can be obtained that the inter class variance of each class is:

$$\sigma^2(k_1, k_2, \ldots, k_{M-1}) \sum \omega_j(\mu_j - \mu_T)^2. \tag{6}$$

Take the value σ^2 in Eq. (6) as the maximum threshold group $(k_1, k_2, \ldots, k_{M-1})$, and take it as the best threshold group for M-valued. If it is divided into two categories, i.e. M is 2, the threshold of binarization can be obtained.

For some cases of images, such as the contrast between the object and the background caused by uneven illumination, in this case, the ideal segmentation effect cannot be obtained using a single threshold segmentation. In this case, the image can be divided into sub regions, and the local threshold can be set for each sub region, so as to get a better segmentation effect. The best segmentation threshold between billet and background can be obtained through experimental measurement, so as to realize the rough segmentation task of the billet image, and then carry out secondary processing through morphology.

2.1.2 *Billet image post-processing and quantity calculation based on morphology*

After the previous image segmentation, there is still the problem of imperfect segmentation. For example, when there is light for the billet, the segmented image has holes in the billet surface. In addition, as the background part, the cooling bed is also partially retained in the segmented image.[7] Therefore, to achieve more recognition effect, it is necessary to improve the morphology of the segmented image.

Corrosion, expansion, opening, and closing operators are the basis of morphological image processing. Using the combination of these four operations, various image processing can be completed.[8]

Binary corrosion operation can shrink the image. Corrosion means to detect an image with structural elements to find out the area where the structural elements can be put down in the image

The set A is corroded by the set$B$, which is recorded as $A\Theta B$and defined as

$$A\Theta B = \{x | B + x \subset A\}, \tag{7}$$

where A is the input rough segmented billet image and B is the structural element.$A\Theta B$ represents a collection of all points x that will still be included A after translation B, i.e., when the set obtained by B corrosion A is the set of B origin positions when it is completely contained in A. If the origin is inside the structural element, the corroded image is a subset of the input image. If the origin is outside the structural element, the corroded image cannot be inside the input image.

Expansion operation can be regarded as the dual operation of corrosion operation, which is the operation of lengthening or thickening in binary image. This special way and coarsening degree are controlled by structural elements. The set A inflated by B recorded as $A \oplus B$, and defined as

$$A \oplus B = \{z|(\hat{B})_z \cap A \neq \Phi\}, \tag{8}$$

where B is a structural element, which $A \oplus B$ means that the B translation and intersection to A are not empty relative to its own image about the origin, and the set is composed of all z points that meet the above conditions. The specific method of expansion is to correspond the origin of the B to the point on the x and the surrounding points x one by one. If a point on the B falls within the range of x, the point is the point on the image.

The structure element B performs the opening operation on the set A, which is recorded as $A \circ B$ and defined as

$$A \circ B = (A \Theta B) \oplus B. \tag{9}$$

That is to say, the open operation B to A is B corrode A first and then expand the result with B. Another mathematical formula of open operation is

$$A \circ B = \cup \{(B)_z|(B)_z \subseteq A\}, \tag{10}$$

where $A \circ B = \cup \{\cdot\}$ refers to the union of all sets in braces. The above formula can be understood as $A \circ B$ referring to the union of B translations with perfect matching inside A. The operation generally makes the contour of the object smooth, breaks the narrow discontinuity and eliminates the thin protrusion.

Closed operation is the dual operation of open operation. The structural element B performs closed operation on the set A, which is recorded as $A \cdot B$ and defined as

$$A \cdot B = (A \oplus B) \Theta B, \tag{11}$$

i.e., the closed operation B to A is expansion B to A first and then corrode the result with B. The closed operation also makes the contour line smoother, but different from the open operation, it usually eliminates narrow discontinuities and slender gaps, eliminates small holes, and fills the fracture of the contour line.

First, delete the small area according to the following formula. Since the billet area is much larger than the incorrectly divided background sub area, the area of all areas can be counted by the area threshold method, and then set the threshold to delete the small area:

$$B_{i+1} = (B_i \oplus S) \cap A.$$

The above process is carried out until the image is no longer transformed. After the image label is completed, the whole image is traversed through the label value cycle, and the number of pixels under different numbers is counted to realize the calculation of different area. When the area is less than the threshold T, the area is deleted. In addition, the above Eq. (8) can be carried out many times to realize the filling operation of the cavity part on the billet surface, and the filling operation is completed after repeated calculation until the image is no longer transformed. On the basis of deleting the small area, count the number of areas larger than the threshold T as the number of billets. If the action limit of steel moving machine is reached, push operation is realized.

2.2 *Billet Positioning and Identification before Rotation of the Turntable*

Before the billet rotates, first judge whether it reaches the specified position through machine vision, including the front and rear positions. Install the monitoring cameras at the corresponding positions respectively to obtain the position of the billet in real time. Since the position of the picture taken by the camera is relatively fixed and the relative position between it and the specified position remains stable,[9] set the mark positions A and B in the template image, as shown in Fig. 1.

The specified position of the calibrated billet is specified in the figure, including two specified positions at the head and tail. It is required that the billet shall not exceed the front end and rear end of the position. When it is just between the specified positions, it will start to rotate. At

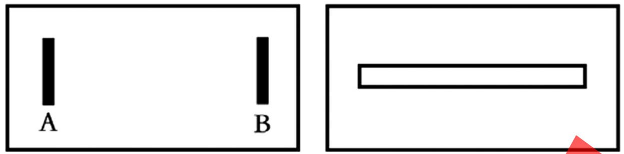

Fig. 1 Schematic diagram of designated position and billet in place in the formwork drawing.

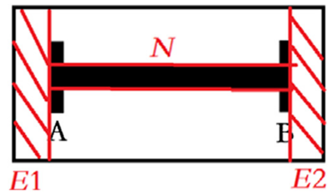

Fig. 2 Definition of logical area.

this time, the image information of the billet is obtained through the fixed camera, and the segmented and filled billet image S' is obtained through the above image segmentation and morphological post-processing methods. Logic diagram is defined as follows.

In the calibration diagram, the positions from the front and rear ends of the calibration position to the image boundary need to be calibrated as empty areas, such as shaded areas $E1$ and $E2$ in Fig. 2. It is required that the sum of image pixel values in this area is zero, otherwise it means that some billets in this area exceed the position. In addition, in the middle of the two standard positions, the logical and operation is carried out through the segmentation output diagram and marking diagram of the billet image:

$$S' \cap K' = I.$$

At this time, the sum result of the two is the complete set I. It indicates that the billet length in this area is consistent with the specified length, and there can be no vacant image pixels, otherwise the surface billet has not reached the specified position.

2.3 *Image Experiment*

Two aspects of image processing experiments are mainly completed: (1) after billet image acquisition and preprocessing, OTSU algorithm is used to realize the segmentation of billet image to eliminate the impact of background on subsequent recognition. (2) On the basis of image segmentation, by measuring the length of the billet and identifying the front and rear ends, the accurate position of the billet is realized, which provides judgment signals for subsequent operations such as rotation.

3 Specific System Implementation and Results

As shown in Fig. 3, the intelligent conveying and logistics tracking system of long small billet based on machine vision mainly includes: (1) billet discharging control unit, (2) conveying control unit, (3) industrial video machine vision system, (4) intelligent billet discharging subsystem, (5) intelligent conveying subsystem, (6) Kanban display system, and (7) robot code spraying system.

The (1) billet discharging control unit and (2) conveying control unit are the original caster billet discharging and roller table conveying with their own industrial control system, which just carry out interface adaptation transformation.

The (3) industrial video machine vision system includes a plurality of industrial cameras installed along the whole process, such as billet cooling bed, steel moving roller table, conveying turntable, conveying roller table, etc., and a machine vision code spraying identification device in

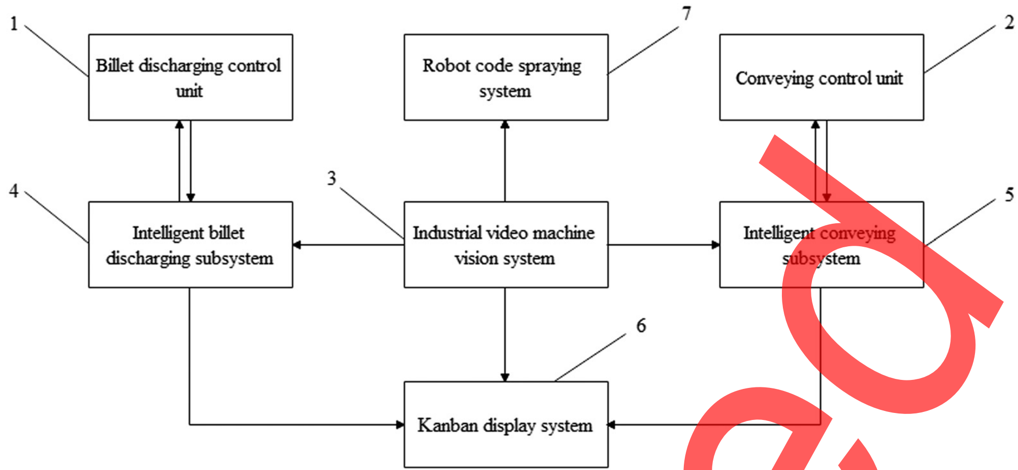

Fig. 3 System structure diagram.

front of the heating furnace. The (3) industrial video machine vision system is mainly used to identify the position, length and identity of cold billet and red billet, and inform the (4) intelligent billet discharging subsystem and (5) intelligent conveying subsystem of the relevant results, respectively.[10]

The (4) intelligent billet discharging subsystem receives the visual analysis signal of (3) industrial video machine vision system and interfaces with the industrial control system of the original caster: (1) billet discharging control unit to control the lifting of baffle plate and the movement of steel pusher, etc.

The (5) intelligent conveying subsystem receives the visual analysis signal of (3) industrial video machine vision system, and interfaces with the industrial control system of the original roller conveying: (2) conveying control unit to control the billet roller conveying, etc.

The (6) Kanban display system is mainly responsible for visualizing the whole process of billet discharging and conveying identified and operated by (3) industrial video machine vision system, (4) intelligent billet discharging subsystem, and (5) intelligent conveying subsystem, and providing the production line staff with a digital twin visual way to monitor the real-time operation of the system.

The (7) robot code spraying system is responsible for the unique identity code spraying of the off-line billet.

The main characteristic steps of the intelligent transportation and logistics tracking method of long and small billets based on machine vision are shown in Fig. 4, including: A inspection of steel pushing, *B* supplement billet before steel pushing, *C* off-line code spraying, *D* transportation tracking and *E* furnace front identification. See Fig. 5 for the A inspection of steel pushing and *B* supplement billet before steel pushing, we can refer Fig. 6 for the *E* identification relationship.

The *A* inspection of steel pushing. Check whether the quantity of billets in each stack position of the billet cooling bed has met the steel pushing conditions.

The *B* supplement billet before steel pushing. According to the quantity of billets missing in each stack position and the distribution of billets at the lifting baffle on all flow channels, calculate the flow number of billets to be replenished and the starting point of steel pushing of the pusher. For the flow of billets to be replenished, issue the instruction to open the lifting baffle. The billet enters the discharge roller table through the lifting baffle. After all billets leave the lifting baffle area, close the lifting baffle, and then send a moving command to the pusher.

The *C* off-line code spraying. When the billet needs off-line inspection due to quality problems or other reasons, the heating furnace cannot heat the billet and needs off-line stacking, the code spraying robot installed at the off-line of the cooling bed is responsible for the unique identity code spraying of the off-line billet.[11]

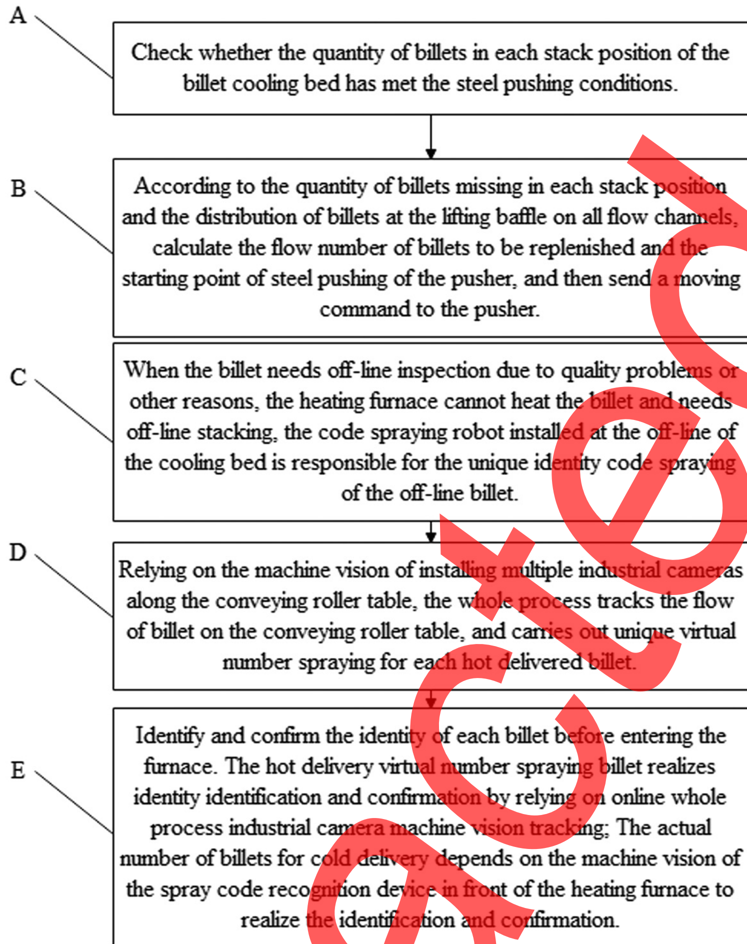

Fig. 4 Flow diagram.

The *D* transportation tracking. Relying on the machine vision of installing multiple industrial cameras along the conveying roller table, the whole process tracks the flow of billet on the conveying roller table and carries out unique virtual number spraying for each hot delivered billet (only the off-line billet need to be actually sprayed).

The *E* furnace front identification. Identify and confirm the identity of each billet before entering the furnace. The hot delivery virtual number spraying billet realizes identity identification and confirmation by relying on online whole process industrial camera machine vision tracking; the actual number of billets for cold delivery depends on the machine vision of the spray code recognition device in front of the heating furnace to realize the identification and confirmation.[12]

Compared with the existing implementation methods, this paper proposed machine vision to realize the intelligent transportation and logistics tracking of billet. The engineering practice shows that the machine vision model proposed in this paper can perfectly solve the problems of identifying the number, length, and position of billet in complex industrial environment.

4 Discussion and Conclusions

The research results presented in this paper are compared with the existing technologies that rely on various sensors to realize automatic billet transportation or solid marking one by one billet to realize billet logistics tracking. The one-time investment cost of the scheme proposed in this study is low, especially for billet logistics tracking of subsequent production control and quality tracking. Because the hot delivery billet only carries out virtual marking, i.e., the higher the hot

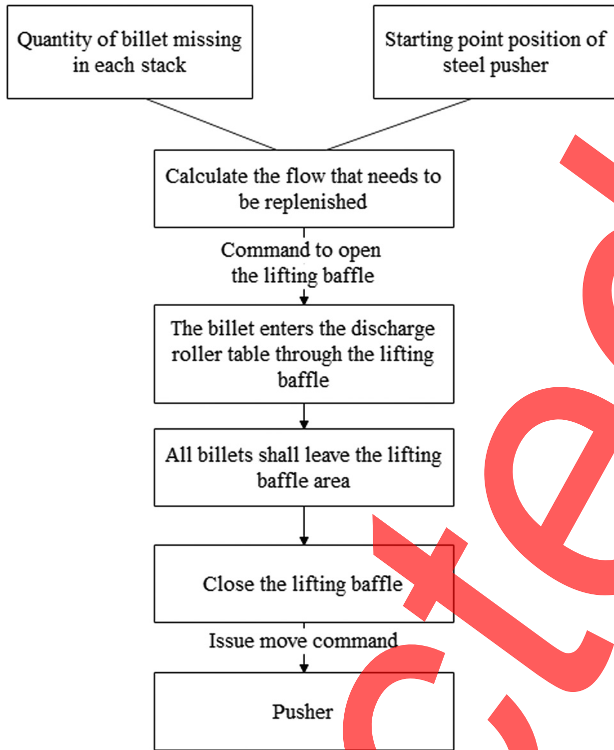

Fig. 5 Process diagram of pushing billet.

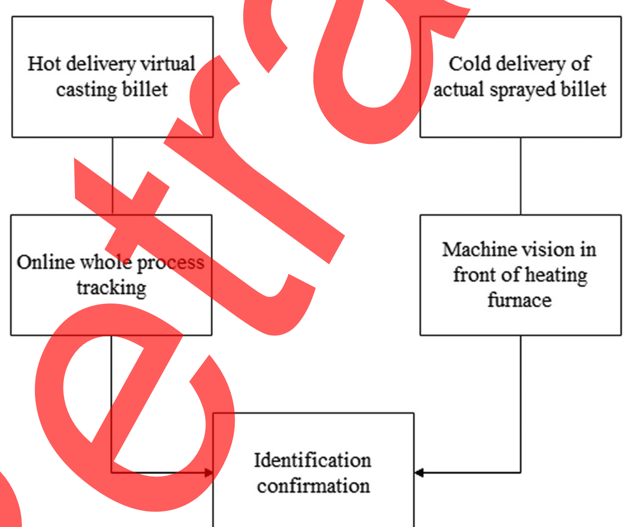

Fig. 6 Identification relationship diagram before the heating furnace.

delivery rate, the lower the average marking cost of billet, Moreover, due to the non-contact of machine vision, the system failure probability is lower.

The follow-up research will focus on the following aspects: (1) implement the billet image segmentation method based on the deep learning model to further improve the segmentation effect and performance of the billet, and overcome the accurate positioning of the billet under the moving background and interference. (2) Research the front and rear positioning algorithm in the dynamic process of billet to realize the pre perception effect of the controller and actuator, so as to improve the efficiency of the system. (3) Due to the influence of natural light or fill light during operation, the influence of light on billet segmentation and recognition needs to be further studied and improved.

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