

CISDI'S INTELLIGENT STOCKYARD EXPERTISE*

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Resumo

CISDI proposes intelligent solutions to renovate the steelworks' stockyard production and management model. Stockyard is one of the iron and steel production units, covering wide space, causing pollutions and demanding heavy labors. This thesis takes the intelligent stockyard at China's Baosteel Zhanjiang plant as an example to present the advanced system configuration, control principle and key technology. The intelligent system has been developed with a point cloud-based image processing model and with a control model for automatic stacking and reclaiming of bulk materials. The 3D laser scanner and high-performance detection elements and other technical means are used for development and production. The intelligent solutions create a digital stockyard and unmanned operation of stacker-reclaimer facilities. As a result, the stockyard's productivity has been enhanced by 20% while reducing 70% labor cost. The working environment gets better comprehensively.

Palavras-chave: 3D laser scanning; image processing; stockyard digitalization; intelligent control; unmanned operation

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Abstract

CISDI proposes intelligent solutions to renovate the steelworks' stockyard production and management model. Stockyard is one of the iron and steel production units, covering wide space, causing pollutions and demanding heavy labors. This thesis takes the intelligent stockyard at China's Baosteel Zhanjiang plant as an example to present the advanced system configuration, control principle and key technology. The intelligent system has been developed with a point cloud-based image processing model and with a control model for automatic stacking and reclaiming of bulk materials. The 3D laser scanner and high-performance detection elements and other technical means are used for development and production. The intelligent solutions create a digital stockyard and unmanned operation of stacker-reclaimer facilities. As a result, the stockyard's productivity has been enhanced by 20% while reducing 70% labor cost. The working environment gets better comprehensively.

Keywords: 3D laser scanning; image processing; stockyard digitalization; intelligent control; unmanned operation

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1 PREFACE

Stockyard of a steelworks is a site for storing various raw materials and fuels for blast furnace and pelletizing plants. It plays two main functions: storage and buffer [1]. Stocktaking and manual loading and unloading are operated at stockyard heavily and repetitively. That poses a topic of how to reduce the labor intensity, improve the working efficiency and conditions [2].

Great innovations have been made in traditional production and management models with the scientific development and new technological applications.

For example, image processing technology can identify the targets in a harsh environment in a highly efficient way; high-performance sensors can position accurately the production equipment; intelligent control algorithm can make a plan on movement path and do self-learning whenever the process needs.

To promote the inspiring technological highlights, we base on Baosteel Zhanjiang's intelligent stockyard to demonstrate the applications of image processing and intelligent control, seeing how the digital management and unmanned operation are realized.

2 SYSTEM CONFIGURATION

Baosteel Zhanjiang's intelligent solutions include an open stockyard and a closed stockyard. We focus on the closed stockyard for presentation.

There are four material strips named A / B / C / D in the closed stockyard, which store ore fines and pellets. Four stacker-reclaimer units are working respectively on two tracks. The project's intelligence lies in the yard's Digital stockyard system and unmanned stacker-reclaimer system. Figure 1 below shows the system configuration.

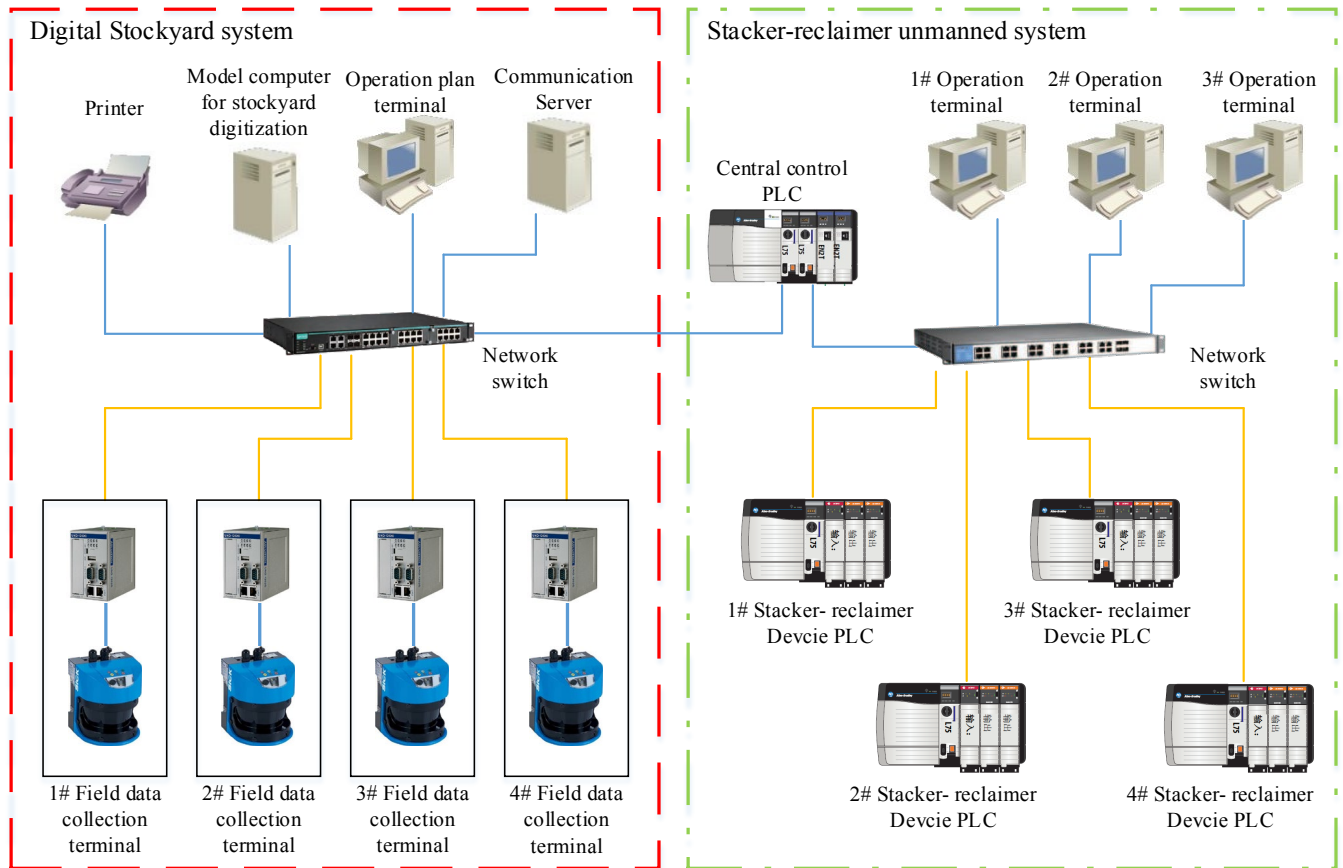


Figure 1. Baosteel Zhanjiang's stockyard intelligent system configuration

The Digital stockyard system enables modeling on both stockyard and stockpiles, analyzing the inventory information and distributing operational plan. The system consists of a model computer for stockyard digitization, an operational plan terminal, a communication server and four field data acquisition terminals. Among them, the model computer is mainly used for data analysis, yard modeling and stocktaking; the operational plan terminal issues a production plan; the communication server is to store and process image data; the field data acquisition terminal with 3D laser scanners and data collecting computers is used for a real-time acquisition of data and pre-process.

The unmanned system conducts remote control of the stacking and reclaiming equipment and makes them operate automatically. It's comprised of three operation terminals, onboard PLC and central control PLC. Among the rest, the operation terminal takes the task of remote control; onboard PLC connects local signals in and controls the automatic stacker-reclaimer operation; central control PLC as the brain of unmanned system, on one hand, converts the operational orders to specific process parameters which are issued to onboard PLC, and on the other hand, obtains the local equipment status and transmits it to operational plan terminal via the network.

3DIGITAL STOCKYARD SYSTEM

The Digital stockyard system is designed for data acquisition, splicing and analysis. It uses a laser 3D scanner to scan the stockyard for collecting the point cloud data of stockpiles and storing them in communication server. The model computer makes processing and analysis on the data and delivers report of stocktaking showing the variety of materials, coordinate positions of start and end points and volumes of stockpiles. At last, this computer generates the 3D map of stockyard.

3.1 Data acquisition

Data acquisition is performed by a laser scanner in front of the cantilever of the stacker-reclaimer. The scanner prefers the model of high performance of real-time, short sampling time, wide scanning range and strong environmental adaptability. The laser scanner is continuously scanning the stockpiles no matter if the stacker-reclaimer is idle or working. By the principle of laser ranging, the distance value on the surface of stockpile is obtained and stored in an IPC. The software takes over the data for filtering and converting the actual data to coordinate data; in this way, the raw data are converted into valid point cloud data for the stockpiles.

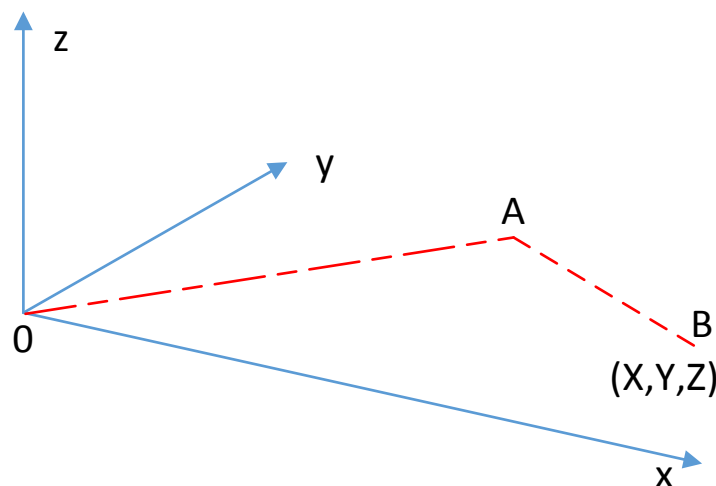


Figure 2. The coordinate conversion diagram

The points collected by the laser scanner are distance values that need to be converted into three-dimensional coordinates by an algorithm. Set the stockyard's coordinate system as Coordinate 1. First, we calculate the coordinates of point A in Coordinate 1. Second, we set Coordinate 2 with point A as the origin, and calculate the coordinates of point B in Coordinate 2. Figure 2 shows the positions of scanner and measured points in the 3D coordinate system (composed by Axle XYZ). Point A is the position where the scanner is installed, point B the measured points by the scanner.

Assume S as the current moving position of stacker-reclaimer, A_1 as the rotation angle, A_2 as the pitch angle, H_1 as the correction value of pitch height. Set the distance between the scanner's position and the center of equipment rotation as

D_1 ; the rotation angle of scanner's rotational station as B_1 , the laser beam angle as B_2 (the corner angle between laser and ground), and the distance between scanner and measurement point as D_2 . Consider the measured coordinates with Axle X-Y-Z.

Then, the space coordinates of measurement point are calculated by the following equations [3]:

$$X = S + D_1 \times \cos A_1 \times \cos A_2 + D_2 \times \sin B_2 \times \cos A_1 + D_2 \times \sin B_1 \times \sin B_2 \quad (1)$$

$$Y = H_1 + D_1 \times \sin A_2 - D_2 \times \sin B_2 \times \cos B_1 \quad (2)$$

$$Z = D_1 \times \sin A_1 \times \cos A_2 + D_2 \times \sin B_2 \times \sin A_1 + D_2 \times \sin B_1 \times \cos B_2 \quad (3)$$

3.2 Data splicing

Since each stacker-reclaimer is individually scanned, the intelligent system is required splicing all the collected data to be able to generate an accurate 3D stockyard map. The model software will combine the point cloud data from different perspectives into a unified coordinate system so that the registration of point cloud data can be achieved [4].

Splicing works well by coordinating both rough registration and fine image stitching. Rough registration can provide the expected initial values of splicing and streamlined data sets. Fine image stitching can reduce stitching errors and improve the convergence speed by iterative algorithm, bettering the stitching effect.

3.3 Data analysis

Data analysis is done by a model computer, involving macroscopic and microscopic analysis. The macroscopic analysis identifies the stockpile's height, volume, start and end; such information is used for an automatic stocktaking. The microscopic analysis is engaged in contour and profile; it's used for guiding the operation of stacker-reclaimer.

Automatic stocktaking is so important for a digital stockyard that it can solve the problem of low accuracy and heavy burden in manual stocktaking. The model calculates the stockpile's volume by integration according to the surface curve of the selected stockpile. The calculation formulas are shown below:

$$M_L(x, y) = M_l(x, y) - M_0(x, y) \quad (4)$$

$$V_L = \iint_{(x,y) \in M} M_L(x, y) dx dy \quad (5)$$

Among them, x and y : stockpile's coordinates x and y

$M_L(x, y)$: Relative height of the stockpile to the ground

$M_1(x, y)$: Absolute height of the stockpile

$M_0(x, y)$: Height of the stockpile site

V_L : Volume of the stockpile

4 STACKER-RECLAIMER UNMANNED SYSTEM

The stacker-reclaimer unmanned system is installed with high-performance detection components and operating with intelligent control algorithms. It's a family of several modules, such as task resolving module, device positioning module, stockpile identification module, intelligent control module, security module and monitoring module.

Specifically, the task resolving module decomposes the plans of central control room into the actions and parameters of the device; the intelligent module controls the automatic operation of device according to the position feedback information by device positioning module and the stockpile status feedback information by stockpile identification module; the device action module controls the movements of stacker-reclaimer, travelling, rotating and pitching; the security module is a necessary consideration for preventing collision between devices and sending an alarm once it happens; the monitoring module acts for remote operation. The software process flow is shown in Figure 3 below.

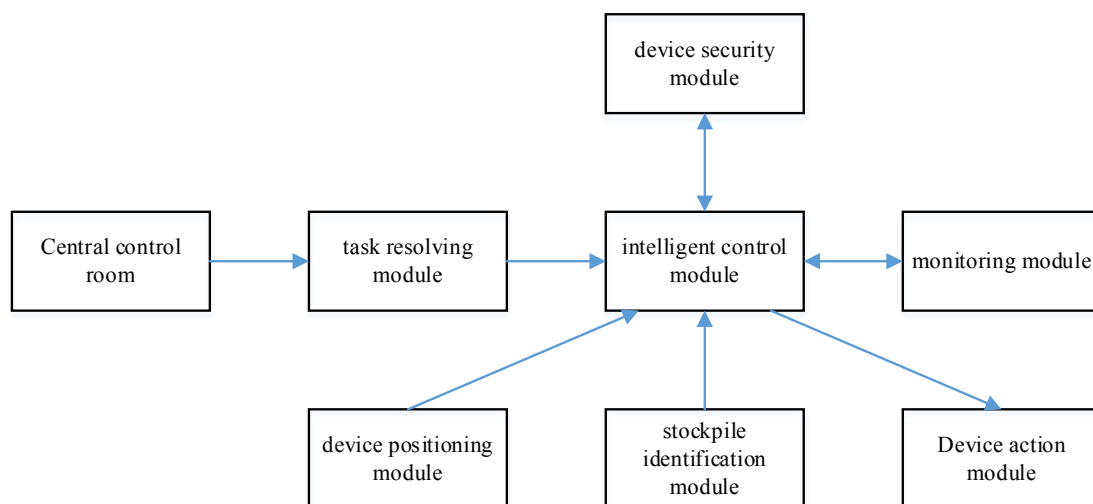


Figure 3. The software flow chart of stacker-reclaimer unmanned system

4.1 Automatic stacking

4.1.1 Automatic stacking process

In an automatic stacking mode, the stacker-reclaimer can unload the material from the belt conveyor to the designated yard and perform stacking as per the preset rule.

The automatic stacking procedure is as follows:

- 1) Move to the first point: The stacker-reclaimer moves to the set position (set value of travel distance, set angle of rotation and set height of pitch), where the start point for the stockpile is taken for start stacking.
- 2) Change row: When the height of stockpile reaches the set value (9m), the stacker-reclaimer will move for a fixed distance (3m) and continue piling.
- 3) Change column: When the length of stockpile (x direction) reaches the set value, the cantilever of stacker-reclaimer will rotate by a certain angle, and it repeats the above Procedure 2).
- 4) Change layer: When the width of stockpile (y direction) reaches the set value, the cantilever of stacker-reclaimer will turn a pitching to the set height, and it repeats the above Procedure 2) and 3).
- 5) End: When the last set stacking is sent from the model or manual ending is performed, it comes to the end of the automatic stacking.

In normal cases, the length and width of stockpiles are decided by the size of stockyard and variety of materials. The stockpile layers are suggested no more than three. This is defined as windrows/cone shells, benefiting improvement of yard utilization ratio and friendliness to environment.

Figure 4 below shows the sketch of automatic stacking. Among them, 1-1 means the first pile on the first layer, 2-4 the fourth pile on the second layer, 3-3 the third pile on the third layer; h_1 , h_2 and h_3 refer to respectively the height of the first, second and third layer; the number of rows (m) is 6, the number of columns (n) 3, the number of layers (p) 3; the stacking direction is in line with the dotted arrows.

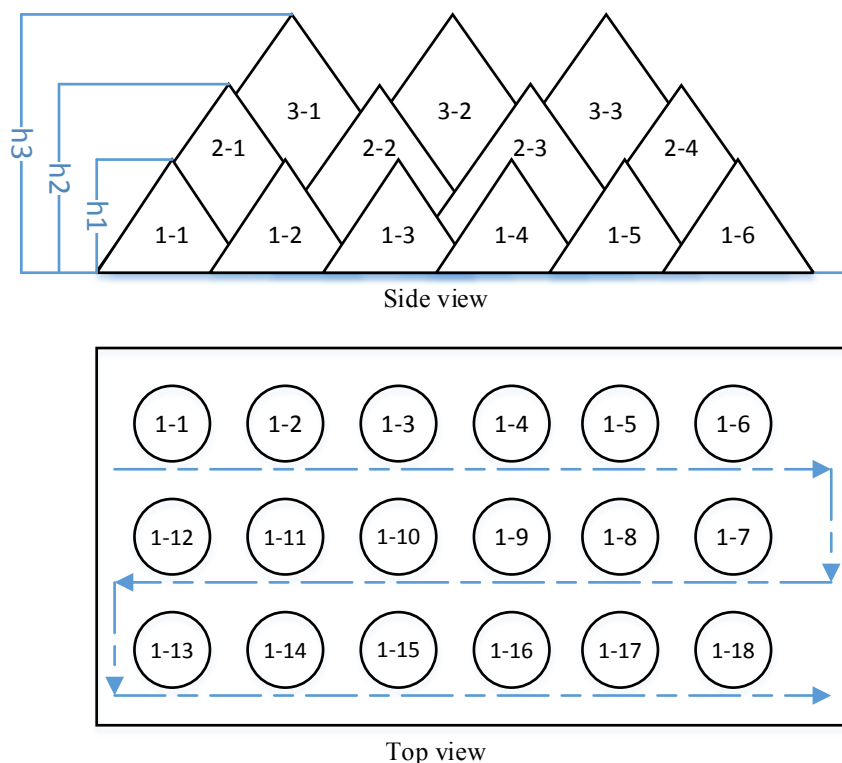


Figure 4. The sketch of automatic stacking

4.1.2 Automatic stacking configuration

The software architecture of automatic stacking is divided into three layers: model layer, resolving layer and action layer.

The model layer invents some dummy stockpiles according to the process requirements in the 3D coordinates of the stockyard and calculates the coordinates of the peak point of each stockpile.

The resolving layer decomposes each coordinate into multiple characteristic points which corresponds to an action function. The function combines action sequence and action parameters for making plans on the movement path of stacker-reclaimer. For example, the characteristic point 1 is called when the stacker-reclaimer moves to the first registration; the action functions encompass sequences of travel, rotation and pitching, and execution parameters of each action. The characteristic point 2 is called when stacker-reclaimer changes rows; the action functions are for travel and action parameters (travel distance). The characteristic point 3 is called when stacker-reclaimer changes columns; the action functions are for sequences of travel and rotation and action parameters (travel distance and rotation angle), and the like.

The Action layer checks and confirms the resolving layer's commands and performs actions.

Coordinates of automatic stacking model is related to the size of stockyard and process parameters. Then, the peak coordinates of the invented stockpile's first layer can be calculated by the following formulas:

$$X_1 = X_b + \frac{H_1}{\tan \alpha} + (m_1 - 1) \times R \quad (6)$$

$$Y_1 = X_d - \frac{H_1}{\tan \alpha} - (n_1 - 1) \times R - C_1 \quad (7)$$

$$Z_1 = H_1 \quad (8)$$

Among them,

Set X_1, Y_1, Z_1 as the coordinates of the peak points of the first layer's piles

X_b : The starting point of pile

X_d : The end point of pile

H_1 : The height of the first layer

α : The material angle of rest (the maximum angle for the material to be able to maintain a natural, steady state, or the one-sided horizontal angle to the stack)

m_1 : The number of real-time rows

n_1 : The number of real-time columns

R : The distance between the peak points of pile

C_1 : The correction coefficient for retaining walls

4.2 Automatic reclaiming

4.2.1 Automatic reclaiming process

In an automatic reclaiming mode, the stacker-reclaimer transport the materials from the designated yard to the belt conveyor, with an automatic adjustment of reclaiming speed to ensure stable material flows, specifically:

- 1) Move to the first point: The stacker-reclaimer move to the set position (set value of travel distance, set angle of rotation and set height of pitching); the starting point for reclaiming is taken, while the bucket wheel machine is started for reclaiming.
- 2) Reclaim per cycle: The stacker-reclaimer travel for a distance (value of footage) and rotate positively by a set angle; it moves for another distance (value of footage), and rotate reversely by a set angle, and the like.
- 3) Change layer: When the length of reclaiming reaches the set value (10m), the stacker-reclaimer adjust itself to the set point of the second layer, and it repeats Procedure 2).
- 4) Change segment: When the first segments of all the layers are reclaimed, the stacker-reclaimer will turn to the second segment of the first layer for another reclaiming cycle; this is defined as a cascade reclaiming mode.
- 5) End: The reclaiming is automatically judged by the system for an end or manually stopped.

During the reclaiming process, it should monitor the current situation of bucket wheel machine against its overload.

Figure 5 shows the sketch of automatic reclaiming. Among them, 4-1 means the first segment on the fourth layer, and 3-2 the second segment on the third layer. The reclaiming direction is in line with the dotted arrows.

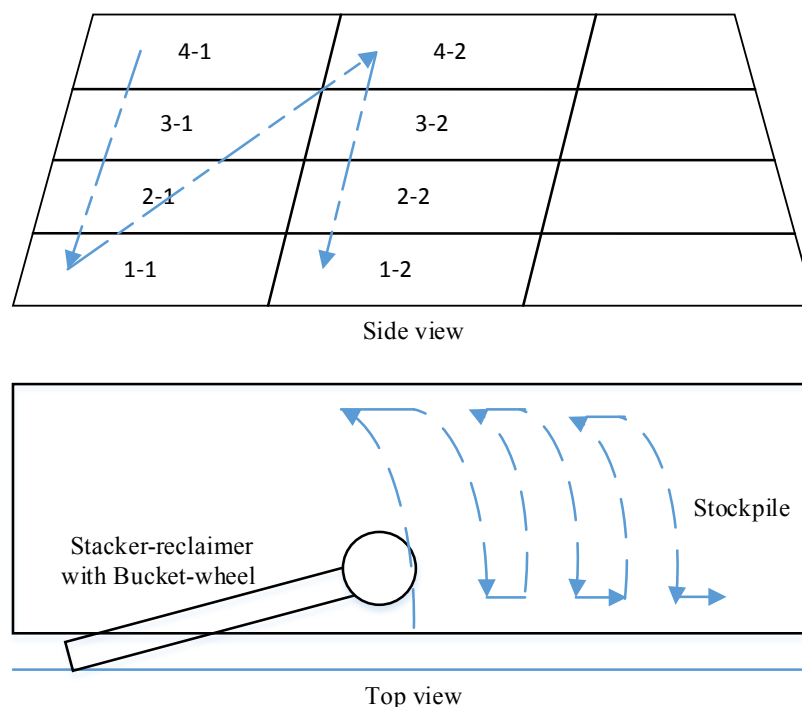


Figure 5. The sketch of automatic reclaiming

4.2.2 Automatic reclaiming configuration

The software of automatic reclaiming is comprised of reclaiming optimization model and reclaiming cycle control module.

Reclaiming optimization model generates the starting point for each layer of reclaiming according to the pile profile from 3D scanner, and consistently corrects the boundary angle of reclaiming process.

Reclaiming cycle control module carries out cyclic actions of inching, rotating, returning and layer changing.

To ensure a constant flow and a smooth process of reclaiming, the system proposes the following two options.

1) The system converts the bucket-wheel motor's current to a reclaiming flow and takes it as a control feedback.

During reclaiming, the bucket wheel machine is started and cantilever of stacker-reclaimer rotates. The bucket teeth reclaim materials from stockpiles by turn and put the materials onto the belt of cantilever [5]. Since the bucket teeth is contacting with the surface of stockpile, the motor's current of bucket-wheel can reflect the changes of reclaiming loads in a real-time manner; the bigger the current value, the greater the reclaiming quantity.

To that end, the current curve of bucket-wheel motor and the flow curve of belt weigher are collected for comparisons. It's found that they are directly proportional to each other. However, the response of belt weigher's flow is 15s later than that of bucket-wheel's motor current.

2) PI controller is used for adjusting rotation speed of stacker-reclaimer. Through setting the speed of bucket wheel a constant value; the system can control the reclaiming flow rate only by adjusting rotation speed. When the flow rate becomes low, the rotation speed should be increased; when the flow rate becomes fast, the rotation speed should be reduced.

Take the set flow and feedback flow (converted from bucket-wheel current) as the controller's inputs, the rotation speed as the controller's output. By an incremental PI, the controller's algorithm is shown below:

$$V(n) = V(n - 1) + Kp \times [\delta e(n) - \delta e(n - 1)] + \frac{Tn}{Ts} \times \delta e(n)$$

(9)

Among them,

$V(n)$: The rotation speed at this moment

$V(n - 1)$: The rotation speed at the previous moment

Kp : The proportional coefficient

$\delta e(n)$: The deviation between set value and feedback of present reclaiming

$\delta e(n - 1)$: The deviation from the previous moment

Tn : The sampling time

Ts : The integration time.

Since the stockpile and the track of stacker-reclaimer are parallel, when the cantilever of stacker-reclaimer revolves around the center of device to reclaiming, the material inside stockpiles is thick and the material outside stockpiles is thin. To ensure a smooth process of reclaiming, the system needs to adjust the rotation speed of the inner and outer borders according to the rotation angle in advance. Figure 6 shows the process of reclaiming the material inside and outside boundaries.

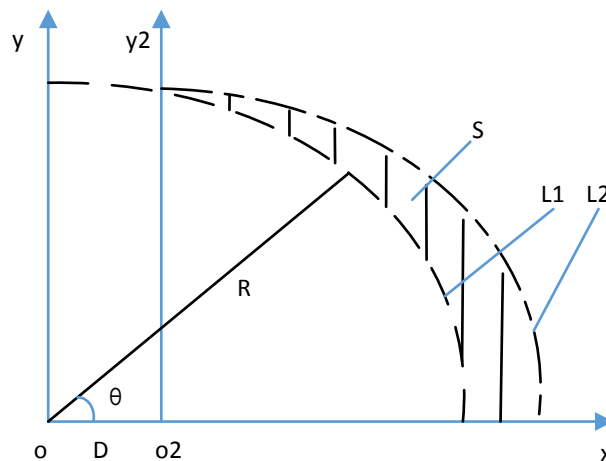


Figure 6. The sketch of reclaiming the material inside and outside boundaries

In this figure, Assume D as the distance of inching, When reclaiming; θ as the rotation angle of the cantilever; R as the length of the cantilever; S as the sectional area of stock, when reclaiming; $L1$ as the path of reclaiming before inching; $L2$ as the path of reclaiming after inching.

According to the book "Bucket Wheel Excavator" written by W. Dust and W. Vogt, the relationship between rotation speed and rotation angle has been given. The book also describes the application in engineering. The final output speed of the stacker-reclaimer is calculated as:

$$V_F = \frac{K_S}{\cos \theta} V(n) \quad (10)$$

Among them,

V_F : The final rotation speed of the stacker-reclaimer

K_S : The proportional coefficient of Boundary speed

θ : The rotation angle of the cantilever

$V(n)$: The rotation speed that is calculated by PI controller

5 CONCLUSIONS

In conclusion, CISDI's intelligent stockyard system adopts a laser 3D scanner for acquiring the yard's point cloud data and builds a model; the stacking and reclaiming equipment can be accurately positioned by the high-performance sensors; the intelligent control algorithms contribute to the digital management and the unmanned operation.

The system is being applied well at Baosteel Zhanjiang's stockyard. The yard is demonstrating an enhanced efficiency and a more comfortable condition while reducing labor cost.

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