# Development of 3D Control Technique for Moving Machines in Raw Material Yard

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## Abstract

The demurrage of ore/coal carriers often occurred at the port of Oita Works because the ships had to wait for an empty area in the raw material yard at which the cargo would be stored. Although the yard area was expanded and remote operation was applied to the moving machines of the yard, the demurrage was not eliminated, and more effective utilization of the yard area and advanced automatic operation of the machines were required. To solve the problem, the Works has developed and actually applied automatic precision control of the machines using ultrasonic sensors to measure the shape of the piles of raw materials and an advanced yard management method based on high-accuracy 3D mapping of the piles incorporating high-accuracy data of their dimensions.

#### 1. Introduction

Automatic operation is applied to increasingly wider fields of industry these days. The steel industry is no exception; in many steel works, automatic operation is being applied to various manual works and facilities that were operated manually.

This paper presents three-dimensional (3D) automatic control of the moving machines of the raw material yard of Oita Works, which was made possible by introducing 3D management of the material storage piles, machine position detection, and the measures to improve the positioning accuracy of the machines.

## 2. Outlines of Facilities in Raw Material Yard

#### 2.1 Characteristics of raw material yard

The raw material yard of Oita Works comprises 15 piling zones, each roughly 700 m in length and 50 m in width, for iron ore, coal, or flux (lime stone, etc.), and there are 18 moving machines in it: eight stackers, eight reclaimers, and two stacker-reclaimers; **Fig. 1** is a map of the whole yard. A piling zone accommodates 20 piles of raw material at the most, and a pile is, on average, 150 m in length, 50 m in width, and 17 m in height, approximately. Since iron ore and coal are in small grains, the piles change shape continuously as a result of piling and reclaiming (scooping up), and discrete control is inapplicable to them. Since, in addition, the chemical composition

and grain size of ore and coal differ from brand to brand, if different brands are mixed and sent to sintering plants or coke ovens, it leads directly to inferior quality of the product, and for this reason, strict brand control is imperative in the yard operation.

### 2.2 Stacker

A stacker (ST) is a large moving machine, roughly 80 m in length and 20 m in height, equipped with a swinging and tilting conveyer boom roughly 33 m in length. It stacks ore or coal unloaded from a ship from the end of the conveyer boom to form a pile in cones; its handling capacity is 6500 t/h, approximately. It moves on a track of rails along a conveyer line at 40 m/min (high speed) or 10 m/min (low speed).

#### 2.3 Reclaimer

A reclaimer (RC) is also a large moving machine, roughly 75 m in length and 25 m in height, equipped with a swinging and tilting conveyer boom, roughly 50 m in length, and at the far end of the boom, there is a bucket wheel 5.5 m in diameter to scoop up the ore or coal from the piles. The maximum handling capacity is 1 300 t/h for iron ore and 900 t/h for coal. It also moves on a track of rails along a conveyer line and the moving speed is the same as that of the stacker, 40 m/min (high speed) and 10 m/min (low speed).

A stacker-reclaimer (SR) is another type of moving machine having the combined functions of a stacker and a reclaimer.

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## 3. Problems of Conventional Yard Operation

Figure 2 schematically shows the conventional yard management method. According to this practice, only the percentage along the length of each zone occupied by piles and the tonnage of each pile were controlled, and there was no distinction between a pile being reclaimed and another before reclaiming. As a result, there were many dead spaces, and the yard capacity was not fully utilized. Although automatic operation was introduced to the stackers and reclaimers, the information of accurate pile shape and the starting point of reclaiming work was not given, and even after the reclaim



Fig. 1 Overview of raw material yard

ing work was automatized, the bucket wheel had to be set at the starting position by manual remote operation before the operation start. In addition, owing to reasons of sensors and machine structure, the accuracy of pile dimension detection and the control of the machine stopping position were dissatisfactory for fully automatic operation. Improvements required in view of the problems were as follows:

(1) Improvement in position control accuracy of the machines

Accurate shape detection of the piles, and effective utilization of pile shape data for precise position control of the machines relative to the piles and decrease in the safety distance to an adjacent machine on the same track.

(2) Three-dimensional management of piles

More efficient use of the yard area by accurate detection of three-dimensional pile shape and multiple piling of different material brands.

(3) More advanced automatic operation of the machines

Efficiency improvement of machine travels and boom operation, expansion of automated operation such as automatic bucket wheel positioning at the start of reclaiming work.

## 4. Development of Automatic Machine Control Based on 3D Yard Map

For 3D management of material piles, high-accuracy information of pile shape is indispensable because it enables stacking a material brand on a pile of another brand, minimizing dead space between piles, and decreasing the safety distance between the machines on the same track. Measures were taken to improve the detection accuracy of machine travel and the swinging and tilting angles of the boom, and yard management based on a 3D map has been made possible. In addition, ultrasonic sensors have been introduced to detect the actual shape of material piles, and high-efficiency automatic control has been applied to the machines, expanding the extent of automatic operation.

#### 4.1 Accuracy improvement in machine position detection

To collect high-accuracy information of the material pile shape, measures were taken to improve the control accuracy of the travelling and boom swinging and tilting of the stackers and reclaimers.

For better position control along the travelling track, touch roll-



Fig. 2 Conventional management of raw material yard

ers, which served as position sensors, were replaced with larger ones; as a result, skidding due to vibration and other disturbances was decreased, and position detection accuracy was improved. In addition, ID tags were provided at intervals of 20 m, and limit switches at intervals of 100 m along the tracks, a system for correcting the machine position more frequently was introduced, and the electrical control of the travelling motors was changed to inverter control.

As a measure to improve the control accuracy of the boom swinging and tilting, the swing angle detector, which had been driven through many stages of gears, was moved to a position in the swing driving mechanism, and as a result, gear backlash was reduced and so was the error in angle detection. Additional limit switches were provided for position adjustment at every swinging or tilting motion. The control function of boom swinging speed, which had been performed remotely by a central sequencer, was changed to feedback control by sequencers on individual machines, and control response was improved.

Thanks to the above measures, the error of the position control of the stackers and reclaimers was decreased from 2.3 m at the largest to 0.3 m.

### 4.2 Development of yard management system based on 3D mapping of piles<sup>1-3)</sup>

Since the materials are in small grains, they are stacked into piles in the shape of continuous cones, and reclaimed by cutting to form benches in horizontal arcs; thus the shape of the pile changes at every reclaiming work. The pile shape changes owing also to local landslide and position errors due to bowing, etc. of the moving machines. While it is desirable to control the yard space by 10 cm units, considering the above changes and errors, such delicate yard management in real time was impracticable, and each of the 15 zones of the yard was controlled two-dimensionally in the length direction only (see Fig. 2).

In view of the fact that, although the pile shape is complicated in the width and height directions, it is rather monotonous in the length direction, it was decided that piles were to be controlled by 10 cm units in the width (Y) and height (Z) directions, and by the distance between two points in the length (X) direction between which a brand of ore or coal was stacked; this pile control method was called the "from-to control method." The concept of the "from-to method" is schematically illustrated in **Fig. 3**. Here a pile is considered to consist not of small cubes but of long rectangular prisms (blocks). By this method, the data size of a pile is reduced to about 1/200 of the case of cubes, and real-time calculation of yard occupancy has been made possible without sacrificing accuracy.

Figures 4 and 5 show models of pile shapes. The shape of an initial pile is calculated from the height Z of the boom end of the stacker and the angle of repose  $\theta$ , which was defined for each brand through actual measurement. The pile shape is adjusted on every reclaiming operation based on the trajectories of the bucket wheel. When a pile changes its shape naturally due to local fall, etc., the pile data in the 3D map is corrected based on actual measurement.

It has been made possible through the above measures to manage the raw materials yard based on a 3D map reflecting the actual conditions of the piles.

### 4.3 Development of high-efficiency automatic operation of machines

After the improvement of machine position detection and the yard management system based on the 3D mapping of all piles, a machine position detection system using ultrasonic sensors was introduced for safe and high-efficiency automatic operation of the moving machines based on the real shapes of the piles (see **Figs. 6** and **7**).

4.3.1 Prevention of boom collision with pile

To prevent a machine boom from hitting a pile of iron ore or coal, ultrasonic sensors were provided at some positions of the



Fig. 3 Pile modeling by "from-to method"



Fig. 4 Modeling of as-stacked pile



Fig. 5 Modeling of pile after reclaiming

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Fig. 6 Positions of ultrasonic sensors (plan view)



Fig. 7 Positions of ultrasonic sensors (side view)

boom of each machine (see Fig. 6). As a result, boom collision with piles and consequent time loss due to the interruption of automatic operation, etc. were eliminated even if the real pile shape was different from the 3D map owing to reasons such as local slide. The sensors thus proved effective for stable automatic operation.

4.3.2 Detection of turning point of reclaimer boom

Ultrasonic sensors were provided at the boom end of each reclaimer as shown in Fig. 6 to detect a turning point of the swing motion before the bucket wheel actually reached there. As a result, the no-load run of the bucket wheel at the end of a boom swing during automatic operation and consequent interruption of the material transport to the succeeding process have been minimized, and the loss in tons per hour during automatic reclaiming has been reduced. 4.3.3 Detection of bench end during reclaiming

To detect the end of each cut bench during reclaiming from a pile, a downward ultrasonic sensor was provided near the boom end of each reclaimer. Thanks to this, the time for switching from the current bench to a lower one has been shortened, and the loss in tons per hour avoided.

### 4.4 Evaluation of improved yard management based on 3D map

**Figures 8** and **9** show some of the benefits brought about by the improvement in machine position and attitude detection, the new yard management system based on the 3D mapping of piles in the whole yard, and high-efficiency automatic operation of the moving machines. Multiple piling of different material brands has been made practicable and the clearance between two adjacent piles has been reduced from 12 to 9 m, and as a result, dead space in the yard



Fig. 8 Efficient use of yard space



Fig. 9 Example of 3-D mapping system

much decreased. It has been made possible to monitor the condition of the whole yard using the high-accuracy 3D map reflecting the real shapes of the piles including the level difference between two benches of a pile being reclaimed, and the position of the boundary between different material brands in a pile.

#### 5. Configuration of Information System

Figure 10 shows the configuration of the information system for the yard management based on the 3D mapping and automatic operation control of the machines. The system includes an information LAN and a control LAN, the former being linked to a system for the yard management based on the 3D mapping, operators' viewing monitors, operating terminals, and the process computers for raw materials handling.

A data server is provided between the two LANs for common use of the data. It stores data, and in addition, controls the operation information (positions, etc.) of individual machines for each of the piles of different material brands as well as the information of operators' supervision, instructions and remote operation. The server also calculates the work starting position for automatic operation of

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Fig. 10 System configuration

the moving machines.

Sequencers that control the yard operation and prevent interference of adjacent moving machines are connected to the control LAN, and are responsible for automatic control of the moving machines. The moving machines undergo periodical inspection and maintenance work at different timings, and to minimize the adverse effects of sequencer stoppage, the sequencers are grouped into three groups: those for the iron ore zones, the coal zones, and the flux zone. These control sequencers direct the automatic operation of the moving machines in close linkage with those on individual machines.

#### 6. Conclusion

Thanks to the developed automatic control of the moving machines and the improved management of the raw material yard using 3D mapping of the piles, the space efficiency of the yard has been markedly improved, and as a result, the demurrage of raw material vessels at the works' port due to waiting for yard vacancy decreased. In addition, by precise position control of the bucket wheel during reclaiming from piles containing different material brands, mixing of different material brands has been avoided, the quality fluctuation of sintered ore and coke has decreased, and the product yield of these processes improved.

#### References

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