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Development of a real-time raw material stockpile measuring system

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To avoid an unscheduled shutdown, a certain amount of reserve of coke and sinter is required as a buffer for continuous dumping in the blast furnace operation. The storage of the stockpiles also affects the schedule of sintering and coking production. Both laser scanning and image telemetry technologies were applied in the study to develop a real-time raw material stockpile measuring system. A three-dimensional polygonal profile of the stockpiles can be visualized from the reconstructed voxel information of the measuring system, and also the volume of the stockpiles can be calculated from it. The measurement deviation of the system was realized to be about 0.1~0.2% by repeatedly measuring the same stockpiles. The inaccuracy of the volumetric reserve calculation of the stockyard was verified to be about 1~2% by measuring a cube of a specified size. Six outdoor sinter, coke, and flux yards have been successively equipped with the measurement system since 2016. Due to the lack of real-time update functions, the commercial stockpile measuring system was found to interfere with the frequent stacking and reclaiming operations, resulting in low utilization. In 2019, two laser scanners were installed and integrated into a coordinate system on #4B stacker and reclaimer to obtain a real-time profile of the stockpile. Using the construction time of the sinter storage shed in 2020, two compact rail-guided vehicles were installed to scan the entire stockyard at a traveling speed of 2 meters per second to achieve faster and more flexible application methods after the use of wheel loaders to move materials during the day. The measurement results from the vehicles were merged into the database of the real-time measuring system installed on the dumping tripper to complete the profile measurement and the reserve calculation of the stockyard so as to improve its operating performance.

Keywords: real-time profile measurement, automated volume calculation

1. INTRODUCTION

The blast furnace has to be maintained in continuous operation to obtain its economic benefits. Sinter, coke, and flux are necessary to be successively dumped into the blast furnace to supply its operation. A certain amount of reserve of these materials is required as a buffer to avoid an unscheduled shutdown due to the interruption of the sintering or coking process. The flow

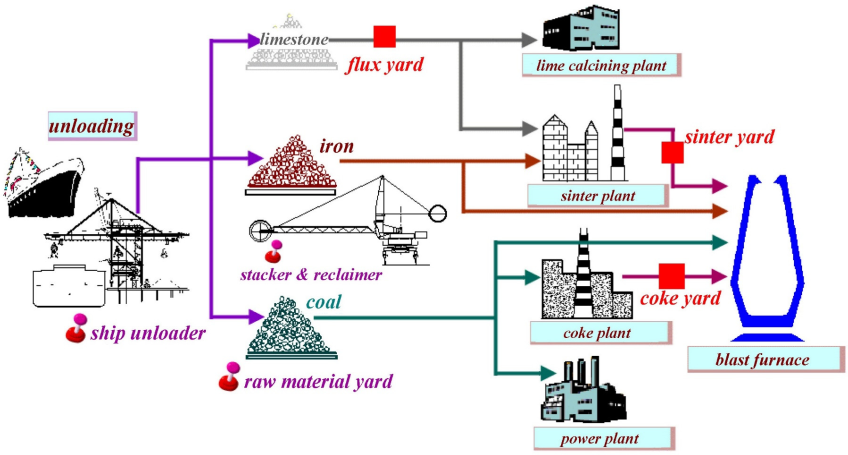

Fig.1. Flow chart of blast furnace material transportation in CSC

chart of blast furnace material transportation in China Steel Corporation (CSC) is shown in figure 1. The compact yard area is a bottleneck affecting the sintering and coking production plan, which makes the storage amount of the sinter, coke, and flux yard important.

In the past, changes in the reserve of the sinter yard were calculated based on the output of the sintering plant and the consumption of the blast furnace. However, the weighing system on the conveyor belt was difficult to be calibrated due to changes in belt tension and blockage of falling materials. The frequent handling of materials by wheel loaders in the stockyard can also lead to changes in the reserve. Finally, an experienced storekeeper was required to manually adjust the numerical value of the reserve from time to time.

The time-of-flight scanning method and multi-angle image recognition method are commonly used to obtain the profile of objects in recent years. Before that, an ultrasonic sensor was usually installed near the stacking or reclaiming area to give feedback on the level of the material stockpiled, as shown in figure 2[1]. The operator remotely located the position of the bucket wheel through the camera image, and then the stacker and reclaimer can be operated automatically according to the stockpile profile calculated from a mathematical model based on the angle of repose. However, the calculated stockpile profile changed after severe weather or manual handling, which reduced its efficiency of automatic operation.

The time-of-flight scanning method was adopted in many profile measurement applications due to its high resolution and guaranteed accuracy. In 2004, a commercial three-dimensional laser scanner was applied in CSC [2] to construct the profile of the material stockpiles through the method of Iterative closest point, as shown in figure 3. Two laser scanners were installed on the

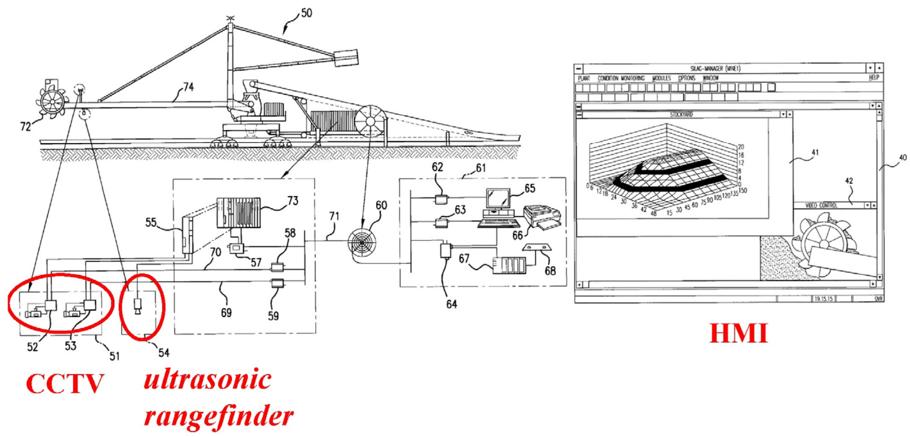

Fig.2. Common stacker and reclaimer operation form[1]

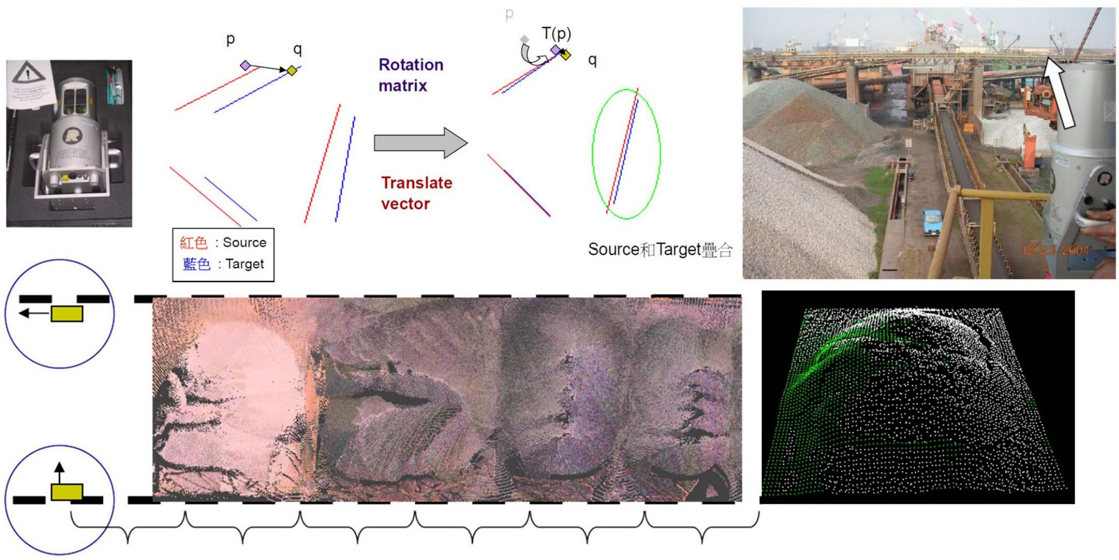

Fig.3. Material stockpile profile measurement in CSC[2]

stacker and reclaimer by nCS(3) in 2009, as shown in figure 4. With the assistance of the global positioning system, a three-dimensional surface profile of the stockpiles was successfully constructed while the laser scanners were still moving.

In 2013, laser scanners were also used to provide a warehouse map in CSC's unmanned crane development project(4) to identify the number and center positions of the steel coils, as shown in figure 5. Indurad also proposed a solution to install their radar scanners on the crane(5) to obtain the stockpile modeling, as shown in figure 6. Even though the radar signal is more resistant against dust interference due to its wavelength characteristics, the measurement accuracy and resolution is less than that of a laser by an order of magnitude.

The multi-angle image recognition method is another widely used technology in recent years. The three-dimensional shape of the object can be constructed by identifying features of the multi-angle images. In 2016, three sets of cameras and linear marking lasers were composed to monitor the online roundness of the #2 rod mill rolling line in CSC(6), as shown in figure 7. Unmanned aerial vehicles were applied to topographic surveying by ASM(7), as shown in figure 8. Georeferenced contours, orthomosaic planimetrics, volumetrics for stockpiles or reservoir capacity can be provided based on the results of photogrammetry. Since the profile was calculated based on the image features, it may be influenced by the object's color, surface reflection or even the direction of sunlight, which makes it difficult to guarantee the measuring accuracy.

2. SYSTEM DEVELOPMENT

In this study, the time-of-flight scanning method and the multi-angle image recognition method were both

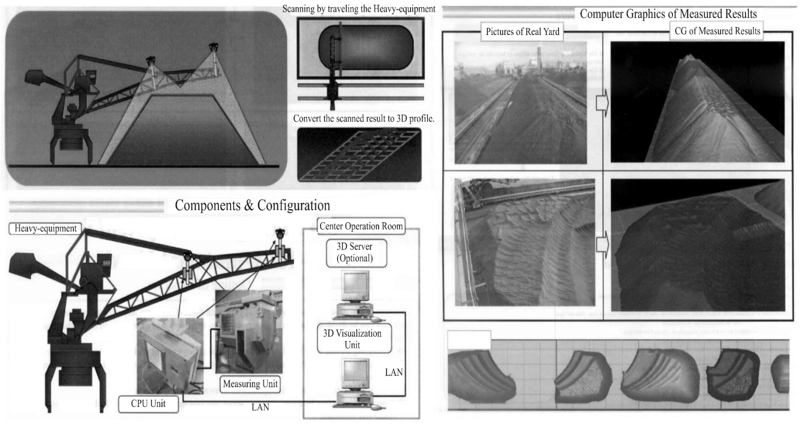

Fig.4. Laser scanners installed on the stacker and reclaimer from nCS(3)

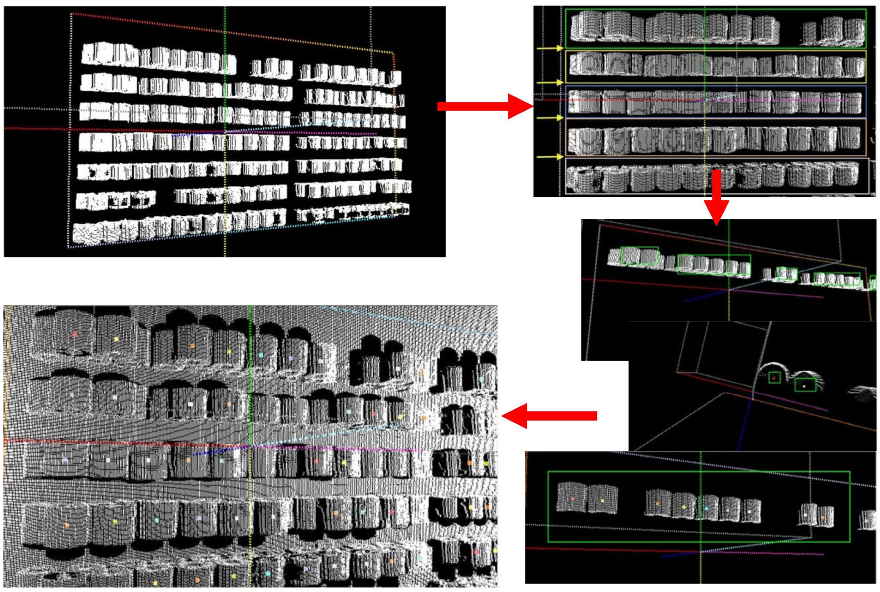

Fig.5. Laser scanners applied in the unmanned crane system in CSC(4)

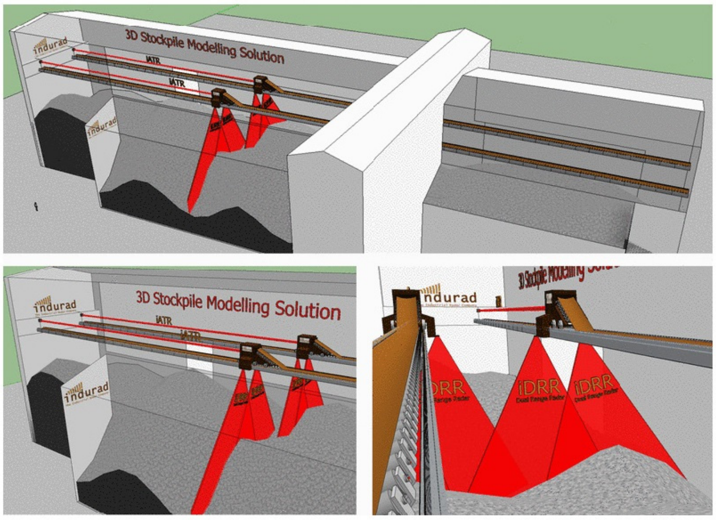

Fig.6. Radar scanners installed on the crane by Indurad[5]

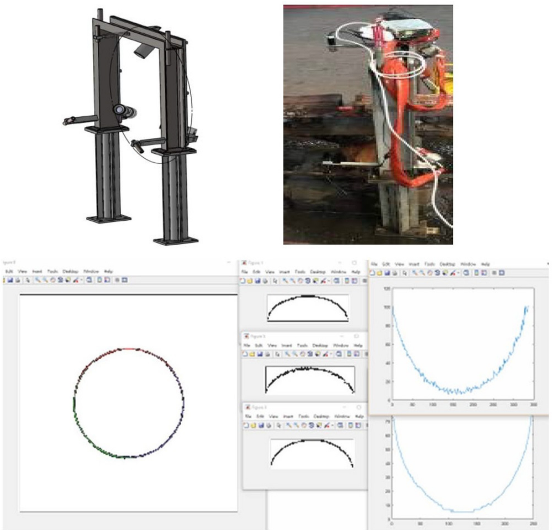

Fig.7. Roundness monitoring in CSC rod mill rolling line[6]

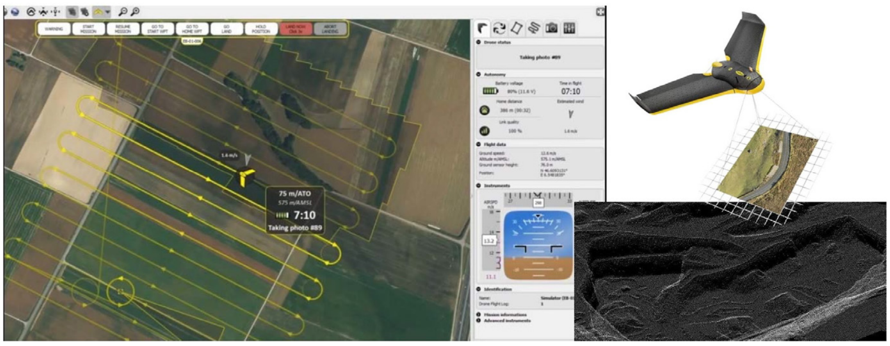

Fig.8. Topographic surveying by unmanned aerial vehicles[7]

adopted for different application situations. Laser scanners and laser distance sensors were adopted to compose an outdoor raw material stockpile measuring system, as shown in figure 9. A wireless communication system was adopted for the data transfer to reduce the measuring system construction costs on the tripper. A 3D server with stockyard engineering drawings was used to remove the plant structure from the measuring results, and fill in the area blocked from the scan based on the angle of repose of the raw materials to improve the accuracy of the reserve calculation. Finally, the reserve and profile of the stockyard were both presented on the webpage for all production-related personnel to review.

Two-dimensional laser scanners were installed on both sides of the tripper to feedback the linear profile on the ground material stockpiles, and were aligned orthogonal to the tripper traveling direction, as shown in figure 10. A three-dimensional surface profile of the stockpiles was able to be constructed based on the combination of the linear scanning profile and the dumping tripper position. The location of the dumping tripper was provided by a laser positioning sensor, which was selected according to the function of its rain filter to prevent interference from rainy weather when used outdoors. The scanning of the stockpile directly below the tripper may be blocked by the structure, so a dumping level sensing laser was necessary to be installed to provide a reference point for the height of the stockpiles. The signals from the laser scanners and laser positioning sensors were recorded in real-time to the database in the IPC on the tripper. The 3D server was set to automatically request an update of the database and refresh the webpage every five minutes with the results of the constructed profile and the calculated reserve of the stockyard. There was also a manual trigger button, which was connected to the PLC to drive the tripper to perform a full-stroke movement, so the operator can update the profile and the reserve of the entire stockyard as required.

Since both sides of the material stockyard were out of the traveling range of the dumping tripper and were rarely used for a long time, its profile and reserves were almost unchanged. Therefore, a drone was used to obtain images around the stockpiles manually, and the multi-angle image recognition method was adopted to construct the profile for the calculation of the reserve on both sides of the stockpiles to make the reserve calculation complete, as shown in Figure 11.

The deviation of the volumetric reserve calculation was realized to be about 0.1~0.2% by repeatedly measuring the same stockpiles, and the measurement inaccuracy was verified to be about 1~2% by measuring a cube of a specified size, as shown in figure 12. In addition to the bulging of the inflatable cube, the inaccuracy of the

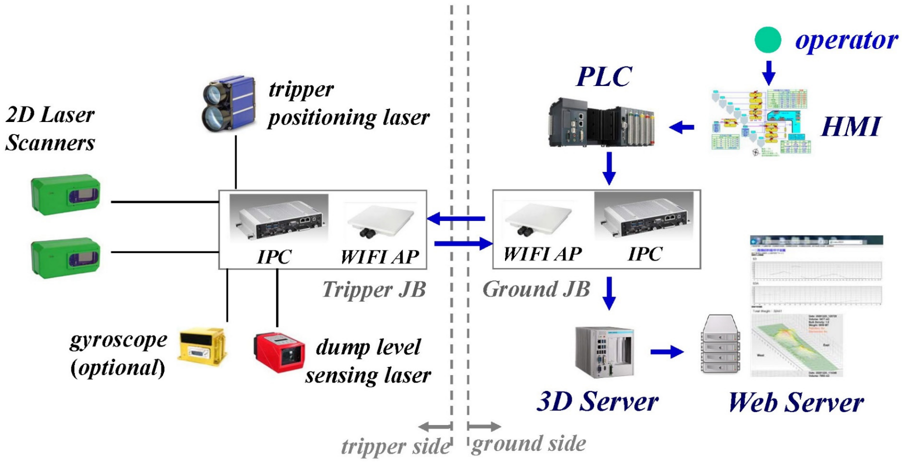

Fig.9. Diagram of the measuring system on the dumping tripper

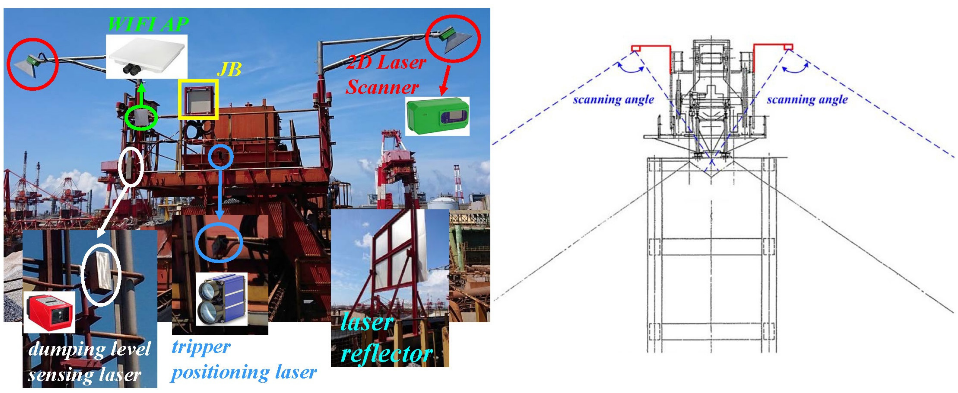

Fig.10. System arrangement on the dumping tripper

reserve calculation mainly comes from the reduced calculation cost due to the division of the fixed-size geometric grid of the stockyards. The points in one grid will be averaged to the height of a column after removing a certain percentage of the maximum and minimum values. The reserve of the stockyard will be the total volume of these small columns after removing the plant structure. Finally, six outdoor sinter, coke, and flux yards have been successively equipped with the measurement system since 2016.

The profile and the reserve of the raw material yard shown in figure 1 were also needed to be digitized by the sensors. In 2019, two laser scanners were installed on #4B stocker and reclaimer in CSC, as shown in figure 13, one near the bucket wheel at the end of the boom, and the other near the middle of the boom to obtain the profile on both sides of the stockpile under the boom. After integrating the measurement system into the

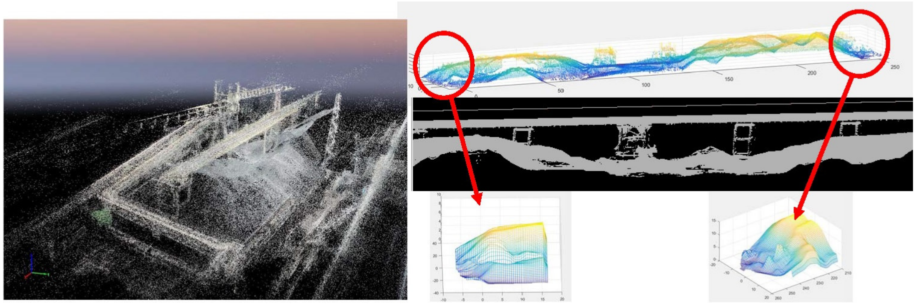

Fig.11. Multi-angle image recognized profile

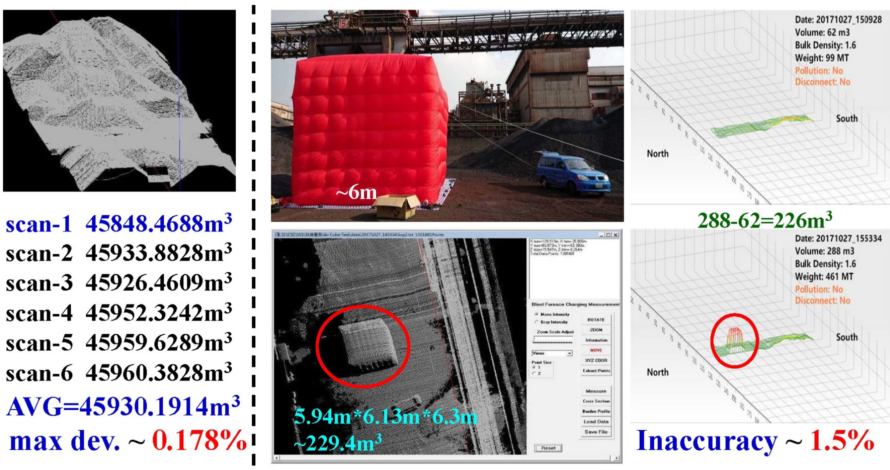

Fig.12. Measurement deviation and calculation inaccuracy validation

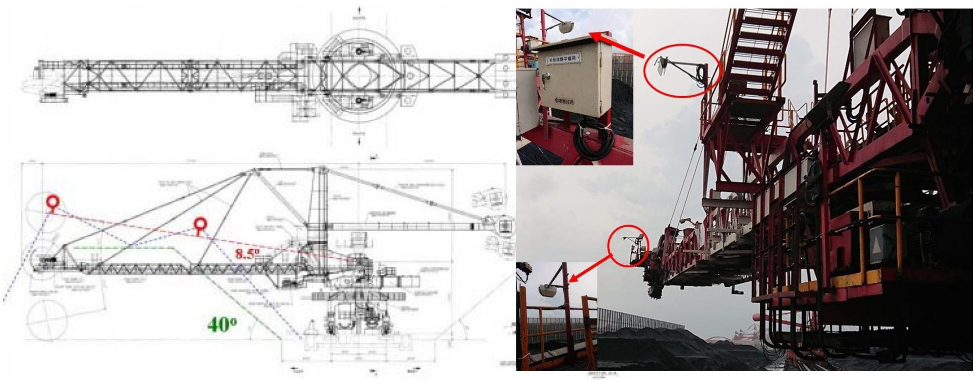

Fig.13. Measuring system on the stacker and reclaimer

coordinate system of the stocker and reclaimer, the profile under the boom was able to be measured and recorded in real time. Therefore, the stacking and reclaiming operation doesn't need to be suspended during the measurement process, and the low utilization problem of the traditional on-board stockpile scanning system is no longer required.

The diagram of the real-time raw material stockpile measuring system on the #4B stacker and reclaimer in CSC is shown in figure 14. Due to the limitation of the PLC update rate, the data from the two laser scanners was recorded with the coordinates of the stacker and reclaimer ten times per second. Since there is no structure under the boom, the 3D server only needs to define the boundary of the stockyard, then the profile constructed within five seconds can be updated to the Web Server database successively. Finally, the image update rate can be set to every minute or every hour in the Web Server according to the requirements of the operators. The profile of the stockpiles can also be integrated into the Process Server to improve the performance of stacking and reclaiming operations. The connection to the Maintenance PC was only necessary in the early stages of development.

Indoor bulk storage of raw materials has been the trend in recent years. Using the construction time of the bulk storage shed, a compact rail-guided vehicle was designed and installed outside the maintenance trail near the top of the shed to measure the profile of the stockpiles, as shown in figure 15. The vehicle moves at a speed of two meters per second, which is much faster than the traveling speed of a dumping tripper or a stacker and reclaimer. Since the use of wheel loaders to move materials during the day can also change the profile of the stockpiles, the vehicle can be set to automatically scan the entire stockyard at certain specified times of the day, or manually triggered according to the operator's request. The vehicle adopts a completely wireless design, connects to the ground through wireless communication, and charges the battery on the vehicle through a wireless charging device with a power of 300 watts. The measurement results from the vehicle were merged into the aforementioned database of the real-time measuring system installed on a dumping tripper or a stacker and reclaimer to complete the profile measurement and the reserve calculation of the stockyard.

Only by including the rail track in the design scope before the construction of the bulk storage shed, can the construction cost of the rail-guided vehicle be reduced; otherwise the construction cost of the rail track will be much higher than the vehicle itself. In 2020, two rail-guided vehicles were installed near the roof of the sinter

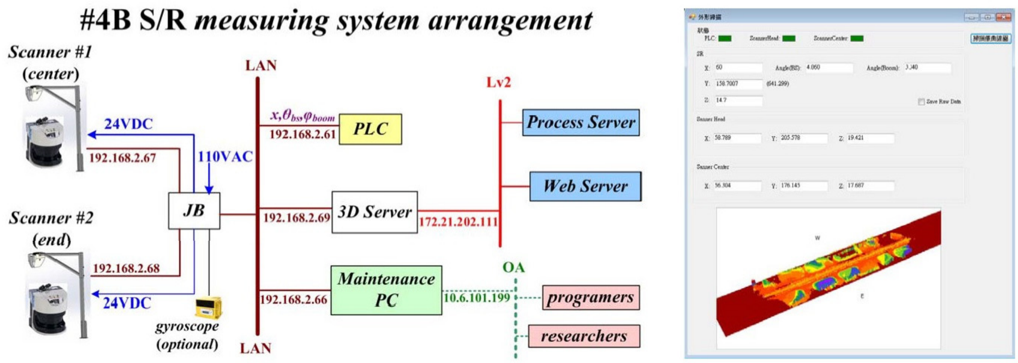

Fig.14. Diagram of the measuring system on the stacker and reclaimer

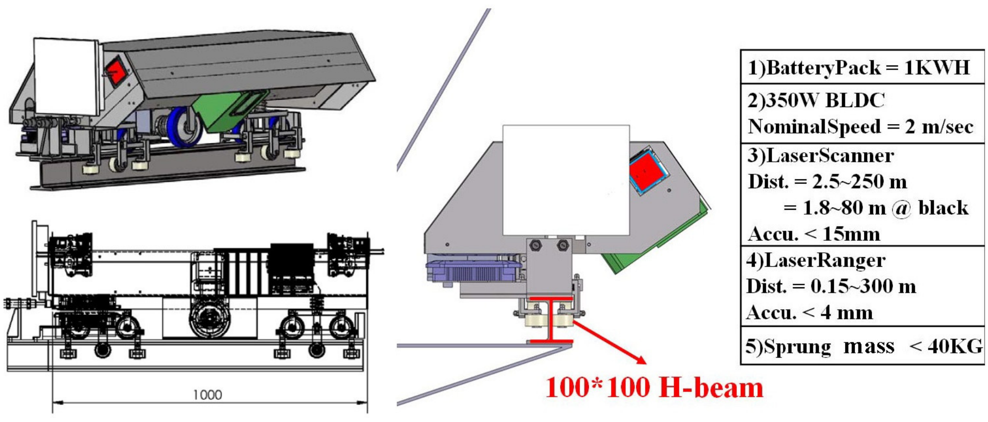

Fig.15. Compact rail-guided vehicle for the bulk storage shed measurement

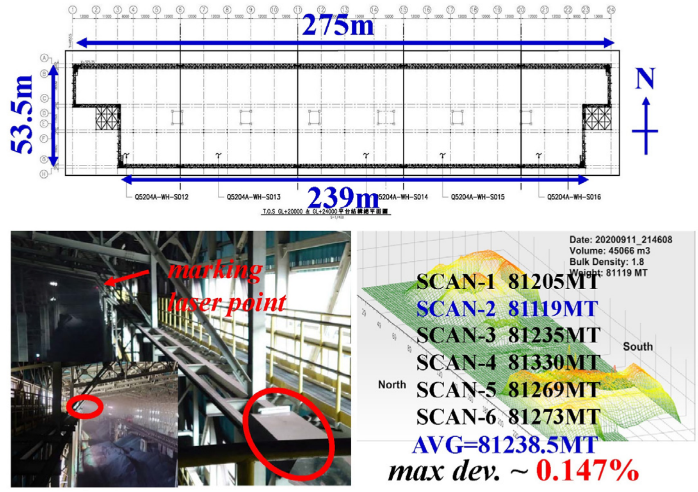

Fig.16. Arrangement and measuring results of the indoor rail-guided vehicle

storage shed in CSC, one on the north side while the other on the south side. The moving direction of the rail-guided vehicles was the same as that of the dumping tripper to obtain the profile on both sides of the stockpiles, as shown in figure 16. By repeatedly measuring the same stockpiles, the deviation of the volumetric reserve calculation was also realized to be about 0.1~0.2%, which is the same as the real-time measurement system on the dumping tripper because these two systems use the same laser scanner, laser positioning sensor, and construction algorithm.

3. CONCLUSIONS

A real-time raw material stockpile measuring system was developed in the study mainly based on the time-of-flight laser scanning technology. The image telemetry technologies were also applied to measure the profile beyond the traveling range of the dumping tripper. Since the profile was calculated based on the image features, multi-angle image recognition method may be interfered by the object's color, surface reflection or even the direction of sunlight, which makes it difficult to obtain desired measuring accuracy. A drone was once used to manually complete a profile measurement of the entire stockyard.

The three types of stockpile profile measuring applications are the dumping tripper, the stacker and reclaimer, and the rail-guided vehicle were introduced in the study to measure the profile and calculate the reserve of the stockyard to improve its operating performance. The measurement deviation of the laser scanning system was realized to be about 0.1~0.2% by repeatedly measuring the same stockpiles. The inaccuracy of the volumetric reserve calculation of the stockyard was also verified to be about 1~2% by measuring a cube of a specified size. A three-dimensional polygonal profile of the stockpiles can be visualized from the constructed voxel information of the measuring system, and also the volumetric reserve of the stockpiles can be calculated from it.

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