Research and development of automatic bulk cargo equipment in modern ports: Part 2

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Part 1 of this article was originally published in edition 40 of Port Technology International and is available for download at www.porttechnology.org under journal archives.

The abstract is provided once again as a refresher. Part 1 introduced bulk grab ship unloaders and automatic and fully automatic bulk loading bucket wheel stacker-reclaimers, jointly developed by Shanghai Port, Shanghai Port Machinery Plant, ABB (China) and Shanghai Jiao Tong University. Part 2 focuses on key technologies and methods involved in automated bulk operations including contour detection technology, materials distribution testing, optimisation of ship unloading strategy, fixed-point ship unloading, balance ship unloading, continuous ship unloading, and automation equipment operations.

Abstract
This paper describes research and development into automatic grab ship unloaders, automatic loading machines, and automatic bucket stackers and reclaimers for bulk cargo in the Port of Shanghai, which have been integrated with a multitude of advanced technologies, such as long-range detection, computer networks, automatic control, and intelligent decision-making etc. With the above integration, efficient automatic bulk loading and unloading can be implemented in the port, along with creative management and integrating control into automated operations, and establishing a solid foundation for building fully automatic bulk cargo terminals.

Key technologies
Contour detection technology
Within bulk cargo handling operations, real-time monitoring is needed, with certain rules of calculation to determine the working parameters of follow-up operations. Certain parameters cannot be measured, such as irregular bulk height, using a ruler and other such conventional measurement tools. At present, this type of data is estimated by the driver with the naked eye, or through installation of cameras, which help to monitor the situation. However, while the results of any observation will be affected by a driver’s experience, emotions, weather interference, and other such factors, it is difficult to guarantee accuracy, and incidents such as the ship capsizing, the bulkhead (end) receiving damage, or yard ground damage occurring, could easily happen if the driver is the slightest bit negligent or he loses control.

It is with this in mind that automatic contour detection technology is used in port bulk materials handling operations, which is of great value. Furthermore, automatic contour detection technology is also the major prerequisite for realising the automatic operation of feeder loading and unloading equipment, such as ship unloaders, loading machines and bucket stackers.

There are many advanced detection technologies used to automatically detect contour materials, such as photogrammetry, machine vision, laser scanning, ultrasound detection, ray detection, etc. The port of materials testing applications determines the appropriate detection technology with its own characteristics. For example, when detecting the contour of a container, a sensor is installed in a gantry crane, with detecting distance of about 2-30 m. When detecting the materials contour of a large yard, a sensor is usually installed in the yard next to fixed platforms or large-handling equipment, with a detecting distance of about 5-100 m. The larger the surface area, the greater the detection challenge, the goal being to apply efficient contour detection while ensuring accuracy. If the pick-up speed is slow, it will be difficult to meet the industrial application of real-time requirements.

As the target has a very large detection area, the amount of data detected is also unusually large. In order to meet industrial application in real-time, we must adopt efficient data processing algorithms in order to obtain results in a short period of time, and transport the results to the control system to realise automatic operations in time. For large pile material detection applications, the working conditions are usually adverse, including conditions such as vibration, shock, pollution, corrosion and electromagnetic interference. With port handling equipment, detection devices must sometimes be installed outdoors, thus the disruption caused by working conditions can be very significant. Therefore, detection systems must have a stronger anti-interference capability; otherwise it will be difficult to achieve a smooth target detection task.

Before the beginning of shipment operations, the TPS sensor (see Part 1) will scan the cabin to measure the location of the edges and the height of the hatch, and obtain the regional border operations of the shipment. In order to ensure safe and reliable shipment operations, the TPS continuously scans the cabin. The hatch height and location is measured, and in the main controller, AC800M data is kept for comparison. If the error between the two sets of data goes beyond a certain permitted scope, the measured data will replace the data of the main controller, and the cabin location change point will be displayed on the cab cabin view.

Figure 1 and Figure 2 show cabin edge detection results, which are scanned by the TPS, and show detection results when the large cart is moving. In the figures, the red box shows the cabin side, which is detected, and the green box shows the next reclaimer points, which are calculated.

In the above detection, the key data-processing algorithm is the edge recognition algorithm for two-dimensional scanning data. The analogous study has been carried out for many years both at home and abroad, and a referenced algorithm is too in-depth for our purposes. This paper focuses on solely on bulk shipment operation characteristics, and chooses a simple and efficient vertical edge of recognition algorithm based on the slope.

Firstly, as the berthing ship’s tonnage is more than 1,000 tonnes on the bulk shipment terminal, most of the ships have multiple cabins. Hatch sizes are larger and square, and the edges are not
covered with anything else, thus the vertical edge of recognition algorithm based on the data points slope can be accurately identified.

Secondly, as the shipment grab’s size is very large, a safe distance between the large grab and ship bulkhead is usually set when operating. Thus, the identification accuracy demand for the hatch is cut down. Generally speaking, identification accuracy in the centimetre-level precision can meet the requirements of automatic operation.

**Materials distribution testing**

Horizontal 2-D scanning on the hull is undertaken by the TPS on the materials within the operation region, and data is obtained about the surface contour of materials. After the data pre-processing, a two-dimensional outline of the materials curve can be obtained.

After the large cart moves some distance, the scanning for the next horizontal section can be carried out, and another two-dimensional contour of the curve can be obtained. After the three-dimensional reconstruction of the number of horizontal contour curves of the cabin has been carried out, three-dimensional curves of the surface can be obtained. This surface is displayed in the course of analysis, and the driver can choose a suitable unloader strategy according to the distribution of materials.

After pre-treatment, the scanned TPS data obtains the overall rectangular coordinates of every point, stores a two-dimensional curve as the way of array, and draws two-dimensional curves.

The three-dimensional material outline surface is composed of many two-dimensional curves, as in the pre-treatment, and adjacent vertex coordinates mean a substitution method is used to deal with noise. Therefore, the number of points in each curve is the same, which can be pieced together by continuous triangular bands in the OpenGL graphics library.

For every point on the line, select the adjacent curve with the code of online follow-up to this point and the neighbourhood to form a triangle. Traversing the curve points, draw a series of triangle, which have the same line, and put a complete outline of the synthetic surface together.

In the course of auto-shipment operations, identify the next cycle of return in accordance with the pre-shipment chosen. Discharging strategists automatically detect the return location of the point and output to the controller.

When the grab is at the top of the hopper, the TPS scans the surface of bulk cargo along the hull horizontally, measuring the height of all materials. The TPS will send the measurement results to the main controller, which will then compare the actual height of the materials at the crawl point with the height of preserved cabin bottom. If the difference between the height of the security is bigger than the default values, the current crawl point can be taken as back points (determined by the shipment strategy). Otherwise, the return location is calculated by the discharging strategy, the main controller is sent the return measurement instructions to the TPS, and the TPS measures the height of the materials at this point, qualifying it as the starting position of the return point.

To avoid grab impact, materials distribution testing and return point detection are carried out when the grab returns to the top of the hopper. Considering the impact of uncertain factors such as grab crawling and materials flow, as well as collapse, the TPS continues to carry out materials distribution testing and returning points detection, in order to update stored materials data in order to ensure the efficiency and security of crawling.

**Ship unloading strategy optimisation**

According to the type and distribution of materials, the unloading ship driver can choose different ship unloading strategies. The different strategies represent selected models of ship unloading paths based on different requirements of ship unloading. Each strategy is in line with the safety rules of automation system, that is, when materials dropping from the ship reach a certain unsafe height, unloading is automatically stopped for artificially clearing operation.

**Fixed-point ship unloading**

According to the materials’ distribution graphics, the driver designates the location snatched at on the screen. Carts and cars then move to the designated point, automatically controlled by the system. This approach is less efficient because it requires drivers to select material locations each time. This strategy is similar to the traditional mode of operation by driver’s eyeballing, which is commonly used in the ship unloading end when a large number of materials distribute in the bulkhead, or when it’s unfit for other ship unloading strategies.

**Balance ship unloading**

When materials in the cabin are high in density, grabbing near the bulkhead where the centre of gravity of the stockpile is located, an increase in the inclination of the hull will result via vast scale migration. Therefore, throughout the ship unloading process, the stockpile centre of gravity must be maintained as close as possible in cabin to the vertical axis line of the hull, which maintains hull balance and prevents capsizing. This strategy is commonly used when there are excessive materials but uneven distribution in the cabin. The system automatically calculates the return-point, keeping hull balance, but dispensing with the driver’s cross repeatedly found under the fixed-point ship unloading strategy.
The balance ship unloading strategy idea is based on the distribution of material detected by the TPS, which automatically calculates optimum feed location for next time, preventing the centre of gravity of the stockpile migrating in vast scale.

**Continuous ship unloading**

According to the distribution of materials detected by the TPS, discharging is based on optimised paths. The step-by-step order is lifting, car and cart. This strategy is applied when there are excessive materials in the cabin and plane heap. The system automatically steps to the return-point in a row to unload on the snatch operating line.

Snatch paths of continuous ship unloading include:

1) Ship unloading operations begin on one side of the inboard cabin. Set different values of “n” according to different ship types and different kinds of materials. The grab buckets continuously grab “n” times in starting position

2) The cars move forward a step and continue to operate in the same way until reaching the outboard cabin

3) The carts move forward a step. The cars start from the inboard cabin and continue to grab as in the previous process until the entire cabin is discharged

Automatic loading can optimise the loading mode. Stacking operating points will be programmed automatically by the system with the choice of the driver. It could improve the quality and efficiency of loading, at the same time guaranteeing the safety of loading.

After scanning the cabin, the driver chooses the loading point row number (1-3 row), the cycle numbers and the automatic loading operations. If loading is set in the 3rd row, loading machines will load in order from the bow to stern (or from stern to bow, related to the signal given by the terminal control system), and automatically select the distance of material heap and the distance between the material heap and the edge of the cabin in accordance with the driver’s habits and the cabin size, and stack the materials according to the driver’s habit, using the boat balance as the main reference.

In Figure 4, the rectangle represents the cabin, and the circle represents the location of stacking. The number refers to the number of stacking point. According to past experience, in the loading model of the first and second rows, all material heaps are equal in weight. In the 3rd row model, materials heaps inside and outside the two rows are small, while the materials heaps in the middle are large.

### TABLE 1.

<table>
<thead>
<tr>
<th></th>
<th>Automatic grab ship unloader for bulk cargo</th>
<th>Automatic loading machines for bulk cargo</th>
<th>Automatic bucket stacker and reclaimer for bulk cargo</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stacker</td>
<td>Reclaimer</td>
<td></td>
</tr>
<tr>
<td><strong>Total working out during the test phase</strong></td>
<td>67,100 tonnes</td>
<td>50,000 tonnes</td>
<td>347,000 tonnes</td>
</tr>
<tr>
<td><strong>Automatic Scanning time-consumption</strong></td>
<td>TPS scanning ≤ 60s</td>
<td>Cabin scanning ≤ 6s</td>
<td>88,000 tonnes</td>
</tr>
<tr>
<td></td>
<td>Cart motion scanning ≤ 30s</td>
<td>Data download ≤ 22s</td>
<td></td>
</tr>
<tr>
<td><strong>Error analysis in automatic mode</strong></td>
<td>No additional error</td>
<td>No additional error</td>
<td>Scanning time for 100 m stockpile ≤ 20 min</td>
</tr>
<tr>
<td></td>
<td>Path accurate calculation ratio ≥ 98%</td>
<td>Cart motion error ≤ 0.5 m</td>
<td>Success ratio ≥ 98%</td>
</tr>
<tr>
<td></td>
<td>Cart rotation error ≤ 2°</td>
<td>Pitching error ≤ 0.2°</td>
<td>Path computing time ≤ 1 min</td>
</tr>
<tr>
<td></td>
<td>X,Y direction position error ≤ 0.5 m</td>
<td>Reactor expected height error ≤ 0.2 m</td>
<td></td>
</tr>
<tr>
<td><strong>Enhanced productivity ratio compared to manual work</strong></td>
<td>3.12%</td>
<td>6.38%</td>
<td></td>
</tr>
<tr>
<td><strong>The auxiliary raise ratio by reducing the auxiliary time</strong></td>
<td>5.37%</td>
<td>1.46%</td>
<td></td>
</tr>
</tbody>
</table>
“Circulation number” refers to the amount of times a material heap can be completed in the calculated position; the default value is one time. If greater automatic tonnage loading is encountered (more than 8,000 tonnes), setting the cycle number as one or two will be more conducive to maintaining the balance of the vessel in the course of operations. “Shipment load” is the load gross of automatically loading. The driver can choose any automatic shipment load from 10 per cent to 100 per cent of the entire shipment task, setting 10 per cent as the step value. This feature will make the whole automation process more flexible and safe.

**Automation equipment operations**

This project began debugging in February 2007. So far the equipment and automation systems are running in smoothly as the system is continuously improved. From January to June 2008, three automatic facilities operated well with a total tonnage of 552,100 tonnes. The specific situation is shown in Table 1.

**Summary**

The automatic grab ship unloader, automatic loading machines, and automatic bulk cargo bucket stacker and reclaimer described above, have brought about automatic bulk cargo loading and unloading operations, as well as automatic control and management for the first time in the world. The overall system performance tests show that automatic operations compared to manual work significantly improve efficiency. Operators substantially reduce labour intensity, while mechanical reliability and security provide a powerful guarantee. At present there is still a lot of in-depth study to be carried out.

Of course, we have just carried out an exploratory study. There still remain some topics that need to be looked into more deeply or touched on in the research field. For example: how to play perfectly the functions of an automation system; the coordination of human–computer interaction; security measures to further improve the system’s operational safety and reliability, etc.

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**ABOUT THE AUTHOR AND THE COMPANY**

**Bao Qifan**, Professional Senior Engineer, Vice President of Shanghai International Port (Group) Co., Ltd. During his work experience, he has lead his S&T team to actively conduct self-innovation and integrated innovation, and to apply digitalisation, intellectualisation and informationisation on continuously updating the core competitions of Shanghai Port. Since 1981, Mr. Bao Qifan and his colleagues have successively finished more than 120 S&T projects in which they were awarded three State Invention Medals, three State S&T Advancement Medals, eighteen S&T Advancement Medals at Ministry or Province levels, and twenty-four Gold Medals in International Invention Fairs held in Paris, Geneva, USA, Brussels and etc.

**Shanghai International Port (Group) Co., Ltd.**, is the exclusive operator of all public terminals in the Port of Shanghai. Incorporated in January 2003 by reorganising the former Shanghai Port Authority, SIPG is a large-scale business conglomerate specialised in the operation of port and related businesses.

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