Development of Hoisting Load Position Sensor for Container Handling Cranes

We developed a position sensor used a 3-element laser target and CCD cameras that detected 2-dimensional positioning (trolley travel position and gantry travel position) of hoisting load, and used the sensor for automatic operation of rail-mounted gantry cranes (RMGCs) in Hong Kong from 1996. The detection principle involves image processing. CCD cameras on the trolley image the laser target on the spreader. The image processing unit (IPU) detects pixel positions of the laser target. We then calculate 2-dimensional hoisting load positioning with the hoisting load height. We now use a 9-element laser target for RMGCs that has high stability in hard rain.

1. Introduction

In recent years, high speed and automation have been promoted to provide higher efficiency for container handling in cranes handling containers such as container cranes and transfer cranes. To bring about automation in these cases, it is important to detect the positioning of hoisting loads accurately.

In 1996, Mitsubishi Heavy Industries, Ltd. (MHI) developed a hoisting load position sensor using a 3-element laser and CCD cameras that highly detected the 2-dimensional positioning (trolley travel position and gantry travel position) of hoisting loads and has expanded the application to the automatic operation system used for RMGCs.

This sensor detects laser light sources mounted on the spreader using 2-dimensional CCD cameras installed on the trolley. Performance and reliability have been highly evaluated by users. So far, the system has been improved to 9-element laser light sources, securely realizing high accuracy position detection even in atmospheres subject to heavy rain, and continues stable and high efficient operation based on the technology of anti-sway and positioning technique used for the above-mentioned RMGC automatic operation system.

2. Hoisting load position detection method

The method of controlling the position and sway of hoisting loads began from pattern anti-sway control where crane motions are physically modeled and the trolley is moved by a trolley travel command. Now this has evolved into the accurate position of the hoisting load detecting feedback anti-sway and positioning control, which controls sway and position. Here, the method of the load position of the hoisting load used in the crane in MHI is shown and also the functions required for automation are examined.

2.1 Hoisting load position detection method and problem

Table 1 shows the hoisting load position detection method used by MHI. In the beginning, accelerometers were used for controlling the anti-sway during manual operation. However, this method involved the following problems:

(a) Resistance to vibration and shock caused by the hoisting loads being landed was insufficient.
(b) It was impossible to secure absolute positioning for the landing target position on the ground.

Consequently, this method has now become almost obsolete. Later, as semiconductor technology advanced, highly accurate 2-dimensional CCD cameras, PSD cameras and high-speed image processing devices were applicable. In addition, semiconductor lasers and high-output light emitting diodes (LEDs) became inexpensive. As a result, the use of detectors comprising 2-dimensional CCD cameras or 2-dimen-

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sional PSD cameras combined with laser light sources or LED light sources that can detect hoisting load position in trolley travel and gantry travel directions has begun. The reasons why light sources are used for such detection are as follows:
(a) It is difficult to detect the hoisting load position from natural images.
(b) It is possible to reduce positional restraints when the detection target is made smaller.
(c) Hoisting load positioning and anti-sway accuracy during container handling

The key to the above-mentioned positioning accuracy is detection accuracy of the hoisting load position sensor. In addition, it is necessary to control all the functions in automatic operations using the information from hoisting load position sensor while the existing anti-sway control has an assistance function for the manual operation. Consequently, the reliability required for the sensors becomes greater incomparably. Taking into account these considerations, hoisting load position sensors used for automation require the following functions:
(1) Detection function of absolute hoisting load position against the ground
(2) Highly accurate 2-dimensional position detection function of several mm covering the whole range of detection
(3) Detection reliability under every environmental condition and for long-term use

3. Laser light source type hoisting load position sensors

As discussed in Chapter 2, MHI is adopting hoisting load position sensors that use laser light sources with higher accuracy and 2-dimensional CCD cameras to meet the functions required for automation. The details of these sensors are as follows:

3.1 System formation

Fig. 1 shows the arrangement of 2-dimensional CCD cameras and laser light sources forming a hoisting load position sensor. Fig. 2 and Fig. 3 show the formation of an image processing device and the laser light sources using 9 semiconductor lasers, respectively. To realize highly accurate position detection, two types of 2-dimensional CCD cameras (two on the left-hand side and two on the right-hand side), one wide-angle camera covering the whole sway angle of the
hoisting load and another narrow-angle camera detecting position with high accuracy are used, with all the cameras operated synchronously to remove errors due to the differences in detection timing. In the laser light sources, a total of 9 semiconductor lasers are arranged at intervals of 10 mm to provide countermeasures against scattering caused by water droplets.

In addition, stabilized detection luminance is attempted by adopting narrow band-pass filters covering plus or minus 10 nm on the side of the camera, and by adding an automatic diaphragm function to the image processing device to automatically control the electronic shutters of each camera.

(1) Basic performance

Table 2 shows the basic performance of the hoisting load position sensor. When narrow-angle cameras are used, highly accurate detection of about 4 mm in trolley travel direction is realized.

In addition, in the detection algorithm of the image processing device shown in Fig. 2, declined detection accuracy due to the removal of the disturbance of sunlight and declined detection accuracy due to the increase in the number of laser elements in laser light sources are prevented by the adoption of a detection window setting function. This is based on the center of gravity function, to calculate the central position of the light sources from plural light source positions and the detection position tracking function.

Furthermore, the image processing shown in

![Fig. 3 Photograph of laser target](Image)

This photo shows the outside appearance of the multi-point type laser light source developed this time.
Fig. 2 has been mostly made in electronic circuits. By this, the detection period has been accelerated to 1/30 second, one-half of the existing period.

(2) Reliability during rainfalls

The laser light sources used for the RMGC for a period of four years from 1996 were of the 3-point type. However, to secure reliability during heavy rains, the present laser light sources are of the 9-point type. The spraying test shown in Table 3 was carried out to verify the reliability of the 9-point type laser light sources during heavy rains. The results of the spraying test shown in Fig. 4 tell us that the effect of an automatic diaphragm function using 9-point type laser light sources and electronic shutters nullifies the frequency of the occurrence of disabled detection, and greatly improves reliability during heavy rains.

4. Application to RMGC and actual results

Hoisting load position sensors have been applied to RMGC automatic operation systems since 1996 and have supported round-the-clock operation with high performance and reliability. Since September 1999,
image processing devices provided with 9-point type laser light sources and automatic diaphragm function have been continuously applied to RMGC automatic operation systems. Now, we will introduce the operating conditions. As shown in Fig. 5, this RMGC is a crane dealing with storage of 6 tiers × 12 rows, moving with a lift of 22 m and a trolley travel distance of 46 m. The 2-dimensional CCD cameras and laser light sources forming the hoisting load position sensor are mounted on the trolley and the spreader. During the automatic operation of this crane, container handling is fully automatic except for final cargo catching and releasing on a truck. Basic container handling by automatic operation includes container handling between the storage yard and trucks, and container transfer inside the storage yard. To realize these operations accurately and safely at high speed, advanced control such as optimum operation trajectory control and landing prediction control, is necessary in addition to highly accurate hoisting load position detection. The following shows the role of this hoisting load position sensor under the advanced control and performance in the actual container handling.

### 4.1 Landing prediction control and hoisting load position sensor

To unload containers into a valley of containers with 6 tiers as shown in Fig. 5, exact stacking of the containers is necessary. In particular, in the RMGC shown in Fig. 5, containers on the first tier required container landing accuracy within plus or minus 50 mm including the mechanical errors of the crane. Such highly accurate landing of loads involves the following problems:

- (a) Sway produced by wind disturbance occurs.
- (b) Sway period becomes longer and it takes time to damp sway because sway is generated at the long position of the rope length, sway is out of the allowable accuracy immediately before landing and the condition that landing accuracy cannot be satisfied occurs.

To solve these automatic operation system problems the position of the hoisting load after the time required for lowering the load until landing is estimated at position 3 in Fig. 5 from the phase and amplitude of the present sway, and the load is finally lowered at a timing that falls inside the setting range.

Here, the most important key technology is highly accurate and stable hoisting load position detection. It is generally said that position detection accuracy, in particular, must be less than one tenth of control performance. These RMGC specifications require an accuracy of plus or minus 5 mm. In that respect, this hoisting load position sensor has realized detection accuracy of plus or minus 4 mm at the height required, estimated control (distance between 2-dimensional CCD camera and laser is about 24 m) and fully satisfied the requirements of control.

Fig. 6 shows the test results of the first tier container landing accuracy using this floor landing control. During this test, automatic operation was repeated on several operation trajectories, and the errors between landed containers and the ground targeted position were measured at this time at the 40-foot container end position. As this figure suggests, 81 landing operations were fully executed within plus or minus 50 mm.

Furthermore, more than 80% are within the high accuracy range of plus or minus 20 mm, showing that the absolute position detection of hoisting loads for ground targeted position has been accomplished with high accuracy. In addition, even after laser light sources have been improved (increase in the number of elements) for the purpose of securing improved reliability during rainfall, realization of highly accurate hoisting load position detection has been verified also on the actual devices in a practical scale.

### 4.2 Stability during spraying tests using actual devices

The improvements in hoisting load position sen-
Fig. 7 Measurement of sway for spraying test at RMGC

The results of hoisting load sway detection during spraying tests using the actual devices assuming heavy rains are shown.

The hoisting load position sensor we are introducing this time were applied to one of 24 RMGCs in September 1999. During the application, a confirmation test was made throughout actual 24-hour operations for a period of one month after a basic adjustment was made. Immediately before actual operation was started, sway tests were carried out assuming local heavy rains to finally verify the reliability of the hoisting load position sensors. The anti-sway was carried out under conditions where the laser light sources on the spreader were sprayed from a fire hydrant.

Fig. 7 shows the waveforms of sway detection by the hoisting load position sensor at this time. Despite the fact that, from the conditions of the sway applied this time, the light sources on the spreader were entirely invisible to the naked eye, the position was detected correctly and anti-sway control was completed without any problems. Also during practical operation after these tests, RMGC continued smooth operation without any serious problems.

5. Conclusion

The hoisting load position sensor we have introduced this time has not only realized highly accurate absolute position detection for the ground target position but also verified stabilized outdoor operation from the actual results of four years of actual container handling by RMGC and improvements made in the interim. MHI intends to continuously promote highly efficient container handling through automation based on this sensor as a core.