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Kunihiko Nishibe and Naofumi Fujiwara

Abstract-- An automatic steel coil recognition system with two types of laser-assisted range sensor has been developed for full automated crane operation in the steel coil yard. Performance tests of recognizing full scale model coils were carried out by mounting the recognition system on a full size crane. As a result, recognition accuracy of coil center position, coil diameter and width were confirmed to be ±20mm, which is enough for practical applications. This recognition system was delivered to commercial operations in the steel maker, and has been operated regularly.

Index Terms—Recognition, shape measurement, laser, measurement and control, automated crane, steel coil transportation, automation, crane operating controller, trailer truck

Introduction— In order to reduce the operation cost of the overhead traveling crane for various industries, such as steel production industries, cement resource factories and garbage furnace facilities, full automated operation has been expected. For this purpose, various full automated crane has been developed and in operation.

This paper describes the newly developed automatic steel coil recognition system in the steel strip coil yard. Fig.1 shows the typical coil yard, where coils are transported from a trailer truck to the stock yard, or to the process line. In order to pick the coils up from the truck automatically, it is necessary to sense the number, their positions and dimensions of the coils placed on the truck.

Several types of recognition systems have been developed and operated commercially. One of the most popular system is to use the computer image processing technology[1], [2]. However this is rather expensive and is very sensitive to the surrounding noise of strong light. Another system is to detect reflecting light from small mirrors putting on the coil-rack of a truck[3]. This system has a merit of low cost. But, on the other hand, it has a inherent demerit of extra expense of keeping mirrors clean.

In this study, laser-assisted range sensors are adopted. Infrared or red laser is used to protect the surrounding noise of light. Scanning the laser spots on the coils and trailer truck deck, we can get large number of the distance data between the coil surface and the sensor. Using these data, the coil position, its diameter and width can be easily computed using a microcomputer.

1. Laser-assisted range sensors

Fig.1 shows a typical full automated crane system in the coil yard. Concerning to the coils on the truck,

(1) the position error of the truck should be allowable maximum ±200mm, because the trailer truck is positioned manually,
(2) several coils of different axial-direction might be loaded together,
(3) and number of coils are not fixed. About 2~4 coils are loaded on the trailer truck.

The coil recognition system should work to meet the above conditions.

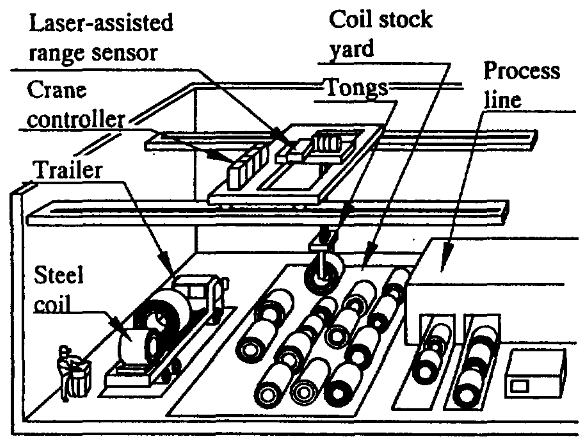

Fig.1 Automated crane system in steel coil yard

In Fig.2, two types of coil recognition system which we developed are shown. The type(a) can be applied to the case of "loading coils of different-axis" or to the general case. In this case, we use the range sensor of swing-type(sensor(A)). On the contrary, type(b) can be used only in the case where all the coils are put to

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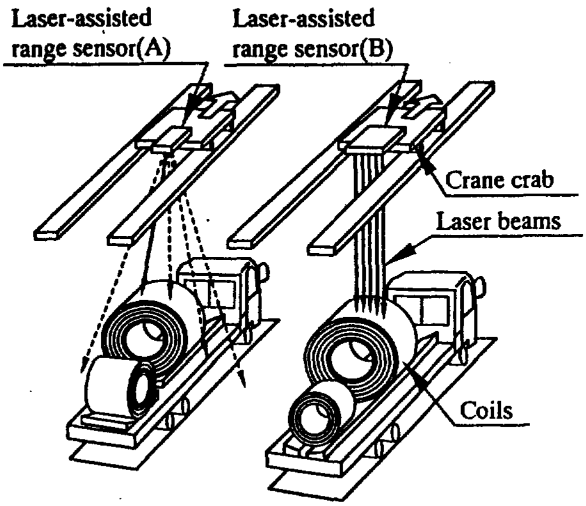

Fig.2 Procedure of automatic coil recognition using laser-assisted range sensor

the longitudinal direction. We adopt, in this case, the 5-beam laser-assisted range sensor(sensor(B)).

Table 1 shows the specification of these two range sensors.

Table 1 Specification of laser-assisted range sensor(A) and (B)

	Swing-type sensor(A)	5 beam-type sensor(B)
Number of laser oscillators	1	5
Dimension(mm)	800W×500D×300H	1,300W×700D×300H
Data acquisition period	1(ms)	16.7(ms)
Data sampling time by crane	60(s)	20(s)
Application (coil loading direction)	Coils both longitudinal and orthogonal	Coils only longitudinal to a truck

In Fig.3, the measured distance errors obtained by the sensor(A) are shown. We can understand that the measured distance errors are within ±3mm in the case where the distance from the sensor to the target is 6–11m.

2. Recognition process with a laser-assisted range sensor(A)

2.1 Principle of coil profile measurement Fig.4 shows the principle of measuring coils profile. The sensor(A) is composed of a CCD-image sensor and a single laser oscillator whose beam is forced to swing with rotating mirror as shown in Fig.5. The resolution of the rotating mirror encoder is designed to be 0.00816°.

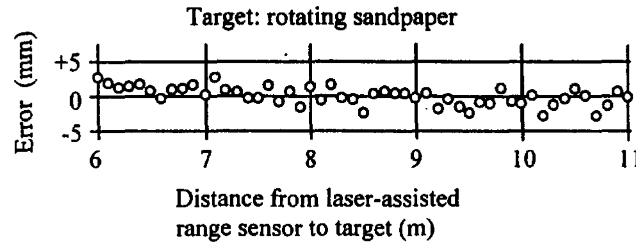

Fig.3 Measured distance errors obtained by the laser-assisted range sensor(A)

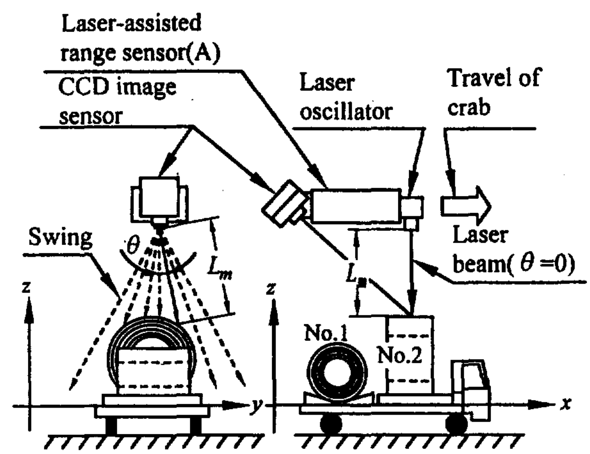

Fig.4 Principle of height distribution measurement using laser-assisted range sensor(A)

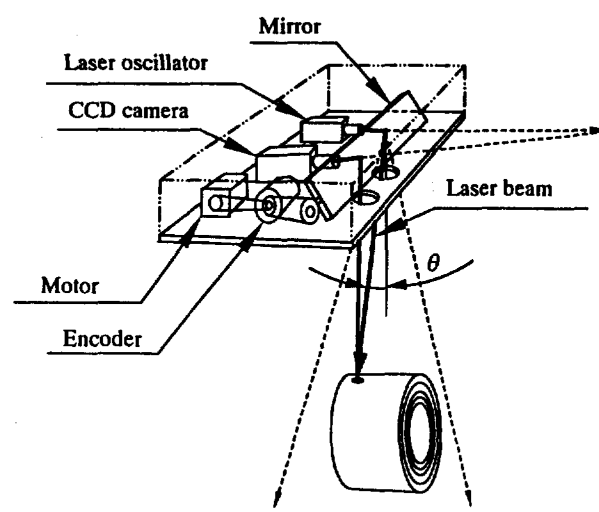

Fig.5 Schematic view of swing-type sensor(A)

The laser beam is shot toward the surface of the coils or the trailer truck. The reflected beam is focused on the CCD-image sensor. With the well-known method of triangulation[4], the distance(L_m) from the sensor(A) to the spot can be calculated. In order to get the coil profiles, following two steps are taken:

(1) Step1: The sensor(A) mounted on the crane crab is forced to move from left to right toward x-axis, without swing the laser beam (swing angle is keeping θ=0). The data acquisition period is set to 1ms(1,000 times per second). Then, the L_m distribution data are stored in the memory of the microcomputer. By this completion of scanning, we can confirm number of the coils, the direction, width (or diameter) and the "center" positions of x-axis of the coils.

(2) Step2: The sensor(A) is forced to move back to the "center position" of an each coil. At this position, we get swing angle θ and L_m distribution data with making laser beam to swing. From the data set obtained, we can easily get the information of the center position of y-axis and diameter(or width) of the coil.

2.2 Algorithm of recognition Fig.6 shows the coordinates system in this case. In this figure, the mark • denotes sampling points on the coil surface and the mark o denotes points outside of the coil surface. The another mark × indicates the points from which reflected laser beams can not be observed from a CCD-image sensor.

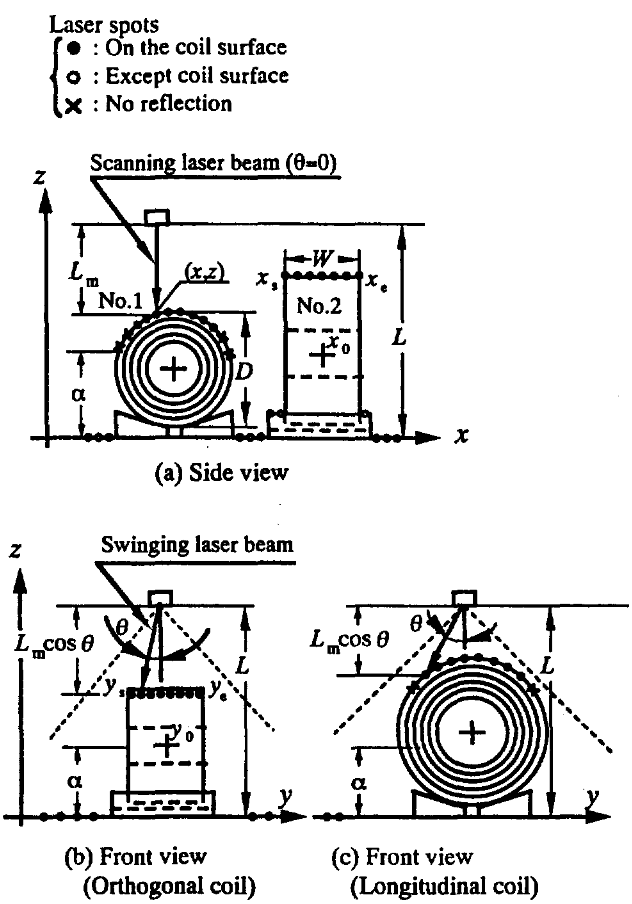

Fig.6 Coordinates system in case using laser-assisted range sensor(A)

In order to eliminate the data outside of the coil surface, the following process of computing is performed:

(1) At the beginning, on the x-z plain((a)side view), using L which is the distance between the top surface of the trailer and the sensor(A) determined previously, we transform z axis into new one as follows:

$$z=L-L_m \tag{1}$$

Next, in order to eliminate the data outside of the coil surface, we introduce threshold α and adopt all the data that is satisfying Eq.(2).

$$z\geq\alpha \tag{2}$$

Threshold α should be determined on the basis of the minimum coil diameter. For instance, when the minimum coil diameter is 700mm, it would be sufficient if α is determined to 500mm.

(2) For the number 1 coil, we can determine the coil diameter and its center position using the data satisfying Eq.(2). First, we choose the three different points data set(x_1, z_1), (x_2, z_2) and (x_3, z_3). These points would exist on a circle, the center coordinate (x_0, z_0) can be given by

$$x_0=\frac{(z_1-z_3)\cdot P^2-(z_1-z_2)\cdot Q^2}{2\{(x_1-x_2)(z_1-z_3)-(x_1-x_3)(z_1-z_2)\}} \tag{3}$$

$$z_0=\frac{(x_1-x_3)\cdot P^2-(x_1-x_2)\cdot Q^2}{2\{(x_1-x_3)(z_1-z_2)-(x_1-x_2)(z_1-z_3)\}} \tag{4}$$

where,

$$P^2=x_1^2-x_2^2+z_1^2-z_2^2,\quad Q^2=x_1^2-x_3^2+z_1^2-z_3^2. \tag{5}$$

Using Eq.(3) and (4), the diameter D of this circle is given by

$$D^2=4\{(x_0-x_1)^2+(z_0-z_1)^2\} \tag{6}$$

We can obtain sufficient number of the center coordinate and the diameter, using another three different points data set. And the recognition accuracy will be improved by averaging them (refer chapter 4.).

(3) For the number 2 coil, the data can be judged to be of small dispersion. Then, we can understand the coil axis is directed toward x-axis. The x-coordinate x_s of the edge position is obtainable by finding the first data satisfying Eq.(2). Similarly, we can determine the another edge position x_e easily. The coil width W and its center coordinate x_0 are obtained by,

$$W=x_e-x_s \tag{7}$$

$$x_0=(x_s+x_e)/2 \tag{8}$$

(4) All the data shown on the y-z plain(front view) are obtained by swinging the laser beam. In order to transform these data set(θ, L_m) into (y, z) plane, following computation is performed.

$$z=L-L_m\cos\theta \tag{9}$$

$$y=L_m\sin\theta \tag{10}$$

(5) Repeating the same procedure from (1) to (8), the coil configuration can be completely determined.

3. Recognition process with a laser-assisted range sensor(B)

3.1 Principle of coil profile measurement This system is only applicable for the case where the coils are all settled longitudinal to the trailer truck. As shown in Fig.2-(b), the sensor(B) is composed of fixed five laser oscillators and a CCD-image sensor.

Fig.7 shows the principle of measuring the coils profile. The laser-associated range sensor(B) is made to travel with crane crab scanning toward x-direction. The sampling period of this sensor is 16.7ms(60 samples per second). After completion of scanning, all data are stored in the memory of a microcomputer. The resolution of distance of this sensor(B) is designed as 2.0 to 3.2mm. The maximum sampling pitch toward x-axis is 16.7mm, and the spacing(y-direction) between each laser beam is 150mm.

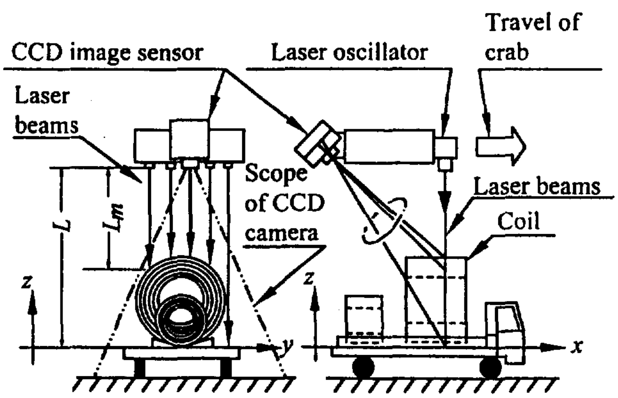

Fig.7 Principle of height distribution measurement using laser-assisted range sensor(B)

3.2 Algorithm of recognition Fig.8 shows the coordinates system in this case. In this figure, the mark • denotes sampling points on the coil surface and the mark o denotes points outside of the coil surface. For elimination of the data outside of the coil surface, the similar method to section **2.2** Eq.(1) and (2) are adopted.

(1) Calculation of coil width(W) and center coordinate x_0: First, as shown in Fig.8, all the data of z given by Eq.(2) are examined one by one toward x-direction. The position x_s where the first data of z which exceeds α=500 is found corresponds to the edge position of the coil. By the same procedure, we can easily find the another edge position x_e.

In order to determine W and x_0, we use the data x_{s-1}, x_s, x_{e-1} and x_e as follows:

$$W=(x_{e-1}+x_e)/2-(x_{s-1}+x_s)/2 \quad (11)$$

$$x_0=(x_{s-1}+x_s+x_{e-1}+x_e)/4 \quad (12)$$

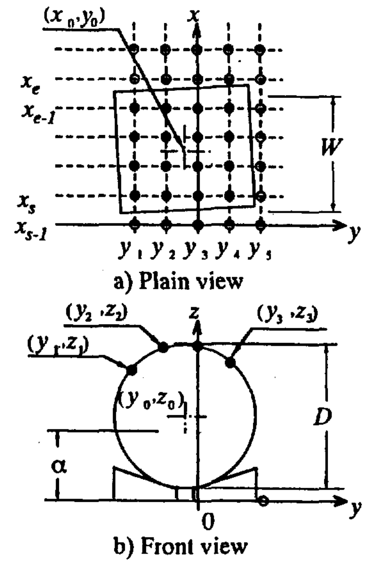

Fig.8 Coordinates system in case using laser-assisted range sensor(B)

(2) Calculation of coil diameter(D) and center coordinate (y_0, z_0): As shown in Fig.8((b) front view), we select arbitrary three points (y_1, z_1), (y_2, z_2) and (y_3, z_3) on the coil surface. These points must exist on one circle, so D and (y_0, z_0) are obtained similarly by Eq.(3), (4), (5) and (6).

4. Error

Error will be occasionally happened during the operation of coil recognition process. Typical errors which seem to occur are derived by following causes:

(1) bossing and depression edge of the coil due to the side walk of the strip during coiling,
(2) interruption with foreign obstacle (for example, flying bird or insect),
(3) disturbance of coil band, etc.,
(4) laser beam distortion by the air convection on the heated ground,
(5) measuring distance error of the laser-assisted range sensor.

In order to avoid these disturbances or errors, average treatment using histogram will be the most powerful scheme of data processing. Fortunately, in this recognition process, we get a large number of recognition data sets. Using them, we make the histogram, and average treatment is performed only for the recognition data sets where the frequency is maximum in the histogram.

(6) Bending, twisting and deflection of traveling rails of a crane crab seem to derive recognition error, therefore, these data of traveling rails are calibrated and compensated in the calculation.

5. Summary of accuracy test in recognition

Recognition system was mounted on the crab of an actual full size crane and performance test has been carried out. A typical example of a measured coil profile obtained by the sensor(A) is shown in Fig.9.

The distance distribution errors are found to be a little larger at around the top of the coil (refer to an enlarged scale graph in Fig.9). This is considered to be caused by the stronger reflected laser light, which makes CCD-image sensor excessively sensitive. However obtained maximum errors are recognized within ±5mm, which is sufficient enough for practical applications.

A series of performance tests for the coil dimensions

$$D=700\sim2{,}800(\text{mm})$$
$$W=500\sim2{,}000(\text{mm})$$

has been performed.

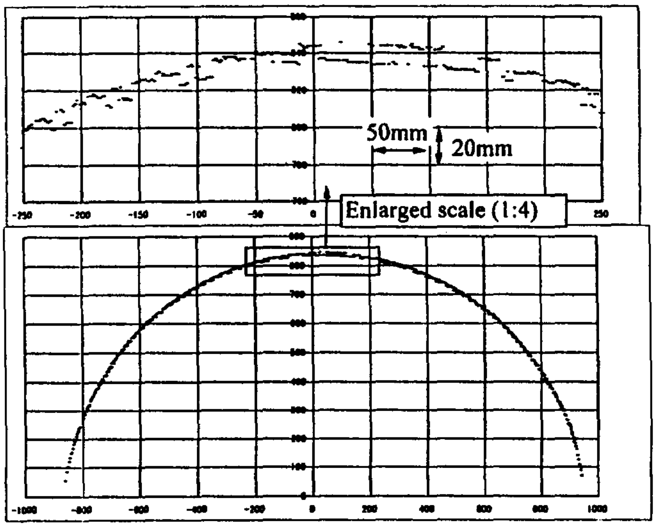

Fig.9 An example of a measured coil profile by the sensor(A)

In Table 2, we summarize the measured error regarding center coordinate, width and diameter. Here Δx_0, Δy_0, Δz_0, ΔW and ΔD denote errors of center coordinate(x_0, y_0, z_0), width W and diameter D. Recognition accuracy was confirmed within 20mm for every dimensions. This is sufficient enough for practical applications.

Table 2 Summary of accuracy test (mm)

	Δx_0	Δy_0	Δz_0	ΔW	ΔD
Avarage of error	1.7	4.1	-1.5	6.9	2.4
Standard deviation	6.1	7.8	5.4	6.2	7.7
Max. of error	18	20	16	18	17

6. Conclusions

(1) New automatic coil recognition system has been developed by using two types of laser-assisted range sensor(A) and (B) mounted on the crane crab.
(2) Performance tests were carried out for full size model coils with coil recognition system mounted on a crane crab.
(3) Performance has been confirmed to be sufficient enough for practical application. This system was delivered to commercial operations in the steel maker, and has been operated regularly.

References

[1] H. Hoshi and T. Horimoto, "Automated Overhead Traveling Crane with Image Processing System," Sangyookikai, pp.41-43, Jun. 1992 (in Japanese)
[2] S. Jikumaru and H. Akasaki, "Coil Position Detector for Automated Crane Control," 7th Symposium on Image Processing Technique for Industry, The Japanese Society for Non-destructive Inspection, pp.163-167, Jun. 1992 (in Japanese)
[3] Y. Yoshida and K. Akamine, "Future Trend on Technology of Crane Control(2)," Crane, vol.25, No.11, pp2-10, 1987 (in Japanese)
[4] P. J. Besl, "Active, Optical Range Image Sensors," Machine Vision and Applications, vol.1, pp127-152, 1988

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