2014 14th International Conference on Control, Automation and Systems (ICCAS 2014)
Oct. 22-25, 2014 in KINTEX, Gyeonggi-do, Korea

# Remote Position Detection of Steel Coils Using 2D Laser Scanners : Two-line-tracker

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**Abstract**: It is important to measure the position of steel coils, especially when automatically transporting them by crane in the relevant industry. To realize a fully automatic coil transporting system, the positions of coils relative to the crane must be measured accurately. This paper introduces a measurement system that can detect positions of the target coil with high robustness and accuracy using 2-D laser sensors. The proposed system can derive the radius, length of a coil, which can be in various sizes, without using any prior informations about the coil. Based on the detected dimensions of the target coil, the sensor system can calculate the positions of coil in real time from a remote distance. The performance of the system is validated through experiments conducted on actual coils, which showed that the precision is within 30mm from a distance range of 5 meters.

**Keywords:** Target tracking, robust sensing, positioning algorithm, and 2-D laser scanner

## 1. INTRODUCTION

Coil transporting automation has been treated as interesting issue in the industry. Because of excessive labor inputs and time inefficiency of conventional coil transporting system, the coil transporting automation would be able to minimize the price on coil transportation. To construct a solid system of coil transporting automation, sensing a coil's position is a key technology for the overall automation system.

The remote three dimensional position measurement system is one of the main issues of the target tracking field. Target tracking is commonly necessary for automation system [1]. One application of such measurement system is a yard coil crane automation [2] (Fig. 1). As steel transported in the form of coil in the steel industry, numerous amount of coils is transported to many manufacture plants. Still, coil transportation needs much human power. An issue of yard coil crane automation is how to measure the position and size of a coil.

In order to be adopted in the coil transporting automation system, the desired characteristic of the coil position tracking is real-time, no marker, robust and sub-cm accuracy at 1m. Such technologies, able to sensing remote 3-D position in real-time, have been reported such as laser tracker, radio frequency (RF) sensor, DGPS, vision camera, 3-D laser scanner, and 2-D laser scanner. DGPS, laser tracker and RF have high accuracy of sub-mm level [3] but they are inadequate for coil detection because they need object marker on target surface. Vision camera is a common method for target object tracking [4], but its performance is sensitive to weather condition and optical disturbance to be used for outdoor measurement. Therefore, the sensor is not applicable on maritime works.

On the other hand, a laser sensor, especially 2-D laser scanner is robust and accurate and used in industrial filed commonly. Most of applications using 2-D laser sensors are mobile obstacle navigation [6-8]. Another application is positioning of object problem [9], [10].

This paper proposes a position sensing system using 2-D laser scanner to apply on coil lift automation system. The proposed method is measuring the position of a coil directly for mid-range application. The virtue of the proposed method is robust and fast for outdoor application by using 2-D laser scanner and appropriate positioning algorithm for cylindrical object. The performance of the sensor is validated on static condition at a distance within 5m using miniature coil model and real coil. The validation would show a potential application of 2-D laser scanner as robust and accurate tracking using surface model, especially cylindrical object. The paper is composed by following order. In System Description, the target sensing system and the sensor unit would be specified. In Sensing Algorithm, three steps of processing the sensing data would be proposed. In Experiment, miniature model test and real-size model test results would be analyzed.

## 2. SYSTEM DESCRIPTION

The sensor unit, called Two-line-tracker, is composed of two 2-D laser sensors. A laser scanner is arranged perpendicularly not to disturb sight of the other (Fig. 1). The horizontal sensor detects a line between edges in the direction of coil width and the vertical sensor scans the perpendicular, radius direction of coil. Two-line-tracker is attached to crane's head. (Fig. 6) A 2-D laser sensor (SICK LMS511-10100) uses invisible laser which radiates a beam at 905nm to be eye-safe and insensitive to surface reflection and weather condition [11]. Its data are gathered by Ethernet protocol [8]. The sensing algorithm is structured in real time C++ MFC program.

Target object is a cylindrical coil. Its radius and width are approximately 0.6m and 1.2m, respectively, and the inner radius is 0.2m (Fig. 2).

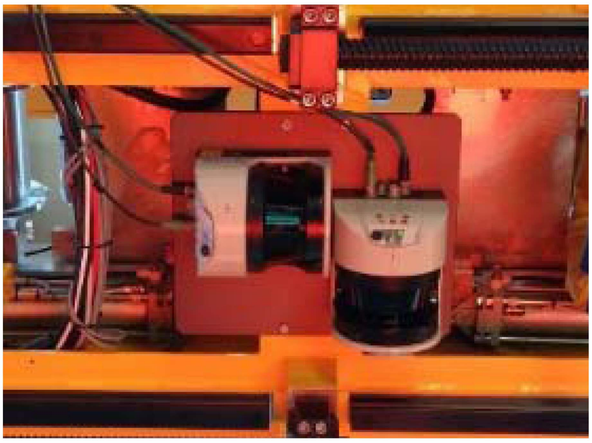


Fig. 1 Perpendicular arrangement of installed sensors

Fig. 2 a) Cylindrical coil and b) the experiment model

## 3. SENSING ALGORITHM

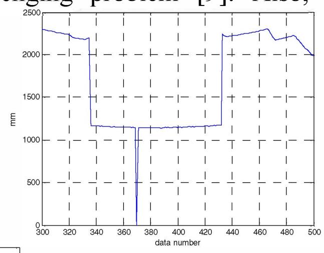
Two 2-D laser scanners detects two lines on coil surface. The sensor algorithm processes the two lines of data to coil position and other outputs. Outputs of Two-line-tracker are a) 3-D position of the coil's center, b) two edges of the coil, and c) the radius of the coil. As assumed that crane and coil are always parallel, the sensing method does not consider angular displacement of the coil.

### 3.1 Signal processing

Outputs of 2D laser sensor are a distance from its center and each distance's angle. A motor driven mirror rotates at 25Hz and gives a distance value at every 0.25 degree on -5° to 195°. It means 761 values of distance are obtained at every 0.04 seconds. Although a 2D laser sensor is robust to optical effect, it is not inevitable to avoid optical disturbances. Because a wrong sensing value looks like a spark, the phenomenon is called "spark" and the spark happens a lot on a long-time operation. Therefore, it is recommend to use a filter for the raw data. The used filter is third order median filter and some minor modifications has used (Fig. 3).

### 3.2 Edge detection

One of the major issues of using 2D laser sensor as position detector is edge detection. Because a laser spot is more blur as the distance longer, accurate edge detection is a very challenging problem [9]. Also, angular



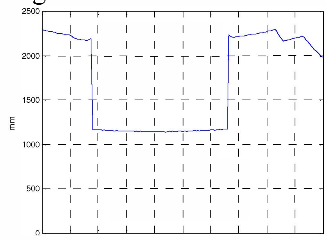




Fig. 3 a) spark of sensing-distance and b) filtered data

resolution limits the accuracy of edge detection. As the angular resolution is 0.25°, edge detection resolution approximately converges to 4.4e-3 d (d: distance from sensor's center). At the distance of 5m, the resolution of edge detection is 21.8mm and its radius of laser spot is 29.8mm. It can be inferred that the accuracy of edge finding is approximately between 21.8mm and 29.8mm.

Three steps are used for edge detection. First step uses point to point differentials to find left and right edges. It fast scans first virtual edges from checking whether differentials of nearby two points exceed a certain threshold value. Second step uses a line fitted using the points within 3/4 of the points between first edges. It is important discard 1/4 of inner points between first driven edges to find more accurate line. The points far from the line are regarded as outliers and removed and the points within a specific distance, triple of standard deviation in this case are considered as valid points and remained. Third step is continuity check which starts from the midpoint among valid points to ± 1m to achieve robustness from obstacle passing through the sight of sensor to the target.

### 3.3 Positioning algorithm

Through finding edges, two kinds of points are able to be achieved - a) left and right edges of width direction and b) two perpendicular lines of points on coil's surface. Two points and two red lines in Fig. 4 are interest 2-D scanner sensing area.

Due to every points are on surface of the cylinder, following cylinder equation can be driven (Eqs. (1) ~ (3)) with an assumption that both coil and sensor unit are parallel to the earth surface.

$$(x-a)^2\sin^2\theta+(y-b)^2\cos^2\theta-(z-c)^2, \\ -2(x-a)(y-b)\cos\theta\sin\theta=R^2 \tag{1}$$

$$(x_{left}-a)\cos\theta+(y_{left}-b)\sin\theta=-W\,, \tag{2}$$

$$(x_{right}-a)\cos\theta+(y_{right}-b)\sin\theta=W\,, \tag{3}$$

The notation of P(x, y, z) is a 3-D xyz-coordinate of a point on the coil surface. The direction of x is parallel to the laser scanner 1 and the direction of y is parallel to the laser scanner 2. The direction of z is depth distance from the sensor unit. The values of a, b, c, R, W, and θ are desired measurement outputs. a, b, and c is the 3-D xyz-coordinate position (a,b,c) of the cylinder center. R is the radius and W is the width of the coil. The notation θ is yaw angle of the coil.

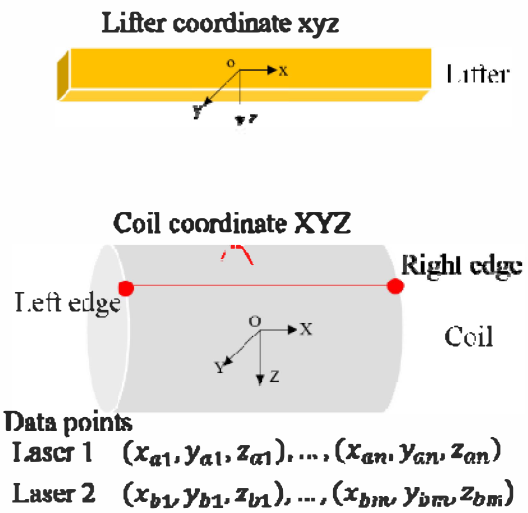



Fig. 4 three-dimensional sketch of the coordinate relationship between the lifter and the coil

As seen in Eqs. (1) and (2), the width of a coil (W) can be computed from only two edges. Moreover coil's x-direction center coordinate, a, is dependent on it of edge values when yaw angle (θ) is near zero and it is in real case. Therefore, the equations can be simplified as following.

$$(y-b)^2 \cos^2\theta - (z-c)^2 = R^2, \tag{4}$$

$$(x_{left} - a) = -W, \tag{5}$$

$$(x_{right} - a) = W, \tag{6}$$

With this result, it is possible for outputs to be computed using linear least square method.

## 4. EXPERIMENT

### 4.1 Miniature model test

Due to convenience of small size coil to verify the method indoor, the miniature model has made. The size of miniature model is approximately 1/3 of an actual coil. All sensor directions are calibrated by checking line of sights at 2m and 5m distance. Experiment is conducted with the miniature to validate that the proposed position sensing algorithm is accurate enough to track the position of coil and compute the size of the cylindrical coil on static condition (Fig 5). The accuracy bound of the experiment is shown in Table 1.

Table 1 Error bound of the miniature model experiment at 2m and 5m distance

| | a | b | c | R | W |
|---|---|---|---|---|---|
| 2m | ±4 mm | ±7 mm | ±3 mm | ±7mm | ±11mm |
| 5m | ±9 mm | ±9 mm | ±5 mm | ±9mm | ±27mm |

The result shows the accuracies of a, and W are quite dependent on distance, while, the accuracies of the others are not sensitive to distance because x-direction position is directly related to edge points. The error bound is acceptable for the coil transporting application.

Fig. 5 Miniature model tracking experiment

### 4.2 Lifter - coil dynamic test

To verify the proposed algorithm works in actual working environment (Fig. 6), three actual size models are made. The radius of coil model is 0.6m and each the radius to width ratio are 1:1, 1:2, and 1:4. The purpose of the experiment is that the suggested method works real-time on the condition of existing relative motion between the coil and the lifter. The sensor unit is on the lifter's top and facing to upper coil.

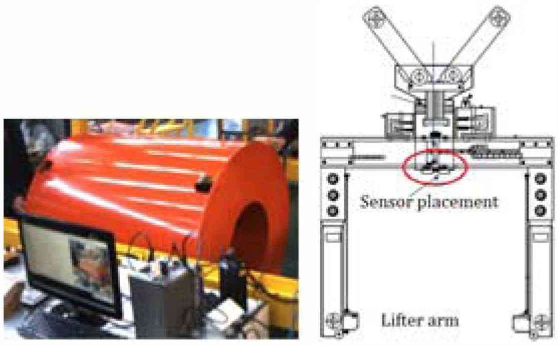



Fig. 6 The actual coil model and the sensor placement

Fig. 7 shows a screenshot of real-time coil position tracking that is robustly done on moving condition. The measurement frequency is not regular but between 9Hz to 12Hz.

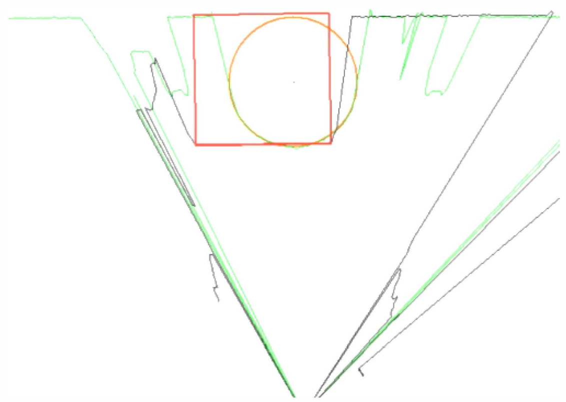


Fig. 7 Real-time actual coil tracking: the black line is the scanned data along width direction and the green line is the scanned data in radius direction. The red box shows the detected width, W, and the orange circle shows the detected circle, R. With this result (a,b,c) can be derived.

## 5. CONCLUSION

The measurement system of two 2-D laser sensors to construct a novel position-tracking sensor is accurate and robust on mid-range application for coil tracking. The dynamic target is coil within 5m distance. The proposed measurement system shows error within 30mm. The accuracy and robustness are validated by both miniature and actual size coil test. The future works remain such as 6-DOF tracking of cylindrical object by nonlinear solver method, sensor fusion with vision sensor and other sensors, the study on optimal arrangement between 2-D laser sensors. Also, the sensing frequency could be improved by optimal code realization.

## ACKNOWLEDGEMENT

This work is supported by RIST and POSCO. This work was also supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MSIP) (No. 2010-0028680 ).

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