3D Spreader Movement Information by the CCD cameras and the Laser Distance Measuring Unit

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Abstract: This paper introduces a method that can derive information about the movement of a spreader and skew in order to drive ALS(Automatic Landing System) in the crane used at a harbor. Some methods that use LDL Corner detectors a kind of 2D Laser scanner sensor or Laser distance measuring units to obtain the information in ALS are used presently. But these have some defects in economic efficiency and performance. Therefore, to correct these defects, we propose a method to acquire the information for the movement of a spreader, skew and sway angle using CCD camera image data and Laser distance measuring unit data.

Keywords: Yard crane, CCD camera, spreader, skew, sway, Laser distance measuring units,

1. INTRODUCTION

Today, international trade has increased volume. Export and import container cargos especially have increased though the sea. But today port systems are manually operated. The only automated part of the system is just the cargo database. So, labor cost increases every year has increasing freight management cost. Also, there is always the danger of casualties.

At the present time, the unmanned automatic control systems for container ports have been researching around world[1-3]. Amsterdam's port system is completely automated including the loading, transporting and carrying. The points that have been researched about port systems are AGVs' (Automated Guided Vehicles)[4], Automatic gate systems, loading device systems as well as others. We focus on the loading device system.

Our main research is to obtain accurate spreader position information in order to pick up containers with ALS (Automatic Landing System) from automatic device systems. Several methods using 2D LDL Corner detectors and many using laser distance measuring units have been development.

A superior system, in terms of economic performance and efficiency, has been made using two CCD cameras, a laser distance measurement unit and rotary encoder trolley

The crane spreader of this paper utilizes two CCD cameras and a laser distance measuring unit. We process the data by image reduction, edge detection and Hough transform. This paper presents the method for calculate height, skew angle and movement information, sway angle and sway angle velocity between the spreader and the container.

2. THE COMPOSITION OF CRANE

Fig. 1 shows the crane used in our research.

The axis configuration is shown in Fig.1. The x-axis represents the direction of movement of the crane. The y-axis and z-axis represent horizontal movement of the trolley and vertically movement of the spreader, respectively.

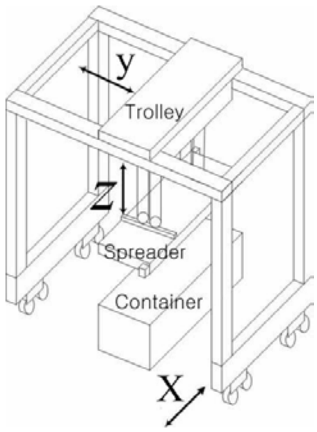


Fig 1. Crane

The CCD camera is located at the corners of the spreader so that the corners of the container can easily be found. The laser distance measuring unit is placed in the center of spreader as shown in Fig. 2.

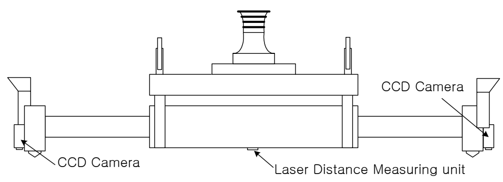


Fig. 2 Spreader

3. IMAGE PROCESSING FOR DETECTING CONTAINER CORNER

3.1 Edge detection

An edge is where the intensity of an image moves from a low value to a high value or versa. In other words, there is a differential intensity at the edge. We generally use a partial derivative to detect an edge. Fig. 3 shows the results of a first order derivative and a second order derivative at the gradient graph.

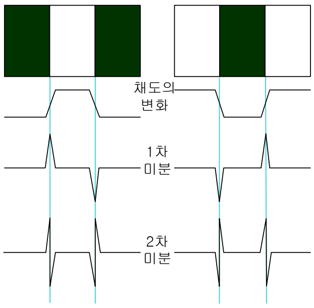


Fig 3. Edge detection by partial derivative

The value of the first order derivative represents the existence of an edge and a sign value of the second order derivative indicates a region that has both high and low intensity[5-6].

But, It is difficult to calculate each pixel, so, to decrease processing time we use homogeneity operator. In this paper, we use the Sobel mask to obtain edge information.

1	2	1
0	0	0
-1	-2	-1

-1	0	1
-2	0	2
-1	0	1

Fig 4. Sobel mask

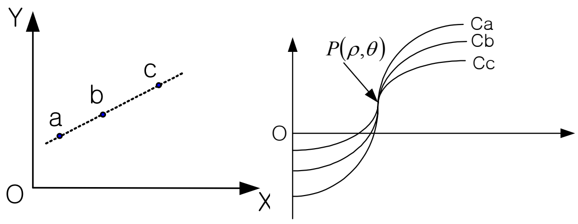
3.2 Hough transform for line detection

The Hough transform is a technique which can be used to isolate features of a particular shape within an image[7-8].

To detect lines, we transform the line Eq. (1) into polar coordinates Eq. (2) and then we carry out inverse transformation.

$$y = \alpha x + \beta \tag{1}$$

$$\rho = x\cos\theta + y\sin\theta \tag{2}$$



(a) x,y Image surface (b) Hough surface

Fig 5. Cartesian coordinates and polar coordinates

As shown in Fig. 5, the points a, b, c in x-y coordinates can display curves in polar coordinates and the lines a point. Then we can find the line by using the principal that all points on a line can represent a point in polar coordinates.

$$x = \frac{\rho - y\sin\theta}{\cos\theta} \tag{3}$$

4. 3D DISTANCE INFORMATION BETWEEN THE CONTAINER AND THE SPREADER.

In order for the spreader to grasp the container, the corners of the spreader must match up to the corners of the container. Therefore, we can find the corners of the spreader in the image by using CCD cameras which installed diagonally opposite to the corners of spreader, and find the corners of the container by image processing.

Then we can calculate the distance error through the corners information.

4.1 Extracting Image coordinates from the spreader when the laser distance measuring unit has height information.

We used a pin-hole camera model to estimate the position of a real object in the image. The pin-hole camera model, focuses on a point and all of the pixels in the image represent the distance from center as shown in Fig 6[9].

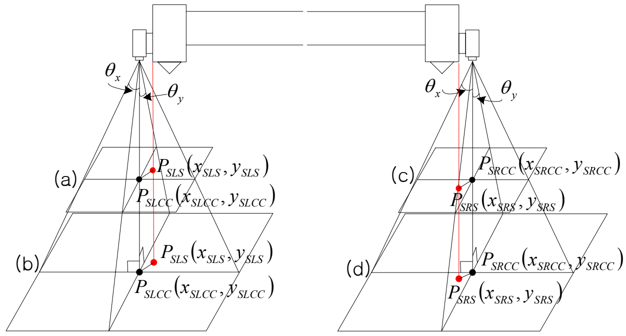


Fig. 6 The spreader left and right corner points by the pin-hole model

We obtain the relation between image features and real conditions from the pin-hole camera model. In Fig. 6 (a),(c) and (b),(d) planes show an area which is subjected to the height of the camera. The size of planes in Fig. 6 (a),(c) and (b),(d) are the same, but they are different in the real world. The image at (a),(c) and (b),(d) planes is shown in Fig 7.

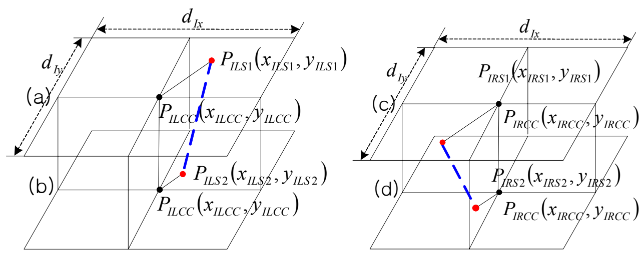


Fig 7. Image of different height between the spreader and the container

Comparing Fig. 6 with Fig. 7, $P_{SLS}(x_{SLS}, y_{SLS})$, $P_{SRS}(x_{SRS}, y_{SRS})$, the corners of the spreader which are equal to real distances in same coordinates represent $P_{ILS1}(x_{ILS1}, y_{ILS1})$, $P_{IRS1}(x_{IRS1}, y_{IRS1})$ in Fig. 7 (a),(c) and represent $P_{ILS2}(x_{ILS2}, y_{ILS2})$, $P_{IRS2}(x_{IRS2}, y_{IRS2})$ in Fig.7 (b),(d) as position error of z-axis. Note that the corners coordinates of the spreader are in the same position as the linear relation by distance between the container and the spreader.

In the Fig. 8, the image feature at the corners of the container are diagonally opposite to those where the CCD camera is located as shown in Fig. 8.

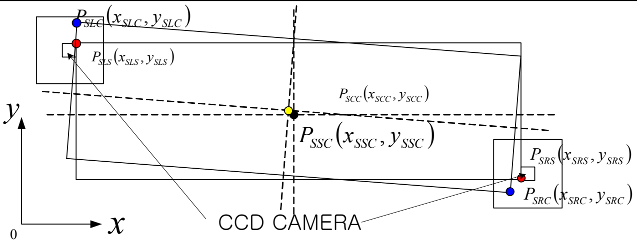


Fig 8. Container Corners and Spreader Corners

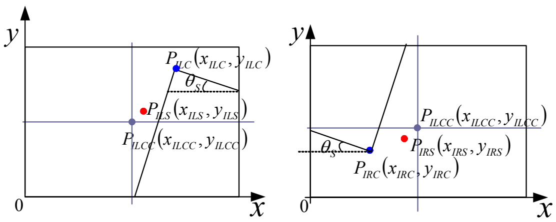


Fig 9. CCD Camera Image Data

If we know the height d_{sc} between the spreader and the container then the point coordinates of the spreader in the image coordinates is given by

$$x_{ILS} = (x_{SLS} - x_{SLCC})\frac{d_{Ix}}{2d_{SC}\tan\theta_x} + x_{ILCC} \quad (4)$$

$$y_{ILS} = (y_{SLS} - y_{SLCC})\frac{d_{Iy}}{2d_{SC}\tan\theta_y} + y_{ILCC} \quad (5)$$

$$x_{IRS} = (x_{SRS} - x_{SRCC})\frac{d_{Ix}}{2d_{SC}\tan\theta_x} + x_{IRCC} \quad (6)$$

$$y_{IRS} = (y_{SRS} - y_{SRCC})\frac{d_{Iy}}{2d_{SC}\tan\theta_y} + y_{IRCC} \quad (7)$$

From Eqs. (4)~(7), we know the world coordinates of the spreader. So, if we know the height by laser distance measuring unit, we can calculate the image coordinates of the height.

4.2 Measuring the height when the laser distance measuring unit can't provide the height between the container and the spreader.

When the laser distance measuring unit fails, we should derive the height between the container and the spreader by using the features of the images from the CCD cameras.

From the Eqs. (4)~(7), we can obtain the height between the container and the spreader if we know the corner of spreader at least. Here, we should know relationship between the container and the spreader. In this paper, we derive corners of the spreader from the image coordinates because the corners of the spreader and the container are exactly matched when the spreader holds the container. In other words, if the corners of spreader are matched up with the corners of container then distance error disappears.

We can use the symmetrical image to obtain coordinates and the size of the spreader and container is same. The CCD camera is located diagonally opposite the center of the spreader and then the coordinates of the spreader are located diagonally opposite in the image plane. If the skew angle is zero, we can calculate the x-coordinate values at the left corner of the spreader in the following equation. So we can obtain the height d_{sc} .

$$x_{ILS} = x_{ILC} + (d_{Ix} - x_{IRC})/2 \quad (8)$$

$$d_{sc} = \frac{(x_{SLS} - x_{SLCC})d_{Ix}}{2(x_{ILS} - x_{ILCC})\tan\theta_x} \quad (9)$$

However, if the skew angle θ_S exists, Eq. (9) is incorrect and we cannot calculate the corners of the container $P_{SRC}(x_{SRC}, y_{SRC})$ and $P_{SLC}(x_{SLC}, y_{SLC})$ ..

But, we know that the size of the spreader and the container are equal to the world coordinates and we also know that the image coordinates at the corners of the container $P_{ILC}(x_{ILC}, y_{ILC})$, $P_{ILS}(x_{ILS}, y_{ILS})$ and the world coordinates at the corners of the spreader. So we can assume that the corner coordinates of the spreader are rotated by the the skew angle θ_S according to center of the spreader $P_{SC}(x_{SC}, y_{SC})$.

The virtual spreader $P_{SVLS}(x_{SVLS}, y_{SVLS})$,which has rotated world coordinates at the left corner is defined by Eq. (10).

$$\begin{bmatrix} x_{SVLS} \\ y_{SVLS} \end{bmatrix} = \begin{bmatrix} \cos(\theta_S) & -\sin(\theta_S) \\ \sin(\theta_S) & \cos(\theta_S) \end{bmatrix} \begin{bmatrix} x_{SLS} - x_{SSC} \\ y_{SLS} - y_{SSC} \end{bmatrix} + \begin{bmatrix} x_{SSC} \\ y_{SSC} \end{bmatrix} \quad (10)$$

Using the left corner as the world coordinates in Fig 11, we have x-coordinates at left corner of the spreader by Eq.(10). Here, we can obtain the height by following Eqs. (11),(12).

$$x_{IVLS} = x_{ILC} + (d_{Ix} - x_{IRC})/2 \quad (11)$$

$$d_{sc} = \frac{(x_{SVLS} - x_{SLCC})d_{Ix}}{2(x_{IVLS} - x_{ILCC})\tan\theta_x} \quad (12)$$

4.3 Derive the distance error between the spreader and the container

The image coordinates of the container changed world coordinates because we need a real distance error instead of an error in the image coordinates. The Eqs. (13)~(16) change the image coordinates into the world coordinates.

$$x_{SLC} = (x_{ILC} - x_{ILCC})\frac{2d_{SC}\tan\theta_x}{d_{Ix}} + x_{SLCC} \quad (13)$$

$$y_{SLC} = (y_{ILC} - y_{ILCC})\frac{2d_{SC}\tan\theta_y}{d_{Iy}} + y_{SLCC} \quad (14)$$

$$x_{SRC} = (x_{IRC} - x_{IRCC})\frac{2d_{SC}\tan\theta_x}{d_{Ix}} + x_{SRCC} \quad (15)$$

$$y_{SRC} = (y_{IRC} - y_{IRCC})\frac{2d_{SC}\tan\theta_y}{d_{Iy}} + y_{SRCC} \quad (16)$$

The center point at the container $P_{SCC}(x_{SCC}, y_{SCC})$ is

$$x_{SCC} = (x_{SLC} + x_{SRC})/2 \quad (17)$$

$$y_{SCC} = (y_{SLC} + y_{SRC})/2 \quad (18)$$

Therefore, the distance error d_{Ex} of the x-coordinates and the distance error d_{Ey} of the y-coordinates are derived by the following equations.

$$d_{Ex} = x_{SCC} - x_{SSC} \quad (19)$$

$$d_{Ey} = y_{SCC} - y_{SSC} \qquad (20)$$

5. THE SWAY INFORMATION MEASUREMENT OF THE SPREADER

What is the sway angle? The trolley occurs acceleration and deceleration when it moves from start and stop. So, the spreader swings because of the inertia. At that time, the spreader's swing angle is the sway angle. The measurement data of sway angle needs to control anti-sway for the spreader[10-11].

5.1 The measurement of sway angle through the sampling image data by CCD camera.

First, we calculate the sway cycle for measuring sway angle. The spreader is connected to the trolley by same four lines. Also, the sway of the spreader can be analyzed by means of a pendulum dynamics equation, because the sway angle is very small.

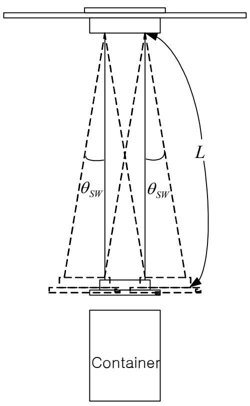


Fig. 10 Sway

The sway cycle of spreader T_{SW} is represented by Eq. (21).

$$T_{SW} = 2\pi\sqrt{\frac{L}{g}} \qquad (21)$$

L : *Wire Length*
g : *Gravitational Acceleration*

The lift motor rotary encoder in the trolley earns this L.

The distance the spreader moves is used to calculate the sway cycle of spreader T_{SW}. It divides same term. The corner points of the container are derived from each sampling of the image data. We calculate the distance the spreader moves to compare with previous corner points of container. So, the distance the spreader moves is calculated from each sampling data. Eq. (22) is the total the distance the spreader moves.

$$d_S = \sum_{t=0}^{T_{SW}} d_{st} \qquad (22)$$

d_{st} : Sampling spreader movement distance

The sway of spreader traces a shape like a bisector triangle as can be seen in Fig. (10), because the sway angle is small. Eq. (23) is the sway angle θ_{SW}.

$$\theta_{SW} = \arcsin\left(\frac{d_S/4}{L}\right) \qquad (23)$$

Eq. (24) determines the sway angle acceleration $a_{\theta_{SW}}$.

$$a_{\theta_{SW}} = -\frac{g}{L}\sin(\theta) \qquad (24)$$

6. EXPERIMENTATION AND RESULT

6.1 Experiment

The experimental crane for this research is shown in Fig (11). Its rail length is 540 mm by 3580 mm. The crane height is 1640 mm. The experimental container length is 240 mm by 600 mm. The height is 130 mm.

The spreader's CCD camera's horizontal image angle θ_x is 22.68 degrees, and its vertical image angle θ_y is 17.95 degree. The number of horizontal pixels of the image data d_{Ix} is 375, and the number of vertical pixels of the image data d_{Iy} is 221. The length between the CCD camera center point and the corner point of the spreader d_{RS} is 40 mm.


Fig. 11 Experimental Crane

The laser distance measuring unit is placed in the center of the experimental spreader and it's range is from 0.2 meter to 30 meter on all natural surfaces. Sometimes the laser distance measuring unit is not able to provide measurements due to environment obstacles.

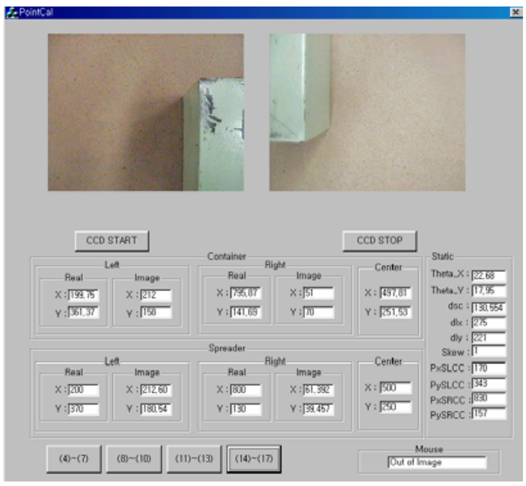


Fig. 12 Experimental program

6.2 Experiment result

We experiment several test for the proving algorithm in this paper. Each test experiments 20 times and its results is averaged.

First test, When the spreader has a zero skew angle, real values are d_{Ex} :30mm d_{Ey} :20mm d_{sc} :150mm. Compare to use the Laser distance measuring unit with to use only CCD cameras.

Table 1 First test results (Unit : mm)

	d_{sc}	d_{Ex}	d_{Ey}
Real Value	150	30	20
Laser distance measuring unit	150.2	30.5	20.4
CCD Cameras	151.9	31.1	20.7

Second test, When the spreader has a zero skew angle, real values are d_{Ex} :30mm d_{Ey} :20mm d_{sc} :300mm. Compare to use the Laser distance measuring unit with to use only CCD cameras.

Table 2 Second test results (Unit : mm)

	d_{sc}	d_{Ex}	d_{Ey}
Real Value	300	30	20
Laser distance measuring unit	300.2	31.2	20.9
CCD Cameras	295.3	31.3	19.4

Third test, When the spreader has a four skew angle, real values are d_{Ex} :30mm d_{Ey} :20mm d_{sc} :200mm. Compare to use the Laser distance measuring unit with to use only CCD cameras.

Table 3 Third test results (Unit : mm)

	θ_S (degree)	d_{sc}	d_{Ex}	d_{Ey}
Real Value	4	200	30	20
Laser distance measuring unit	4.2	200.1	30.6	20.4
CCD Cameras	4.2	198.9	29.2	20.9

Fourth test, When the spreader has a eight skew angle, real values are d_{Ex} :30mm d_{Ey} :20mm d_{sc} :200mm. Compare to use the Laser distance measuring unit with to use only CCD cameras.

Table 4 Fourth test results (Unit : mm)

	θ_S (degree)	d_{sc}	d_{Ex}	d_{Ey}
Real Value	8	200	30	20
Laser distance measuring unit	8.4	200	30.9	20.6
CCD Cameras	8.3	205.6	28.8	21.1

Fifth test, the wire length is 1200mm and sway angle is 2 degree and 5 degree. We compare the real values with measurement values.

Table 5 Fifth test (Unit : degree)

	θ_{SW}	θ_{SW}
Real Value	2	5
Measurement Value	1.4	4.1

We derive good experiment results from the first test to the fourth test, but fifth test that is sway angle test results is not good. We do not consider the influence of the disturbances in this algorithm. So we will improve the sway measurement algorithm after this.

7. CONCLUSION

This paper presents is algorithm for deriving the 3D movement information between a spreader and a container and the sway information of the spreader about ALS of the unmanned automatic port system research. We derive the edge line of the container by the image pre-processing from the image data of the CCD cameras. So we know having confidence in the pre-processed image data is very important. If image data pre-processing is not confidence, 3D movement and sway information data error will be increased.

The 3D movement and sway information data of a yard crane spreader is used to control ALS (Automatic Landing System) and to decrease accident by the beginner operator. This algorithm does not exactly reflect the distance information of 3D movement because the image data was scaled-down to improve processing speed. Recently, computer speed has increased, so if we use speedy computers, the iamge data will not need to be reduced and the 3D movement distance error will be decreased.

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