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A Study on Skew Measurement Technique for the Crane Spreader using a Camera
카메라를 이용한 크레인 스프레더 스큐모션 계측기술에 관한 연구

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주요용어 : 컨테이너 크레인(Container Crane), 카메라(Camera), 스큐모션(Skew Motion), 랜드마크(Landmarks), 스큐계측기술(Skew Measurement Technique)

요 약 : 본 논문에서는 카메라를 이용하여 크레인 스프레더의 스큐모션을 계측하는 계측기법에 대해 고찰하고 있다. 계측장치는 트롤리에 설치한 카메라와 스프레더에 설치한 두 개의 랜드마크로 구성된다. 랜드마크를 이용하여 크레인 스프레더 흔들림과 상하위치를 검출하는 기법은 저자들이 이미 제안한 기술이며 실험을 통해 그 유용성을 검증하였다. 크레인 스프레더의 스큐모션 계측기법 또한 제안된 계측기법에 기초한 것으로 두 개의 랜드마크를 검출하여 템플릿 매칭기법으로 스큐모션을 계측할 수 있다. 스큐모션은 스프레더의 회전각도를 검출하여 계측해야 하는데 계측정도와 신뢰도는 정확한 템플릿매칭의 가능여부에 의존하게 된다. 즉, 랜드마크의 회전으로 매칭이 실패할 경우에는 정확한 회전각도를 검출할 수 없는 경우가 발생할 수 있게 된다. 따라서 본 논문에서는 랜드마크 회전에 따라 템플릿을 회전시키는 방법을 도입하여 템플릿매칭의 신뢰성과 계측정도를 개선하는 방법에 대해 연구하였다. 제안된 방법을 이용할 경우 템플릿매칭이 실패하는 경우가 없음을 실험을 통해 확인하였으며, 측정범위는 ±12° 이고 이것은 크레인 스프레더의 스큐모션을 파악하고 제어하는데 충분한 정도의 범위이다.

Ⅰ. Introduction

The container cargo is the central means in transportation, and a lot of containers transferred are handled in the port. Therefore the container cranes are widely used to handle containers in the port. In the recent years, the operating efficiency in size and handling speed has been required to get larger and faster according to the increase of container amount to be handled. However, in the surroundings for crane operators, it is the current state to be unable to follow the force of the mechanism improvement. Therefore, those studies such as anti-sway control[1,2] and anti-skew control[3,4] of a container spreader have been required to treat a number of containers as fast as possible. To accomplish adequate anti-sway control and anti-skew control, a measurement system with reliable accuracy is required in which the position and the skew angle of the spreader should be measured.

Many measurement techniques and systems have been developed for the anti-sway and anti-skew controls[5,6]. However, these systems can not simultaneously measure the position and the skew angle due to their architecture.

In the previous study, we proposed a camera-based sensing system to measure the spreader position with the robustness against light fluctuation caused in outdoor environment[7].

In this paper, we propose a technique to measure the skew angle of the spreader using a camera. This measurement system is composed of two landmarks located on the spreader and a

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camera installed on the crane trolley. If we use the proposed sensing system based on the previous result[7], the skew angle can be measured in which two landmarks are detected using a template matching method. However, the measuring accuracy and stability may be degraded by false detection of the template matching when the rotation of landmarks is shown in skew. To overcome this problem, a new method is adapted to cope with the landmark rotation. In this method, a template image is rotated according to the measured skew angle, and then the rotated template image is used for the next template matching. Since the rotated template image is similar to the rotated landmarks in captured images, the landmarks can be detected without false detection. The usefulness and performance of the proposed measurement system is introduced from the experimental results which is obtained by using the pilot system.

Ⅱ. System Description

Fig. 1 shows the schematic diagram of our measurement system in a container crane. This measurement system is composed of two landmarks located on the spreader and a camera in the trolley, which are arranged with the midpoint between landmarks located on the center of a captured image.

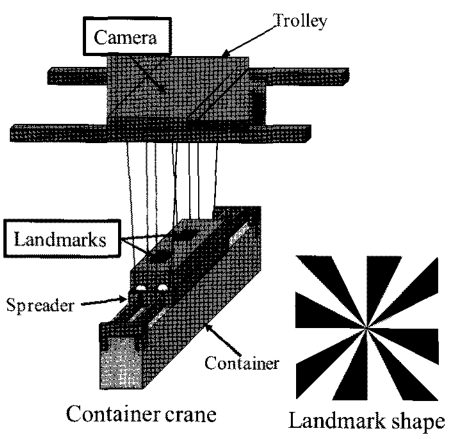


Fig. 1 Schematic diagram of the proposed measurement system

The landmarks used in this system have a specific shape, as shown in Fig. 1, in order to accommodate our system to change of the spreader height. The position and skew angle of the spreader is measured by our system as following.

At first, two landmarks in a captured image are detected using a template matching method. Then, the spreader position and the skew angle are measured with the detected position of landmarks. Fig. 2 shows the schematic diagram of position and skew measurement method of the spreader. In our measurement system, the midpoint between landmarks is defined as the measured point $(X_s, Y_s, Z_s, \theta_s)$. Where X_s and Y_s represent the displacements from the static position of the spreader, Z_s represents the spreader height from the trolley, and θ_s represents the skew angle to the Y axis, respectively.

The measurement of the position and skew angle is based on the central positions of two landmarks (x_1, y_1) and (x_2, y_2), which are detected with the template matching. From these central positions, the distance between landmarks d and the midpoint of landmarks (x_s, y_s) in a captured image are calculated by Eq. (1), (2).

$$d = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \quad (1)$$

$$(x_s, y_s) = \left(\frac{x_1 + x_2}{2}, \frac{y_1 + y_2}{2} \right) \quad (2)$$

Then, (X_s, Y_s, Z_s) is calculated by Eq. (3) with the ratio of d to the actual distance between landmarks D.

$$(X_s, Y_s, Z_s) = \left(\frac{D}{d} x_s, \frac{D}{d} y_s, \frac{D}{dp} f \right) \quad (3)$$

Where p is the pixel size and f is the focal length of the camera. The skew angle θ_s is also calculated using the (x_1, y_1) and (x_2, y_2) by Eq. (4).

$$\theta_s = \tan^{-1} \frac{x_1 - x_2}{y_1 - y_2} \quad (4)$$

Ⅲ. Template rotation with measured skew angle

To detect a landmark from a captured image, a template matching method is used. The template matching method is widely used in various applications because of its usability. Unfortunately, the template matching method also has a weaknesses against light fluctuation, scaling, and rotation of a target. The proposed measurement system has already overcome the weaknesses against light fluctuation and scaling by adopting a template matching method. In the previous research, the robust to light fluctuation and the landmark with a specific shape has been proved[7]. However, the measuring accuracy and stability of the proposed measurement system may be degraded when the rotation of landmarks is shown in skew. This degradation is caused by false detection of the template matching in which the rotated landmark becomes dissimilar to a template image as shown in Fig. 3 (a).

As a solution to the degradation problem, a template replacement method which replaces a current template with the detected landmark is generally considered.

However, landmarks may not be accurately detected if some errors are included in the replaced template image. Other methods with groups of affine transformed templates[8] or pre-computed scores[9] have been proposed. But it is necessary to increase the computational cost.

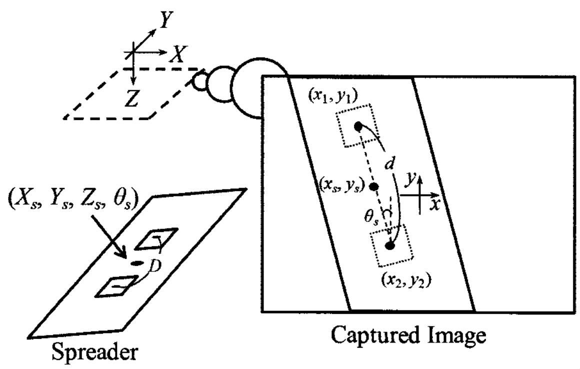
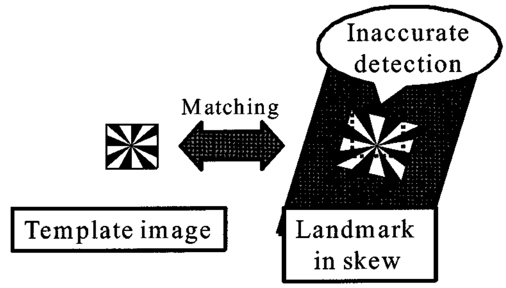
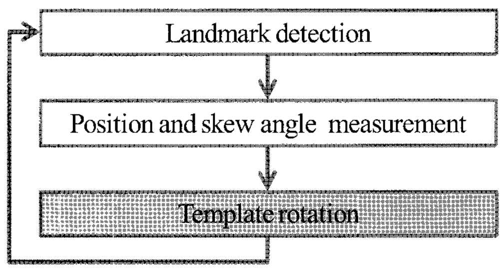


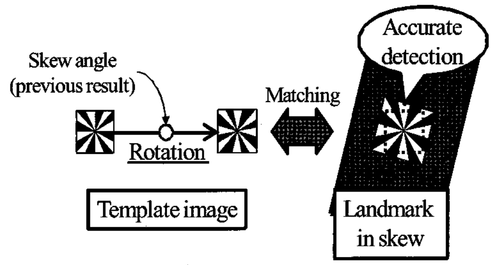
Fig. 2 Schematic diagram of position and skew angle measurement of the spreader by the proposed measurement system



(a) Landmark detection using one fixed template



(b) Processing flow of the proposed measurement system with template rotation



(c) Landmark detection using a rotated template with the measured skew angle

Fig. 3 Schematic diagrams of our skew measurement technique

These problems are caused by the difficulty of estimating a rotation angle from the matching. But in the proposed system, the skew angle θ_s which can be assumed to be the rotation angle of landmarks is measured.

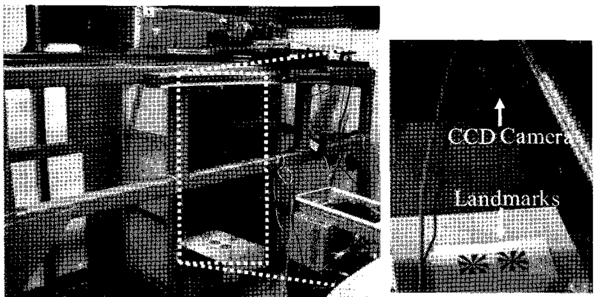
Fig. 3 (b) and (c) show the processing flow and the scheme of our measurement system with template rotation method. The template rotation is conducted from measuring the position and skew angle. In the template rotation method, an original template image representing the landmark at $\theta_s = 0$ is rotated according to the measured angle θ_s. Then, the rotated template image is used as a new template image in the landmark detection of the next captured image. Since the rotated template image is more similar to rotated landmarks than the previous one, the landmarks can be accurately detected without false detection.

Ⅳ. Experiments

To evaluate the performance of the proposed measurement system for the skew angle calculation problem, we performed experiments using the container crane model as shown in Fig. 4. This crane model is made up of a trolley at the top of the crane and a spreader suspended by four ropes from the trolley. The proposed measurement system is composed of a CCD camera which is installed on the center on the trolley, and two landmarks which are attached on the level surface of the spreader as shown in the Fig. 4 (b).

And the specifications of the proposed measurement system are summarized in Table 1.

For experiments, the spreader is located at the height of 465 mm, and rotated within $\pm 12^{\circ}$.



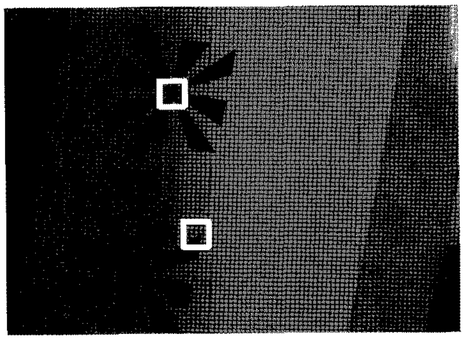
(a) Overall view of the crane model (b) Measurement system

Fig. 4 Crane model with the measurement system

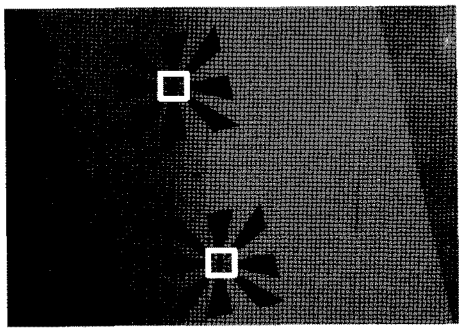
Table 1 System parameters for experiments

Captured image size	640×480 [pixels]
Template image size	34×34 [pixels]
f	12 [mm]
p	0.0074 [mm/pixel]
D	78 [mm]
Measuring period	70 [fps]

And, the spreader position and skew angle are measured by the proposed measurement system in which the proposed template rotation method is included.



(a) Without template rotation



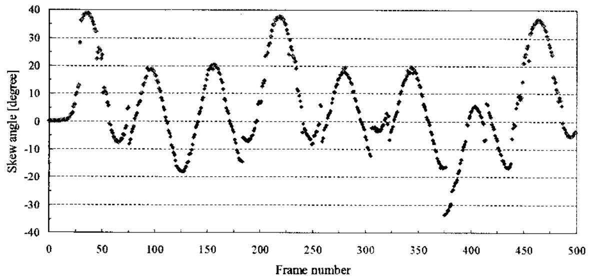
(b) With template rotation

Fig. 5 Captured images when the spreader is skewed

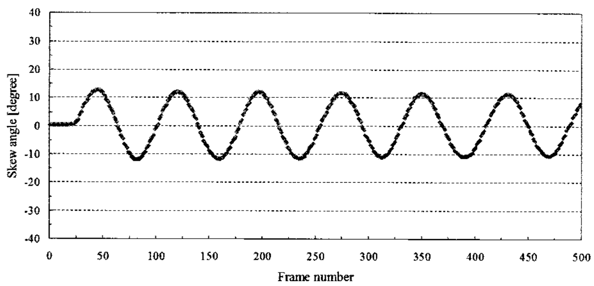
To verify the performance of the developed system, an experiment based on a general measurement method without the template rotation is performed also.

Fig. 5 shows captured images containing results of the landmark detection while the spreader is skewed. Each image includes two rectangles which show the detected positions of landmarks. In the Fig. 5 (a), the rectangles are not accurately located at the centers of landmarks. In particular, the under rectangle is located at the edge side of the landmark. From these results, it is clear that the landmark detection may fail due to the skew without the proposed template rotation.

In contrast, two rectangles shown in Fig. 5 (b) are located near the centers of each landmark. This result means that the rotated landmarks can be accurately detected with the template rotation method.

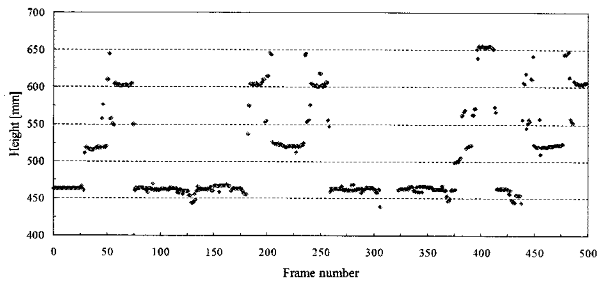


(a) Skew angle measured without template rotation

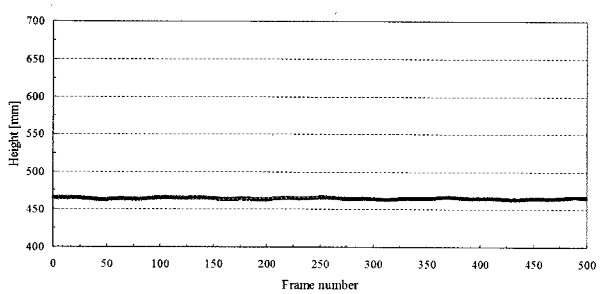


(b) Skew angle as measured with template rotation

Fig. 6 Comparison of measuring result for skew angles obtained from two conditions



(a) Spreader height measured without template rotation



(b) Spreader height with template rotation

Fig. 7 Comparison of measuring results for the spreader height obtained from two conditions

Fig. 6 shows the comparison results obtained with and without template rotation. Where, the horizontal and the vertical axis represent the frame number and the measured skew angle, respectively. We can see from the variation of the skew angle shown in Fig. 6(a) that the skew angles is not accurately measured. On the other hand, as shown in Fig. 6 (b), we can see that the skew angles are accurately measured with template rotation. Additionally, we can confirm that the resolution of the proposed measurement system is approximately 0.2 degree in this experimental setup.

Fig. 7 shows the comparison results for the spreader height obtained with and without template rotation. Where, the horizontal and the vertical axis represent the frame number and the spreader height, respectively. Even though, the actual spreader height is not changed in the experiment, the spreader height measured without template rotation is excessively changed as shown in Fig. 7 (a). However, if the template rotation method is used, the measured spreader heights is kept around the actual spreader height as shown in Fig. 7 (b).

From these experimental results, we can see that the template rotation method can allow the proposed measurement system to continuously measure the skew angle without the degradation which may be caused by the false detection of landmarks.

V. Conclusion

A skew measurement technique for a container spreader using a camera-based sensing system has been proposed. In the proposed skew measurement technique, a template image is rotated according to the measured skew angle, and then the rotated template image is used in the next template matching. Since the rotated template image is similar to the rotated landmarks in captured images, the landmarks can be detected without false detection. From the experimental results obtained using a model crane in which the proposed measurement system is installed, we verified that the skew angle within $\pm 12^\circ$ can be continuously measured without false detection. Hereafter, we will verify the accuracy of the measured skew angle by comparing with other sensors.

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