Technology Introduction

Research on Excavator Posture Estimation Technology with Image Processing

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1 Introduction

Recently construction equipment is required to have advanced safety functions such as fall prevention. Future construction equipment is estimated to be automated more than ever and will be required to address the rising need for stability during high-speed operation. Under this situation, I decided to launch an effort to improve excavator safety using ZMP [Note 1)] as an index of excavator stability. To calculate ZMP, however, a number of sensors of different types, including angle and acceleration sensors need to be installed on the rotating platform, boom, arm and bucket of an excavator, which would configure a complex system. On the other hand, recent lower-priced cameras and improved communication and data processing capabilities have contributed to the wide-spreading of sensing technology using cameras and image processing. This study has developed a method of identifying the posture of an excavator necessary for calculating ZMP with a relatively simple system configuration using cameras and image processing. This report will introduce the excavator posture estimation technology using image processing addressed in the study.

Note 1) Zero Moment Point. ZMP is defined as the point where the total of gravity, inertia and external forces applied to a machine installed on a road surface does not produce any moment (zero moment).

2 System Overview

2.1 Hardware configuration

Cameras used to capture images for image processing were installed in the rotating platform (cabin).

Since multiple cameras should be used to determine the detected angles in this study, a camera model equipped with an external trigger function that allows all cameras to operate at the same time was selected. To capture clear images, even under infrared rays from sunlight, a near-infrared lens was selected.

2.2 How to estimate posture with image processing

To estimate the posture of an excavator, the link length and angle of the rotating platform, boom, arm and bucket of the excavator are needed. Link length refers to the direct distance from one rotation axis of a moving element of the excavator to the other rotation axis of the same part. Link angle refers to the rotating angle of a moving element. Since the link length can be measured in advance, this study used image processing to determine the link angle (Fig. 1). To determine the link angle, the link images captured by the cameras were first subjected to image processing to detect the target edge. Then, the angle between the target and known edges (Fig. 2) were calculated.

Target edge means an edge that cannot be detected without image processing. Known edge is an edge whose position is obvious even without image processing. Any boom that turns about the rotating platform mounted with the cameras can be the known edge. On the crawler, the frame of a camera can be used as the known edge. Once the target edge of the boom is detected with image processing and the detected boom angle is calculated, the boom edge can be used as the known edge to determine the detected angle of the arm rotating about the boom. The reason for the boom edge being able to be used as the

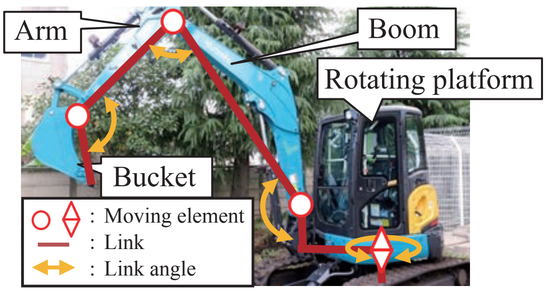

Fig. 1 Link angle

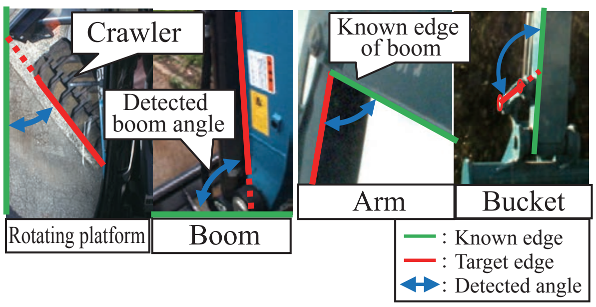

Fig. 2 Detected angles

known edge is because, by mapping the relationship between the detected boom angle and the position of the known edge of the boom on the image beforehand, calculating the detected boom angle will automatically determine the position of the boom from the mapped information.

3 Calculation of Detected Angles

Detected angles are calculated as follows:

(1) Detected boom angle

For detection of the boom angle, the target boom edge is detected with image processing. Then, the detected boom angle between the detected target edge of the boom and the screen frame is calculated.

(2) Detected arm angle

Since the detected boom angle has been calculated in (1) above, the position of the known edge of the boom is automatically available. The target arm edge is detected with image processing. Then, the detected arm angle between the estimated known edge of the boom and detected target edge of the arm is calculated.

(3) Detected bucket angle

Since the detected boom and arm angles have been calculated in (1) and (2) above respectively, the position of the known edge of the arm is automatically available in the same manner as the known edge of the boom. It is now desired to detect the target bucket edge with image processing, but the bucket has a complex shape and has no straight edge. So, the link joint region between the bucket and arm (Fig. 3) should be detected with image processing. A straight line is calculated from the two points in the center of the region. Then, the detected bucket angle between the straight line connecting the detected two points in the joint region and the estimated known edge of the arm is calculated.

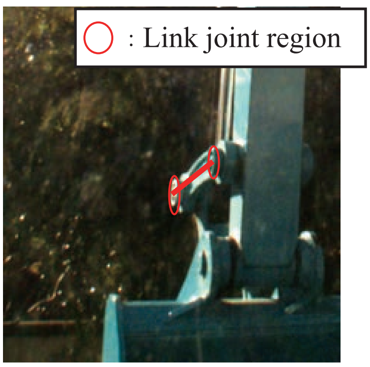

Fig. 3 Link joint region

(4) Detected rotating angle

The target edge of the crawler is detected with image processing. The detected rotating angle between the detected target edge of the crawler and the screen frame is calculated.

4 Detection of Target Edges

Target edge detection can be roughly classified into two types: image processing and edge/region identification.

4.1 Image processing

Image processing is applied to the excavator components according to the following procedure:

(1) Boom, arm and rotating platform

In the image captured by cameras (Fig. 4 ①), lens distortion is eliminated to produce a corrected image (Fig. 4 ②). Next, the image is processed to extract edges on the screen (Figs. 4 ③, ④) and to remove rough screen edges (Fig. 4 ⑤). In this process, all edges are removed except several top ones in a descending ranking that seamlessly extend as a single edge with the highest pixels. Finally, among the remaining edges, the straight ones are selected (Fig. 4 ⑥).

(2) Bucket

The lens distortion correction is made on the image captured by cameras. Next, the link joint region is extracted.

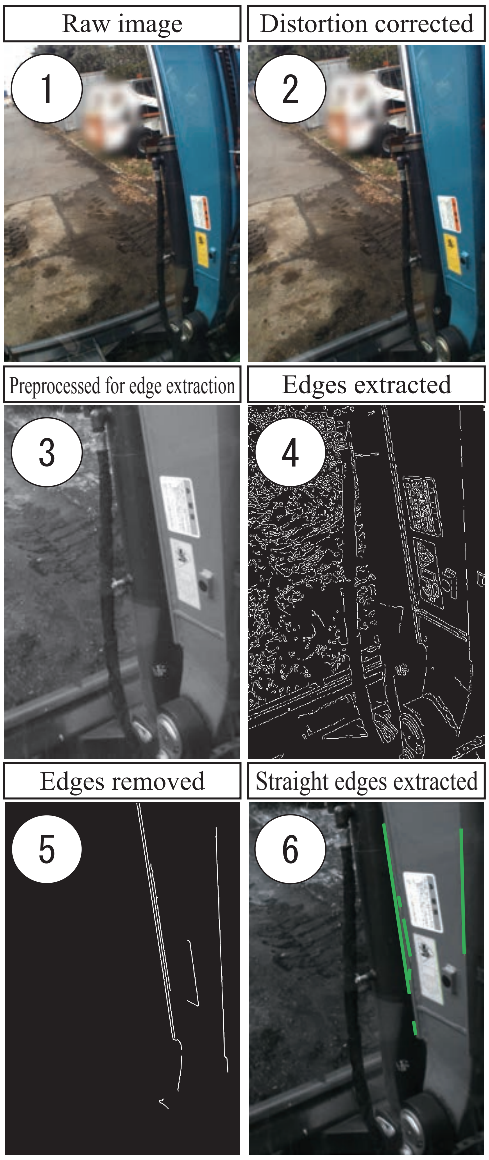

Fig. 4 Example of image processing (boom)

4.2 Edge/region identification

Extracted edges and regions are processed for final identification. They are identified by determining the relationship with a specific circle or by weighting.

4.2.1 Specific circles

Fig. 5 shows images of the boom, arm and bucket captured by cameras from the side and an image of the crawler captured from the top, on which their target edges/regions, as well as specific circles and their center point, are overlaid. The center point of each specific circle is located on the rotation axis of the moving element of the relevant part. Target edges on the same part perform a circular motion about the center of the specific circle. The circumference formed by this circular motion is the specific circle. All target edges of the boom, arm or crawler are a tangent of the specific circle at any link angle. The link joint region of the bucket is within the specific circle at any link angle.

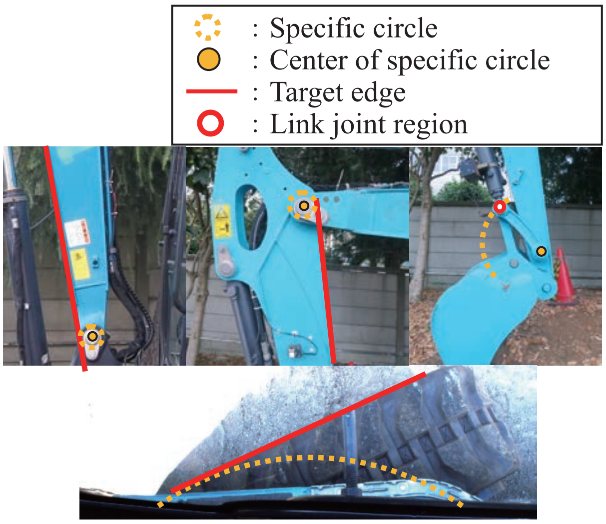

Fig. 5 Target edge and specific circles

4.2.2 Weighting procedure

Weighting is a data evaluation process for ranking a set of data by evaluation item, giving them a score according to the ranking and finally evaluating them with a total score. Among the group of edges detected with image processing, the highest ranked edge is identified using this weighting process.

The evaluation items are listed below (① to ③) and how edges are identified by weighting is shown in Fig. 6.

① How long is the edge?
② How close to the specific circle is the arm?
③ How close to the approximate position where the boom edge intersects with the arm edge on the screen (the intersection point) Note 2) is the end of the edge?

Note 2) Point of intersection is estimated according to the relationship between the boom angle and approximate intersection point that has been mapped beforehand as in the case of a known edge.

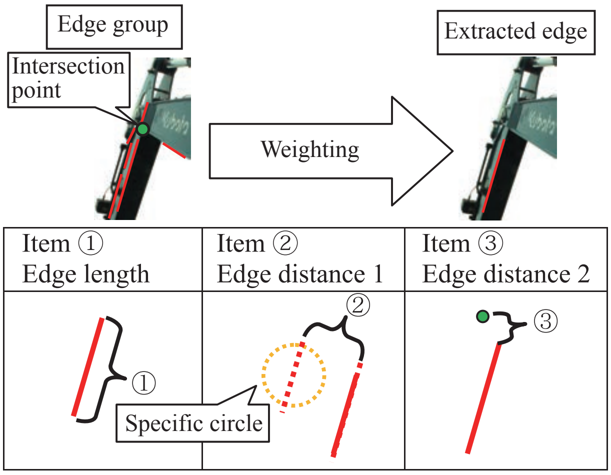

Fig. 6 Weighting items

4.2.3 Identification procedure

(1) Boom

Edges that can be a tangent of the specific circle (Fig. 5) are selected. Of these, the longest edge is selected.

(2) Arm

From the relationship between the detected boom angle and the center of the specific circle on the boom (Fig. 5) that has been mapped onto a table, the position of the center of the specific circle is estimated. Of the straight lines, those that can be a tangent of the specific circle are selected. These selected straight lines are weighted, from which the edge with the highest score is selected.

(3) Bucket

From the relationship between the detected arm angle and the center of the specific circle on the arm that has been mapped onto a table, the position of the center of the specific circle is estimated. Of the link joint regions, the one that passes through the specific circle is selected.

(4) Rotating platform

Edges that can be a tangent of the specific circle are selected. Of these, the longest edge is selected.

5 Calculation of Link Angles

When the detected boom/arm/bucket angle is calculated, this will uniquely determine the link angle. Based on the relationship, the link angle can be determined from the detected angle by simple conversion.

To calculate the link angle of the rotating platform, a combination of the two cameras used for detection and

Table 1: Rotating platform link angle chart

Platform orientation (quadrant)		1st, 4th	4th, 3rd	3rd, 2nd	2nd, 1st
Angle detecting Camera	Camera ①	×	○	×	○
	Camera ②	○	×	○	×
Platform link angle rage θ		315°-45°	45°-135°	135°-225°	225°-315°

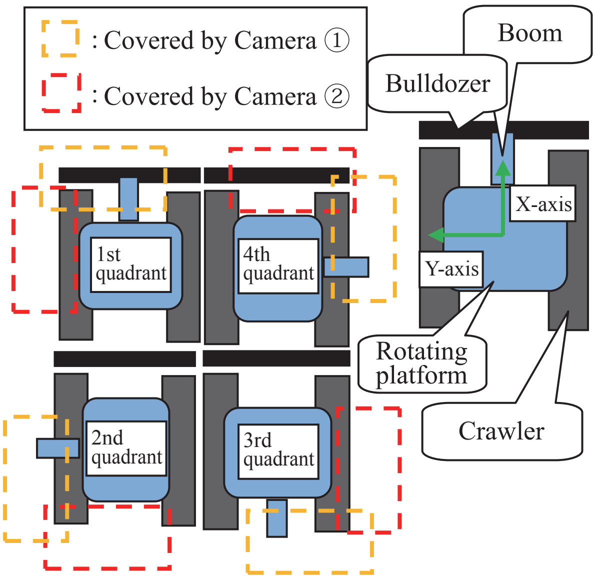

Fig. 7 Camera coverage for various rotating angles

orientation of the platform can be used to calculate the link angle. Table 1 gives a matrix of the combinations. Fig. 7 shows the positioning of the shooting areas of the cameras at different link angles of the platform: 0°, 90°, 180° and 270°.

Table 1 is based on an assumption that the excavator has a coordinate plane with its longitudinal axis as the X-axis and lateral axis as the Y-axis when viewed from the top. The coordinate plane is divided into four areas: 1st to 4th quadrants. The angle detecting cameras are those shooting the crawler. The table indicates the active camera for quadrants with marks ○ and ×. The platform link angle range represents a range of the link angle θ of the platform for each set of 1st to 4th quadrants.

6 Detection Results

Table 2 shows the results of detection of the excavator parts moving within their own movable range with image processing. The "detection rate" indicates the ratio of the number of images in which the target edge can be detected to the total number of images used for detection. "Detection" means the maximum error between the detected link angle and actual link angle [Note 3)].

The detection result indicates that the detection accuracy

Table 2 Detection result

Evaluation item \ (Number of verified images)	Boom (250)	Arm (127)	Bucket (149)	Platform (475)
Detection rate (%)	83.94	74.80	89.25	100.00
Detection [deg]	±0.58	±1.46	±3.11	±0.98

for the bucket and platform that are relatively close to the cameras is higher than that for the boom and arm. The reason for the higher accuracy may be that images of an edge closer to the cameras can be captured with more pixels, and even a shift of the edge by a single pixel would seldom affect the accuracy. Also, an edge closer to the cameras can be detected as a longer one, and even a shift by a single pixel would seldom affect the accuracy as well.

With the current detection rate, it is actually difficult to evaluate ZMP in real time. Still, the machine's ZMP can be adequately evaluated offline with the current detection level. Therefore, it is relatively easier to evaluate machine stability compared to cases of installing various sensors.

Note 3) Refers to the link angle measured using reference sensors installed separately.

7 In Closing

This study used the combination of cameras and image processing techniques to estimate the posture of excavators, instead of angle and acceleration sensors generally used for the same purpose. Although the technology still involves some difficulties in detection accuracy and rate, the study has confirmed that the posture detection system using this technology can be established to estimate excavator posture at an acceptable performance level from inside the cabin with environmental resistance advantage.

The image processing technology using cameras confirmed in this study may replace existing various sensors depending on the application. Recently the combination of cameras and image processing has been introduced to systems in various industries. It is important for KYB to assess the possible effects or added value produced by the combination of cameras and image processing applied to KYB system products. With this in mind, I would like to continue addressing the development of new products and technology.

Author

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Joined the company in 2009.
Motion Control R&D Sect., Basic Technology R&D Center, Engineering Dev.
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