Position Measurement for Image Application Products

Nobuyuki Fujiwara,
Hiroshi Shinji,
Makoto Niwakawa

Keywords Image processing, Position measurement, Projective transformation, Stereo measurement, Triangulation

Abstract

With the recent evolution of computer performance and its prices declining, image analysis technologies have been largely adopted in industrial fields. For many years, we worked on the development of image analysis technologies and released image-application products. Image analysis technologies are defined as the techniques for the image processing to input image data such as "extraction of contour lines," "separation of bright portions and dark portions," "extracting a brightness changing direction," etc. Further, this is a technique to extract the necessary information by analyzing the image processing data. Among image analysis technologies, position measurement is particularly important. Because position measurement by using image data is performed in non-contact mode, the spatial range for measurement is extensive. We applied our position measurement of various methods to our products.

1 Preface

With recent progress of computer performance and declining prices, image analysis technologies have been largely adopted in industrial fields. For many years, we worked on the development of image analysis technologies and developed and released various image application products such as bin picking systems(1), Overhead Catenary Inspection (OCI) systems(2), and intruder detection systems(3). Among the aforementioned products, the bin picking system and the overhead catenary inspection system are products that use position measurement technology.

The bin picking system detects an object from a container bin which photographed with a camera, defines a location of an object, and picks up the detected object using a robot arm. The OCI system checks the status of overhead catenary from which electric power is fed to electric cars, using images from the camera that is installed on the roof of a train. Such an inspection is realized by measuring the position of the contact wire or the width of the wear.

This paper introduces position measurement which is the core of image analysis technologies used to support our various image application products.

2 Outline of Position Measurement

Image analysis technologies are defined as the techniques for image processing that input image data such as"extraction of contour lines," "separation of bright portions and dark portions," and "extracting a brightness changing direction," as well as others. This is a technique to extract the necessary information by analyzing the image processing data. Fig. 1 shows the outline of image analysis technologies. Among image analysis technologies, position measurement is particularly important and its application range is extensive.

In order to determine the position of an image photographed by a camera, it is necessary to have engineering expertise. This is because the distance measuring object is represented as one spot (point) in 2D flat space in the digital image while the actual

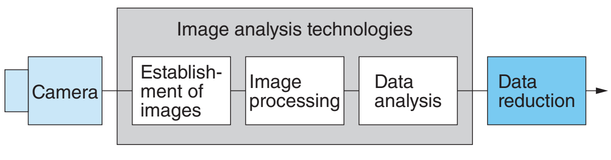


Fig. 1 Outline of Image Analysis Technologies

Image analysis technologies are used for the image processing of image-based data so that necessary information is collected through the analysis of image-processed data.

measuring object exists as one point in 3D space with depth. **Fig. 2** shows a schematic diagram of a relative positional relationship between a camera and an object. Light from the measurement point on an object passes through the lens focus and reaches the image sensor plane located inside the camera. The intensity of this light is regarded as a brightness value and recorded in the image. In the position measurement, the trajectory of light recorded on the image is reversely followed in order to determine the position of the measurement point on the object. It is generally not possible to obtain the position of a measurement point on a 3D object from a 2D image. As such, positional measurement is made possible by adopting several conditions. These image-applied conditions consist of the positional relationship already identified between the camera and the plane where the measurement point exists, the object size is already known, and the same measurement point is photographed with multiple cameras.

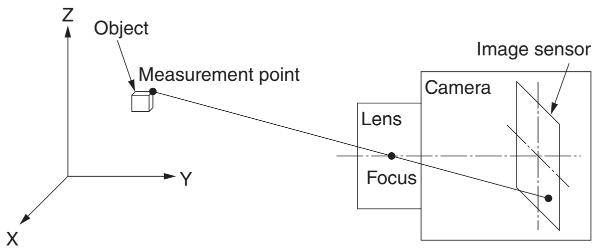


Fig. 2 Relative Positional Relationship between a Camera and an Object

Light from the measurement point passes through the lens focus and reaches the image sensor surface located inside the camera. The intensity of this light is regarded as a brightness value and is recorded on images.

3 Position Measurement of Moving Object Items on a Plane

In the production lines in a plant parts are moving on a conveyer belt (**Fig. 3**). In such production lines, position measurement based on images is adopted for positioning and size inspection of parts. Since cameras are installed in positions facing the conveyer belt, there is a parallel relationship between the image sensor plane in the camera and the plane of the conveyer belt (**Fig. 4**). Furthermore, the distance from the camera to the part is known. In this case, if the position of the measurement point in the image can be identified, it is possible to determine the position of the measurement point of the object in 3D space based on a simple proportional relationship.

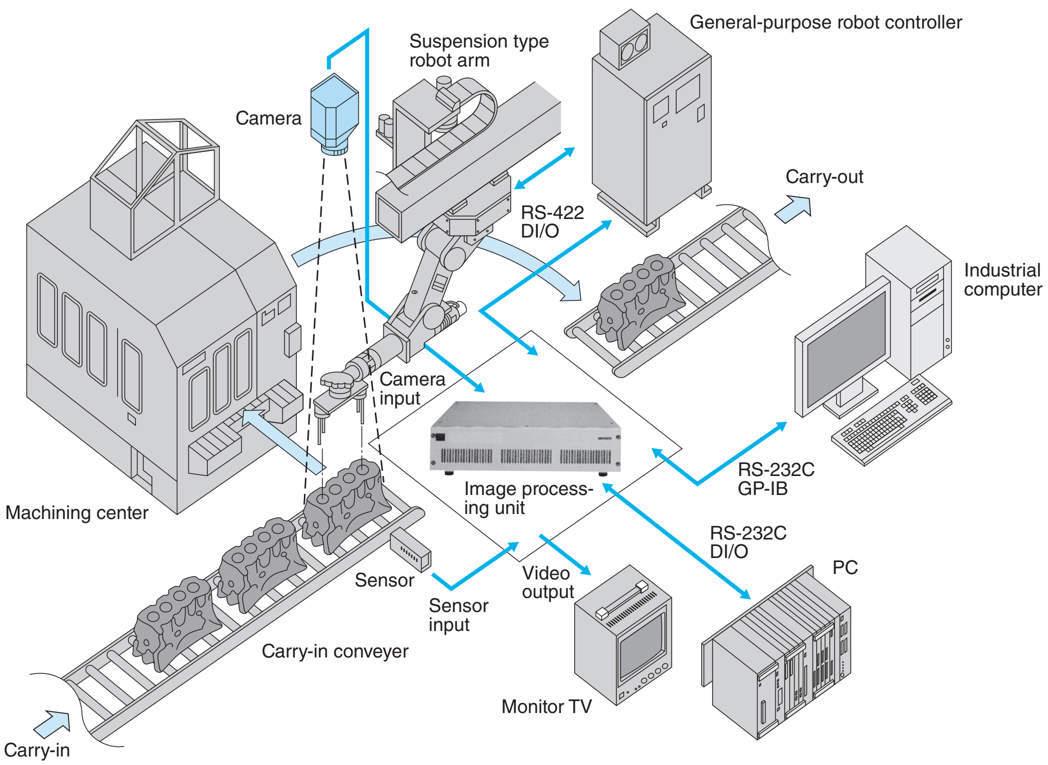


Fig. 3 Example of a Production Line in a Plant

On production lines in a plant, parts are often transported on a conveyer belt.

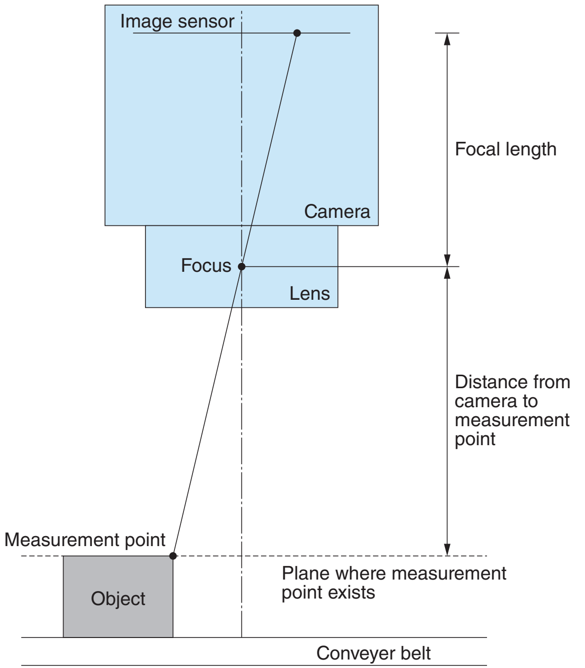


Fig. 4 **Positional Relationship between a Camera and Conveyer Belt**

The plane of an image sensor in a camera is positioned in parallel to the conveyer belt.

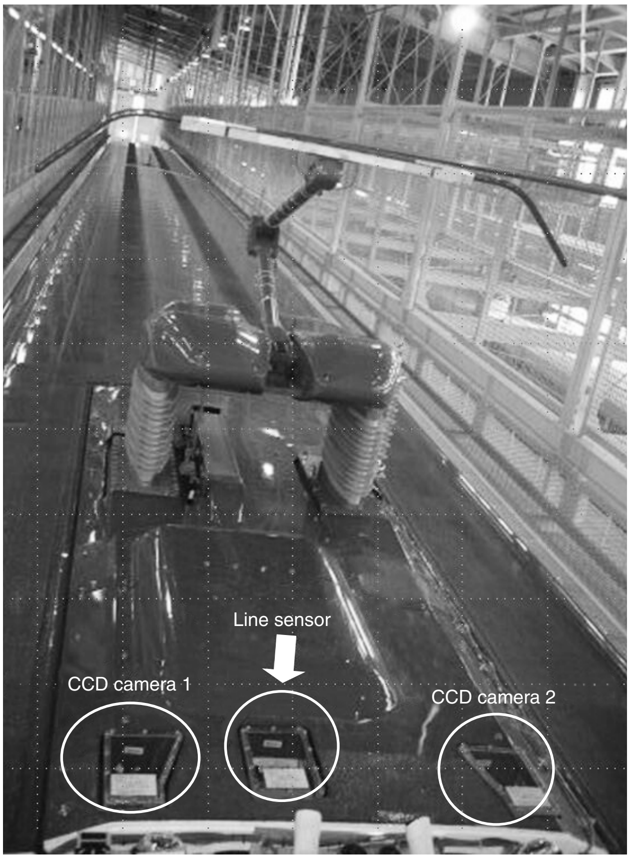


Fig. 5 **Camera Assignment for the OCI System**

Cameras are mounted on the roof of a train car so that they look up the train pantograph at an angle.

In the OCI system, cameras are mounted on the roof of a train car so that they look up the train pantograph at an angle (Fig. 5). For this system, it is assumed that the trolley wire maintains contact with the upper surface of the pantograph. The trolley wire height is determined by measuring the position of the upper plane of the pantograph. Due to the mechanical restraint of the link mechanism in the pantograph, the pantograph side face as seen from the camera exhibits a specified locus. Positional relationship between camera and possible existence of an object is therefore, identified (Fig. 6). In this case, it is possible to determine the position of the measurement point in 3D space by perspective transformation, provided that the position of the measurement point on the image can be identified. The respective transformation parameters needed for perspective transformation are calculated from the positional relationship between the camera and the object locus.

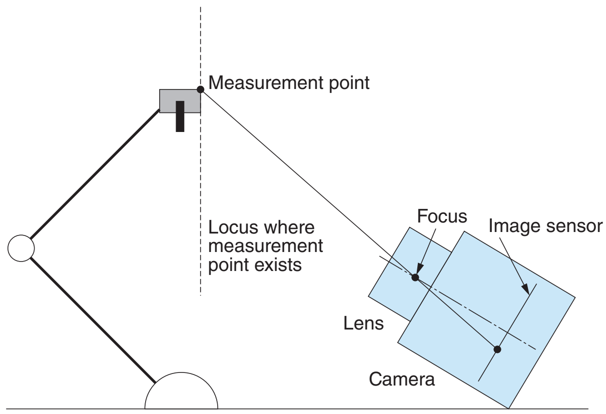


Fig. 6 **Positional Relationship between the Camera and the Pantograph Side Face**

The pantograph side face as seen from the camera exhibits a specified locus.

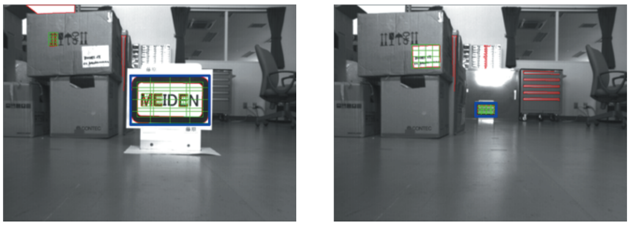
4 Distance Measurement Using a Monocular Camera

When an object size is known, it is possible to measure the distance to the object with a single camera. For example, if the object is a person, this person looks smaller when standing farther away (Fig. 7). A flat marker or a sign changes its size in the image according to distance from the camera (Fig. 8). In this way, the distance to the object is measured based on changes in the object size in the images.

(a) Near person (b) Distant person

Fig. 7 **Impression of a Person Photographed with a Camera**

If the object is a person, this person looks smaller when standing farther.



(a) Near marker (b) Distant marker

Fig. 8 **Impression of a Marker or a Sign Photographed with a Camera**

A flat marker or a sign changes its size in the image according to the distance from the camera.

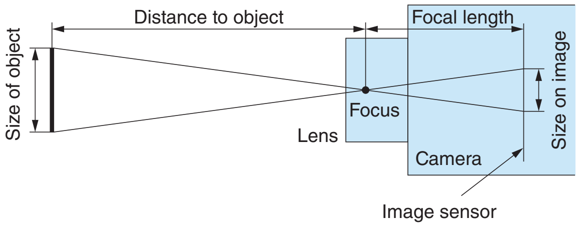


Fig. 9 **Positional Relationship with an Object that is Directly Opposite of a Camera**

Parallel position is maintained between a plane of the image sensor in the camera and another plane where the measurement point exists.

Fig. 9 shows positional relationship between an object and camera when the camera is directly facing the object. In this case, parallel position is maintained between a plane of the image sensor in the camera and another plane where the measurement point exists. If the object size can be identified on the image, it is then possible to determine the distance from the camera to the object according to a simple proportional relationship. The event that case the camera is not directly face to the object, it is still possible to determine the distance from the camera to the object, provided that there are four or more measurement points on the plane of the object. In this case, as shown in **Fig.10**, a method of coordinate transformation of the object from its known reference position to the present position is used.

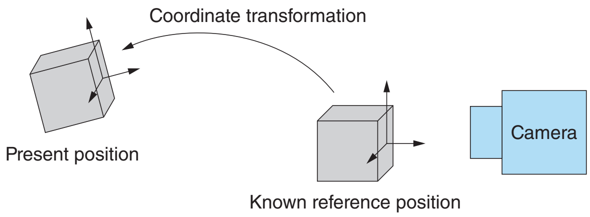


Fig. 10 **Coordinate Transformation of an Object from its Known Reference Position to Present Position**

It is possible to determine the distance from the camera to the object, if there are four or more measurement points on the plane.

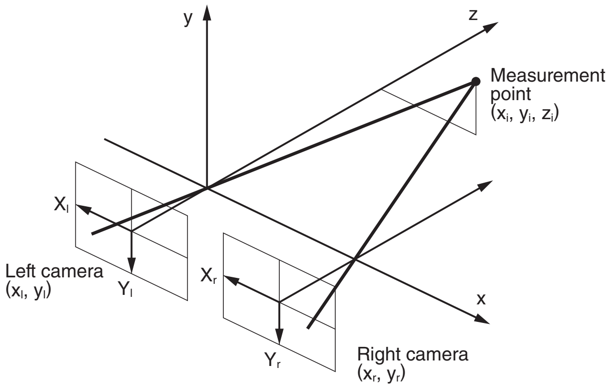


Fig. 11 **Triangulation Survey Method**

A triangle composed of the measurement point on each image and another measurement point on the object is defined in order to measure the distance to the object.

5 3D Position Measurement with a Stereo Camera

A 3D position of the measurement point on an object can be measured by photographing the same object from multiple points. This approach is called stereo measurement. When the same object is photographed with two cameras, the measurement point is then identified on the image of each camera.

A triangle composed of the measurement point on each image and another measurement point on the object is defined in order to measure the distance to the object (**Fig. 11**). This approach is called the triangulation method and it is primarily for a land survey that is applied to the image analysis.

A significant fact in stereo measurement is that

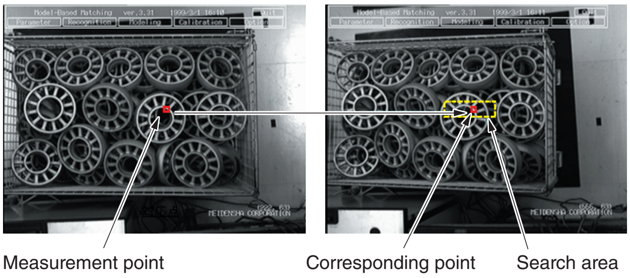


Fig. 12 Search for Corresponding Point

The measurement point on the object is set up on the image of the left camera and a point corresponding to this measurement point is searched for on the image of the right camera.

the same measurement point on the object is correctly determined based on images of the two cameras respectively. This raises the issue of a searching challenge for the corresponding point. In case either of the two cameras identifies a wrong measurement point, correct triangulation cannot be configured; the result of 3D position measurement is incorrect. A corresponding point search is carried out in a procedure described below.

The measurement point on the object is set up on an image in the left camera. A point corresponding to this measurement point (corresponding point) is searched for in the image on the right camera (**Fig. 12**). For this estimation, an image in a small domain near the measurement point set on the image of the left camera is compared with an image within a search area of the right camera. As shown in **Fig. 12**, however, an image of the same parts arranged in a line is often inconsistent in a case when the corresponding point is identified in a wrong position. Cases in which the same parts are arranged in line can be observed frequently in actual production lines. As such, we realized a solution to this problem by developing a method of searching for corresponding points correctly with the use of small image domains in two large and small sizes[4]. **Fig. 13** shows a result of a simple experiment. The upper stage of this figure shows the result of a searching process of an ordinary measurement point. The lower stage shows the result of a specific measurement point searching process where small image domains in two large and small sizes are used. In our newly developed measurement point searching process, multiple corresponding points (a small rectangle) are chosen first, and then final correct corresponding points (a large rectangle) are determined.

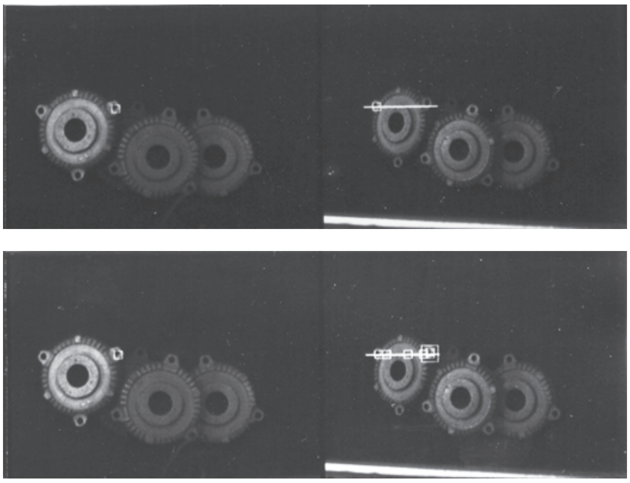


Fig. 13 Example of the Empirical Result of a Corresponding Point Search

A corresponding point is correctly detected with the use of small image domains in two large and small sizes so that multiple corresponding points (a small rectangle) are chosen first, and then final correct corresponding points (a large rectangle) are then determined.

6 Challenges for Improving Accuracy of Position Measurement

In order to improve the accuracy of position measurement using images, there are three challenging issues: quantization error, lens distortion, and the calibration of camera positioning.

6.1 Quantization Error

A quantization error is caused when images have a data construction split in the pixel unit. Position data on images involve discrete values for each pixel size. Only the result of discrete position measurement can therefore be obtained in pixel size unit. For a solution, high definition cameras or a sub-pixel estimation approach should be used. Sub-pixel estimation is a method used to estimate the position of a measurement point among pixels.

6.2 Lens Distortion

When an object is photographed with a camera, the outer periphery of the image may look distorted as compared with its actual shape. This is a phenomenon of lens distortion. To avoid such a lens distortion, we usually use a low-distortion lens supplied by lens manufacturers. By taking this measure, we can with higher accuracy, the manage this challenge in most cases. In cases of measurements re is a method of amendment through the modeling of lens distortion by using polynomial expressions.

6.3 Camera Position Calibration

When position measurement is carried out with images, it is important to determine the positional relationship correctly between the camera and the object. To achieve this measurement correctly, camera position calibration is generally performed. For camera position calibration, camera position and posture are calculated based on the position of each measurement point on a 3D space and an image.

7 Postscript

We have been working on the development of image analysis technologies and have also commercialized these technologies. This paper introduces a position measurement technology that is particularly important among image analysis technologies to support our various products. Position measurement using images is performed in a non-contact mode and the spatial range of measurement is extensive. So long as cameras are installed with high accuracy, the measurement points can be measured even in non-contact mode. In the industrial world, this technology is widely utilized for the positioning of parts and dimensional inspection. We will continue to develop more image analysis technologies in the future in order to contribute to our society through the implementation of image applied products.

《References》

(1) Onda, Fujiwara, Abe, Mori: "Visual-Based Bin Picking System Realized through Parts Positioning by 3D Circle Detection and Preliminary Hand Interference Checks," Journal of The Robotics Society of Japan, Vo.18, No.7, 2000, pp.93-100 (in Japanese)

(2) Niwakawa, Watabe, Fujiwara, Kinoshita, Sato: "Development of Overall Contact Wire Status Inspection System by Image Processing," Lecture Papers of SSII2008, 2008, pp.IN3-10-1-IN3-10-2 (in Japanese)

(3) Fujiwara, Akimoto: "Development of Monitoring System for Detection of Intruders from Monitor Camera Images via Network," Meiden Jiho, Vol.310, No.5/2006, pp.38-42 (in Japanese)

(4) Onda, Niwakawa, Fujiwara: "High Accuracy Stereo Measurement for 3D Position Identification of Industrial Parts," The Institute of Electrical Engineers of Japan, Papers of Sector C, Vol.121-C, No.5, 2001, pp.848-853 (in Japanese)