Data Fusion of Three-dimensional Measurement and CAD in Plant Construction
(with the application to prefabricated manufacture of chemical engineering pipe line as an example)

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Abstract

A system has been established with application of a three-dimensional measurement technology aiming at promoting a pipe prefabrication method in a chemical plant construction. This system makes it possible to measure the dislocation of pipe mounting flange of the equipment installed at the site, prepare As-Build CAD data for the pipe prefabricated pipe. Moreover, the system assures a positional measurement accuracy of ± 1.0mm and an angular measurement accuracy of $\pm 0.1^{\circ}$.

As the three-dimensional measurement technology, a point measurement technique by a total station and a face measurement technique by stereo image using two servo - drive type video total station containing CCD camera have been applied. Especially, the latter technique is characterized by working out a problem of correspondence detection of stereo image obtained by applying CAD based vision which is being advocated in an image recognition field and improving the measurement accuracy by collating the sub-pixel of CAD diagram with an edge image by the image processing.

1. Introduction

The construction of a chemical plant is put forward following such processes as a plant design, construction of steel-frame building, installation of reactor, tank and other apparatus and mounting of manufactured pipe on apparatus. In the plant design, the introduction of a three-dimensional CAD and in the manufacture of pipe, a prefabrication method in the shop are becoming general. The introduction of the three-dimensional CAD is bringing about the affect of rationalization of the design job, whereas the prefabrication method which makes the pipe in the shop is not always linking with the rationalization of the site job. The reason is that when an error in manufacture of the apparatus or an error in installation and further, an error in manufacture of pipe have come about, the manufactured pipe can not be connected to the apparatus at the site and it becomes necessary to do an adjusting work by cutting pipe and welding at the site. Generally, the field adjusting work costs a lot because it involves the fabrication of scaffold, disassembling work and use of hoist, etc. In addition, for a double tube pipe line or a pipe made of titanium, the field adjusting work is difficult or cannot be done. To solve the problem, it is necessary to make accurate measurement of the installed locations of apparatus, modify CAD data based on the judgment of the designer and make sure of the manufacturing accuracy of pipe and for this, a three-dimensional measurement is absolutely necessary.

Therefore, the author et al. embarked on building up a three-dimensional measurement system with the object of promoting the prefabrication method in the construction of chemical plant. A system employing a total station requiring a target at a measuring point has been built up and at present, the system has been applied at the site. This system is such that for measuring a point at a high place, a target has to be put on by using a ladder or a footing. Therefore, in order to save the time and labor for putting this target on place, a three-dimensional measurement system has been examined which is available by collating a stereo image with CAD diagram with the use of 2 units of servo-drive type video total station containing CCD camera and the prospect of putting the system to practical use has been obtained.

This report describes the outline of the system built up with the total station requiring the target and the results of application to the chemical plant site and at the same time, it covers the summary of the three-dimensional measurement system (CAD base measurement system) available with the stereo image and the results gained by making sure of the measurement accuracy.

2. Measurement at chemical plant

Fig.1 shows the layout of the chemical plant. the apparatus and pipe have been bolted through flanges and the pipes connecting between the apparatus are bent three-dimensionally and the

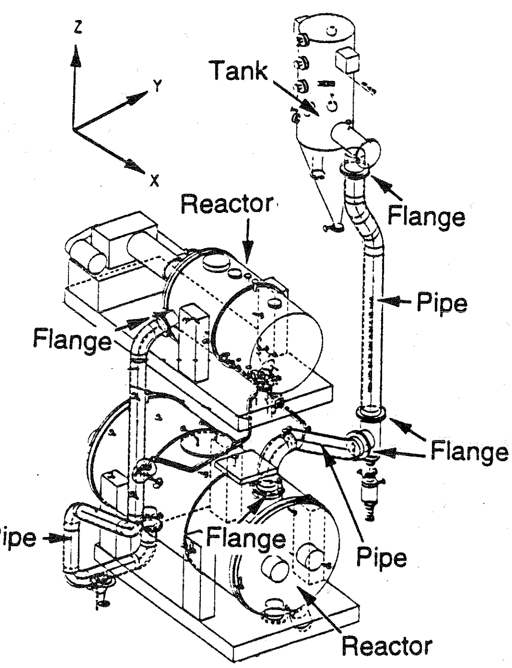


Fig. 1 Layout of the Chemical Plant

shape is complicated. However intricate the midway route of the piping may be, when the pipes are connected, it is important that the centers of the flanges fitted to the apparatus and pipe, inclinations of the faces and bolt hole positions are in accord with each other. Thus, the flanges of the apparatus and pipe have been taken up as the object of measurement, and the measurement items have been decided as follows; (1) three-dimensional coordinate value of flange center, (2) posture of flange face and (3) angle pitch of bolt holes. The range of flange diameter taken up as the object of measurement is wide, i.e., from 200 mm to 700mm. A desired measurement accuracy has been set as follows based on the manufacturing precision standard of pipe; positional measurement accuracy of ± 2 mm and angular measurement accuracy of $\pm 0.5°$. Also, the requirements for the measuring instruments are that it has a wide measuring range and is lightweight.

3. Three-dimensional measurement by total station

3.1 Outline of system

As measuring instruments fulfilling the aforesaid requirements, a total station requiring a target for the measuring point has been selected. The total station has a distance measuring accuracy of 0.8mm and an angle measuring accuracy of 2″ . **Fig.2**

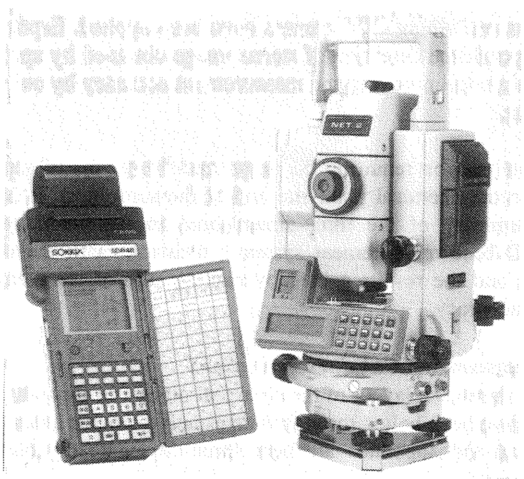


Fig. 2 Total Station

is the photograph thereof. Also, for measuring three items relative to the flange, the target has been made on trial. **Fig.3** is the photograph thereof. The structure is such that at the flange surface, the center of target can be placed on an extension line of the flange center and bolt hole center. By measuring with this target put on three locations per flange, the flange center position, inclination of the face and angle pitch of bolt hole can be calculated. The measurement accuracy is $\pm 0.1°$. This

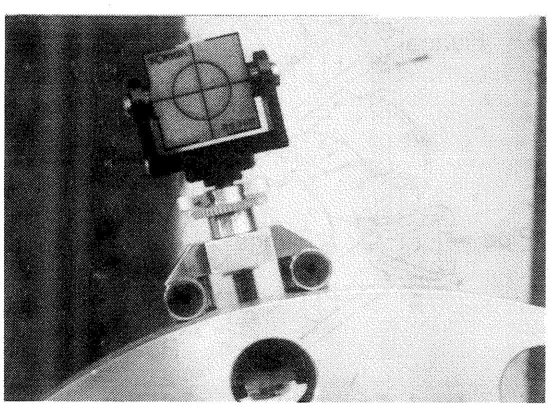
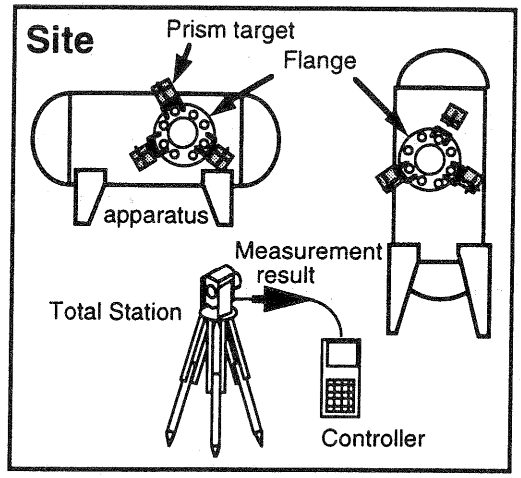
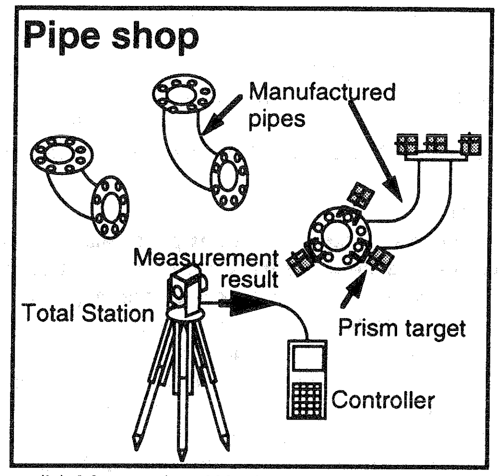


Fig. 3 Target for Flange

would be because that the manufacture accuracy of the target has been added to the measurement accuracy of the measuring instruments and a desired measuring accuracy has been fulfilled.



(a) Measuring Work at the Site



(b) Measuring Work at the Pipe shop

Fig. 4 Outline of the Measuring Work

Fig.4 shows the outline of the measuring work at the site and the pipe shop. At the site, measurement is made by mounting the target on the connected apparatus flange. When there is a difference between the measurement result and design value, the design value is to be changed based on the judgment of the designer. On the other hand, at the pipe shop, the pipes are manufactured based on the changed design value and measurement is made by mounting the target on the completed pipe flange. If the pipe can be connected, comparing the field dimensions with the dimensions of completed product of pipe, the pipe is transported to the site from the shop and if the pipe cannot be connected, the dimensions of pipe is corrected at the shop.

3.2 Results of application at site

Fig.5 shows the piping route of chemical plant measured with the total station. **Table 1** shows the design value between the apparatus flanges and the measurement results. With the measurement results as a true value, the design value has been changed for manufacturing the pipe. **Table 2** shows the measurement results between the pipe flanges after having been manufactured. A difference between the measurement results between apparatus flanges and that between pipe flanges is within ± 2mm and the manufactured pipe has been judged to be connectable and transported to the site. As the result of having been connected to the apparatus at the site, it has been verified that the pipes can be connected without correcting. At present, this system has been applied even to other work sites and good results have been secured.

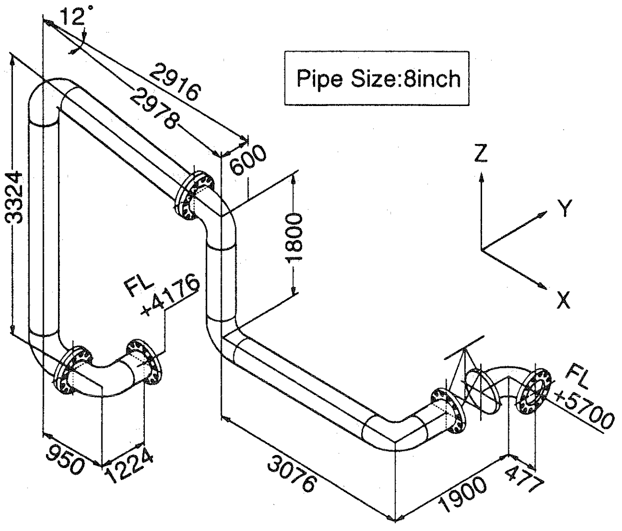


Fig. 5 Measured Piping Route

Table 1.

	X (mm)	Y (mm)	Z (mm)
Design Value	5519	76	1524
Result of Site	5505	36	1537

Table 2.

	X (mm)	Y (mm)	Z (mm)
Result of Shop	5506	35	1538

4. CAD base Measurement System

4.1 Principle of measurement

Fig.6 shows the outline of the system. This system substantially comprises 2 units of servo-drive type video total station containing CCD camera and IBM PC/AT compatible computer containing an image processing board used to grab the images.

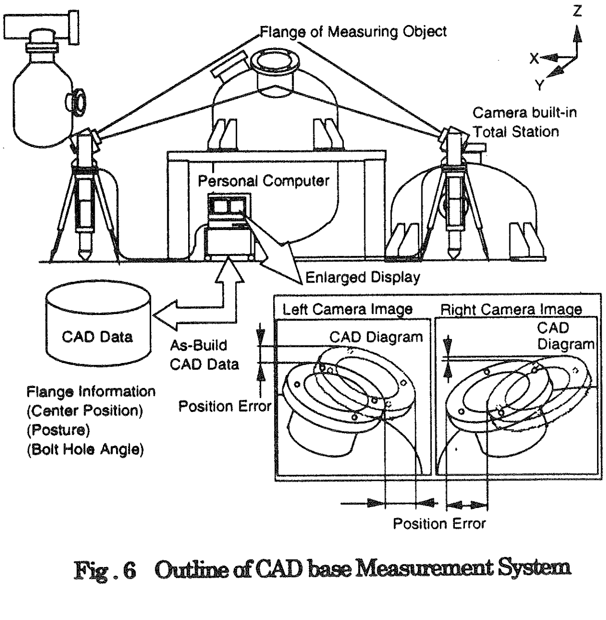


Fig. 6 Outline of CAD base Measurement System

If the position and posture of the camera in CAD coordinate system defining the flange size and position and posture are already known, perspective projection of three-dimensional CAD diagram of the flange into a two-dimensional diagram becomes possible. So long as the position and posture of actual flange are in accord with CAD data when this two-dimensional perspective diagram and the camera image have been displayed on the same screen, the flange image taken by the camera and the flange perspective view by CAD should accord with each other on the screen. Also, if the position and posture of the actual flange differ from CAD data, a discrepancy comes about between the flange images and CAD perspective view and they do not accord with each other. In this case, until both accord with each other, an amount of move obtained by adding CAD data becomes a discrepancy between the actual flange and CAD data.

To get the position and posture of the camera in CAD coordinate system, camera calibration may be made by a colinearity equation to pre - obtain a discrepancy between the principal point or direction (extrinsic camera parameters) of camera and the mechanical zero position or optical axis direction of video total station. This discrepancy and the intrinsic camera parameters such as the focal length or lens distortion of camera are supposed to be a fixed value. The mechanical zero position of the video total station in CAD coordinate system can be calculated by installing the video total station in the plant, placing the targets on the datum point and the line of the plant (equivalent to the zero point and the axis of CAD coordinate system) and measuring the three-dimensional coordinate value of the target. Further, the direction of optical axis can be calculated from the vertical angle and horizontal angle of the video total station at a time when the flange has been photographed. This system has been designed to determine the position and posture of camera in CAD coordinate system by adding the foregoing discrepancy to these values.

4.2 Collation of camera image with CAD diagram

Fig.7 shows a monitor image obtained by display the flange stereo image and CAD diagram with both superimposed. CAD diagram of the flange has been represented as an aggregate of

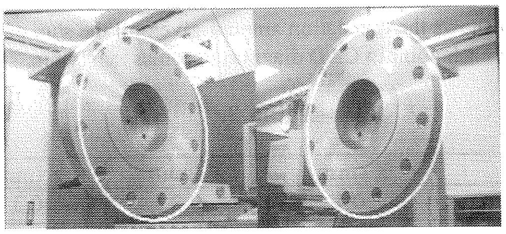


Fig. 7 Flange Stereo Image

points on the outer circumference of the flange. The worker, while observing the monitor image, can confirm the conformity between the flange outer circumference of stereo image and CAD diagram, giving the three-dimensional translation amount and rotation amount to CAD diagram interactively. However, when this method is taken, the worker cannot identify even if an amount of move of lees than 1 pixel of the frame memory is given.

Therefore, a differential processing may by given by the image processing relative to the stereo image to get a stereo contour image of the flange. When this stereo contour image has been superimposed on CAD diagram, a position where the sum of pixel concentration of each point on the flange outer circumference in CAD diagram becomes maximum can be judged to be a position where CAD diagram and stereo image accord the most with each other. What's more, though each point in CAD diagram has a coordinate precision of less than a decimal point after perspective projection has been made, it is cut down to an integral coordinate value on the frame memory (512 pixels × 512 pixels). Thus, a gray level cannot be obtained at the coordinate precision of less then 1 pixel. Therefore, it has been decided to obtain the gray level at the coordinate precision of less than 1 pixel from the gray levels of 8 pixels nearby the pixel of each point in CAD diagram by interpolation. The worker can judge a degree of conformity between CAD diagram and stereo image with the sum of gray levels displayed by the monitor as an index. **Fig.8** shows a monitor image obtained by superimposing CAD diagram on the stereo contour image of flange. This system incorporates such feature that since a three-dimensional translation amount is given directly to CAD data, it is unnecessary to determine a corresponding point which becomes necessary in a stereo photogrammetry.

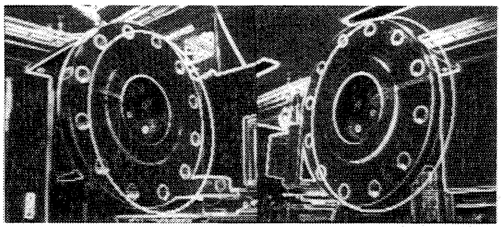


Fig.8 Stereo Contour Image

4.3 Measurement accuracy

With a flange of 350mm in diameter taken as an object of measurement, the center position and posture of the flange was measured by the measurement system of total station using the foregoing target and the measurement accuracy was confirmed by CAD base measurement system with the above measurement results used as CAD data. The flanges taken as the measurement object was photographed as large as possible in the visual field of camera at two video total station. In this case, 1 pixel of the frame memory is equivalent to about 1mm in actual size. **Table 3** shows the translation amount given till the sum of gray levels at each point in CAD diagram becomes maximum.

Table 3.

	X (mm)	Y (mm)	Z (mm)
Position	0.4	0.2	0.3
Posture	0.1	0.2	0.1

The value shown in **Table 3** becomes a deviation between the measurement system of total station using the target and CAD base measurement system. The deviation between both systems was maximum 0.4mm in a translation amount and maximum 0.2° in a rotation amount. It has been verified from the results that the measurement accuracy secured by CAD base measurement system satisfies a desired accuracy even if the accuracy insured by the system of total station using the target is taken into additional account.

5. Conclusion

Aiming at promoting the pipe prefabrication method in a chemical, a three-dimensional measurement system has been built up with the flange of apparatus and pipes in the plant taken as the measurement object. With application of a system using a total station requiring a target at the measuring point of the site, it has been confirmed that the prefabrication method can be realized by the three-dimensional data control. Further, in order to save the time and labor required for mounting the target, the three-dimensional measurement system was examined by collating a stereo image with CAD diagram which is the measurement object and a system including 2 servo-drive type video total station has been built up. In particular, it has been confirmed that a problem of correspondence detection encountered in the stereo measurement can be worked out by applying the concept of CAD base vision which is advocated now in the field of image recognition and also, a desired measurement accuracy can be satisfied by collating the sub-pixel in CAD diagram with a contour image obtained by image processing, and a prospect of putting the system to practical use has been obtained.

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