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DEVELOPMENT OF A COMPACT SURVEY SYSTEM FOR SMALL SHIELD TUNNELING

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ABSTRACT

A compact survey system for small shield tunneling has been developed.

The real time data acquisition system offers information on pitching,rolling and yawing of the shield machine as well as location. A set of the system comprises a target including three LEDs and a prism reflector,a detector including a TV camera and a electronic transit,and a image processor. Since the detector is placed far from the shield machine,the system can be applied to small tunneling under 4 meter of diameter,whereas existing survey systems in laser technology can be applied only to large shield tunneling due to their target size. The performance of the system has been proven through on-site uses at small shield tunneling projects.

1.Introduction

In order to perform shield tunneling very accurately and efficiently, it is necessary to have correct directional control, which holds a shield machine operating on a planned line by continuously recognizing the location and position of the machine.

Transits and levels have been conventionally used to survey the locations and the directional movements of shield machines. Automatic survey systems using lasers and gyro compass have been recently developed and put into practical use. However, most of such systems are designed for large-gage shield tunneling, leaving problems to be solved regarding the compactness and environmental resistance of machines to the recent trends toward smaller shield gages.

Under these circumstances, we have developed an automatic surveying system designed to detect in real-time the location and the position of the shield machine primarily for small-gage shield tunneling. This report presents an outline of this newly developed automatic surveying system and the results of its application in practical construction works.

2. Design concept for automatic surveying system

The system was originally intended to cover wide ranges of shield gages, including smaller ones, in shield tunneling. The basic design concepts were as follows:

a) The target installed in the shield machine should be compact, low-cost and resistant to the environment.

b) The detector should be located in the rear segment, which is scarcely affected by temperature, humidity, vibration, etc., and it should be capable of remotely detecting the location and the position of the shield machine.

The design concept for the automatic surveying system is shown in Fig. 1. The most essential feature of this system is its capability of remotely detecting deviations of the shield machine from the planned line and pitching, rolling and yawing angles to the planned line using a single sensor.

3. Structure of automatic surveying system

The automatic surveying system consists of a target installed in the shield machine, a detector installed in the rear segment, and a processing unit installed in the control room. The structure of the system is shown in Fig. 2.

3.1 Target

The target consists of three light-emitting diodes (LED) located in an equilateral triangle arrangement for detecting location and positional angles, and a reflecting prism for an electronic distance meter. The LED units must be clearly recognizable against the background of the image processor. For this purpose, high-luminance red LED units, easy to see, are used instead of infrared types, which can also be used. To prevent the loss of measuring accuracy for positional angles involved in long excavating runs of the shield machine, the spacing of the LED units (the length of each side of the equilateral triangle) is a 4-step variable in the range of 50mm - 200mm. The structure and the appearance of the target are shown in Fig. 3 and Photo 1, respectively.

3.2 Detector

The detector consists of an electronic distance- and angle-measuring instrument equipped with an electronic distance meter. This instrument, which is called a total station, has a TV camera mounted on it. It also has a motor-drive for horizontal and vertical angle micro-adjustment and focus adjustment. The total station was modified to be capable of remote control from the control room. The TV camera is mounted via relay lenses of 2, 4 and 8 magnifications, which can be selected according to the distance to be measured.

The total station has an RS-232C circuit that provides functions for permitting communication control with a computer. This enables the processing unit in the control room to measure distances and angles in any timing as well as to give the results of such measurements. With these functions the detector can properly detect the location and position of the target even when the shield machine deviates from the planned line or moves on a planned curve. The appearance of the detector is shown in Photo 2.

3.3 Processing unit

The processing unit consists of an image processor and personal computer. Upon receiving picture signals from the TV camera, the image processor picks up the bright points (the 3 LED units of the target) moving in the picture, and describes them as locational coordinates in a picture coordinate system (X=512 dots; Y=384 dots) incorporated in the system. Also, while automatically following the bright points, the image processing continuously outputs X - Y coordinates for them.

The personal computer calculates the location and position of shield machine from the output values of the image processor, from the distance and angle measurements given by the total station, and from the planned line stored in the floppy disk. The appearance of the processing unit is shown in Photo 3.

3.4 Communication unit

To transmit picture signals from the TV camera, the measured data from the total station, and the remote control signals, the automatic surveying system employs a data transmission system using an optical fiber cable. The communication line between the detector and the processing unit consists of a 5-core optical fiber cable 13mm in O.D. (1 core is spare).

3.5 Supervision of excavation

The results of surveys conducted by the processing unit are graphically displayed in real time on the CRT as shown in Photo 4. Using this information, the operator carries out the excavation with the shield machine.

The specifications of the main components of the system are shown in Table 1.

4. Measuring principle

Detection of positional angles (yawing, pitching and rolling) is based on the following ideas (see Fig. 4):

The apexes of the target triangle, whose size is known, are photographed by the TV camera. The resulting picture provides the coordinates of the target triangle. Positional angles are obtained from the locational relations of 3 points in the picture.

Locations are calculated from the coordinates of the datum point at the location of the detector, the distance of the horizontal and vertical angles to the target measured by the total station, and locational data for the apexes obtained from the image processor. This process is shown in Fig. 5.

5. Locational and positional detection performance

This system's ability to detect location and position was checked experimentally.

5.1 Positional detection

For positional detection, a test target was mounted on a theodolite to establish positional angles and measurement was performed by using the survey system. One result of this measurement is shown in Fig. 6. Positional angles depend on the size of the target on the picture of the image processor. The larger the target on the picture, the smaller the errors. The positional angle detection errors of the system can be kept below 0.2 degree by varying the lens magnification and the target size in accordance with the distance to be measured, ensuring that the length of the sides of the target triangle on the image processor are about 200 dots.

5.2 Locational detection

With the target moving against the stationary detector,the locational detection accuracy of the image processor was measured. Fig. 7 shows one result of a test in which the target was moved on the X - Y table for target movement. The maximum dot deviation on the picture is 1 dot. If the sides of the target ensure 200 dots on the picture, detection accuracy is within +- 1mm even with the largest target (a 200mm target).

The detection accuracy of the surveying system is determined by the detection accuracy of the image processor and of the total station. The system covers a measuring range from 10m to 200m. From a series of tests, it has been judged that the locational and positional detection accuracy of the system would also occur in actual works.

6. Results of application to actual works

The system was applied to soil pressure type shield tunneling with a shield O.D. of 3500mm.

The target mounted on the shield machine and the detector installed in the rear segment are shown in Photo 5 and 6, respectively.

6.1 Survey accuracy

Fig. 8 shows the traces of the shield machine surveyed by the system as compared with the results of an assembled segment survey using a theodolite and levels. The assembled segment nearly agrees with the excavation traces and the location of the shield machine can be assumed to be the estimated location of the segment some rings ahead. Thus, if direction control is carried out on the basis of the surveyed results of the system so that the shield machine advances on the planned line,excavation can be performed more accurately with this system than with conventional segment surveying at intervals of several rings.

6.2 Survey efficiency

Generally, in assembled segment surveying, 2 - 3 surveyors perform several surveys per day, each survey taking about 1 hour. Except for datum-point checking, this system can record survey data for each ring almost automatically, enabling survey work to be done with greater efficiency and less labor.

6.3 Resetting of detector

The detector is reset when target collimation becomes impossible due to curved excavation, or when the maximum measuring range is exceeded.

Detector resetting, including removal, mounting and positioning, can be performed by 2 workers in about 30 min. It can thus be performed during the time when workers change shifts, and need not disturb with the normal flow of work.

7. Conclusion

The newly developed automatic surveying system was designed to be usable for smaller-gage shield tunneling, for which the system was originally intended. The employment of this system enables the location and position of the shield machine to be consistently recognized, proving very effective, accurate and efficient in shield tunneling. Data on the excavating traces and the running direction of the shield machine, and on the operator's correcting operations on the basis of surveyed results by the system, was analyzed and automation of directional control is being studied. The locational and positional detecting functions of the system are considered to be applicable in other areas and investigation will be made on those applications.

Acknowledgment

We express our sincere thanks to the concerned who offered assistance in the development of this automatic survey system.

References

1. Takaaki Tsuruoka, Tadao Mikami :" An Automatic Survey System for Small Shield Tunneling ",(in Japanese) . Proc. of The 41st Annual Conference of the JSCE, Nov.1986

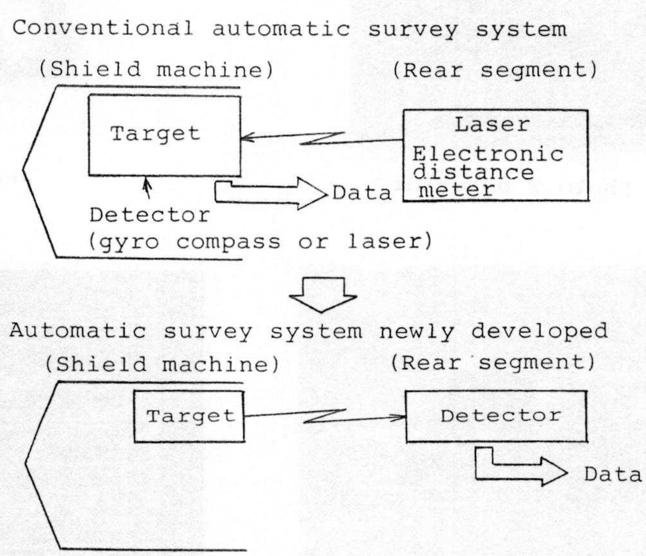


Fig.1 Design concept of automatic survey system

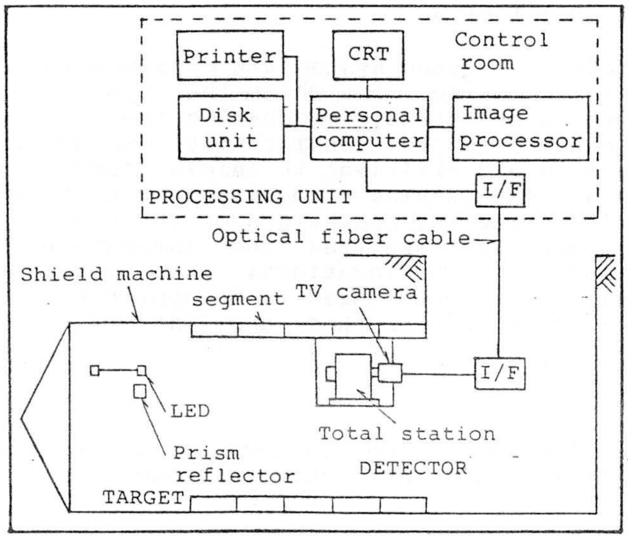


Fig.2 Disposition of survey system

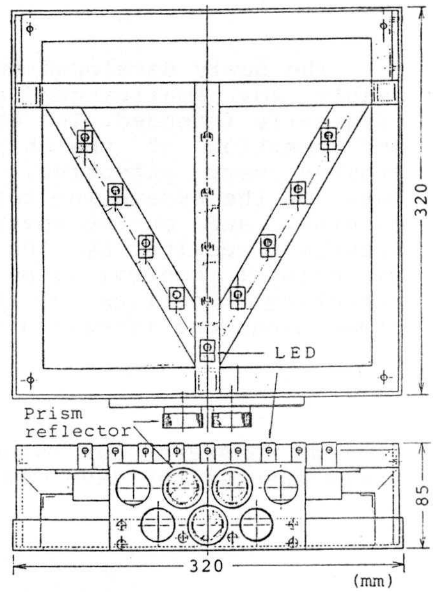


Fig.3 Target

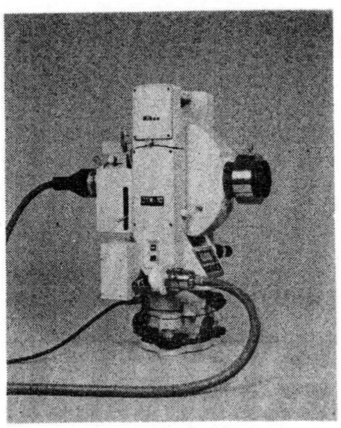


Photo 2 Detector

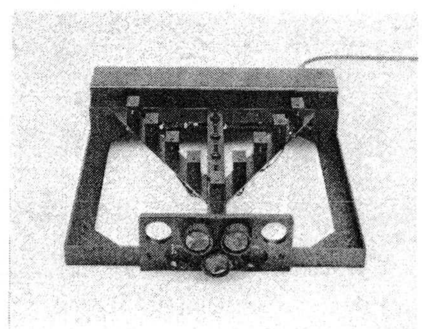


Photo 1 Target

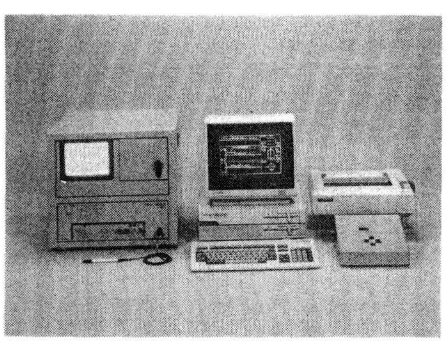


Photo 3 Processing unit

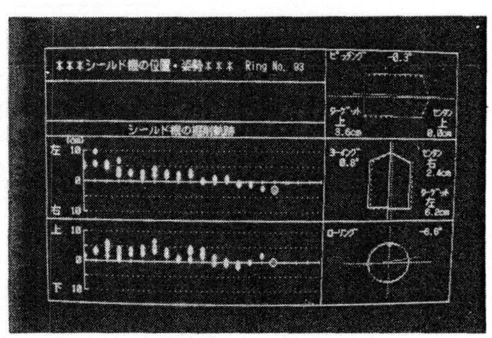


Photo 4 Graphic display

Table 1 Specifications

TARGET	LED	Red (Visible)
	Prism reflector	ϕ24mm
DETECTOR	Total station	Accuracy Distance $\pm$(5+5ppm×D)mm Angle 10"
	TV Camera	Image tube CCD Resolution (H)250×(V)480
PROCESSING UNIT	Image Processor Personal computer	Resolution (X)512×(Y)384 CPU 16bit RAM 640KB

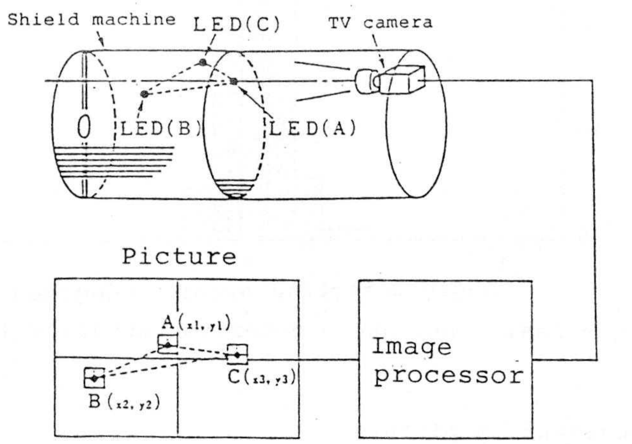
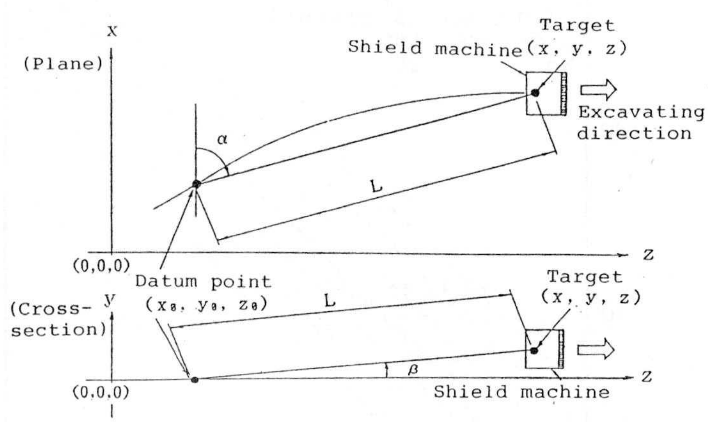


Fig.4 Method for detecting positional angles



$x = x_0 + L \times \cos\alpha + x_1 \quad y = y_0 + L \times \sin\beta + y_1 \quad z = z_0 + L \times \cos\beta$

(x, y, z) : 3-dimensional coordinates for shield machine target

(x_0, y_0, z_0) : 3-dimensional coordinates for datum point

(x_1, y_1) : locational data obtained from the image processor

L : distance between datum point and target

α : horizontal deviation angle β : vertical deviation angle

Fig.5 Location detection method

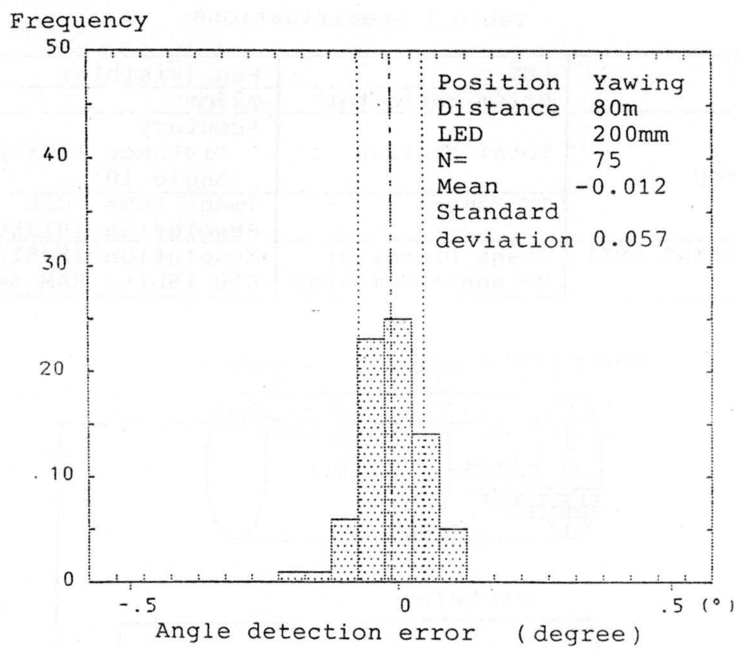


Fig.6 Positional angle detection accuracy (yawing)

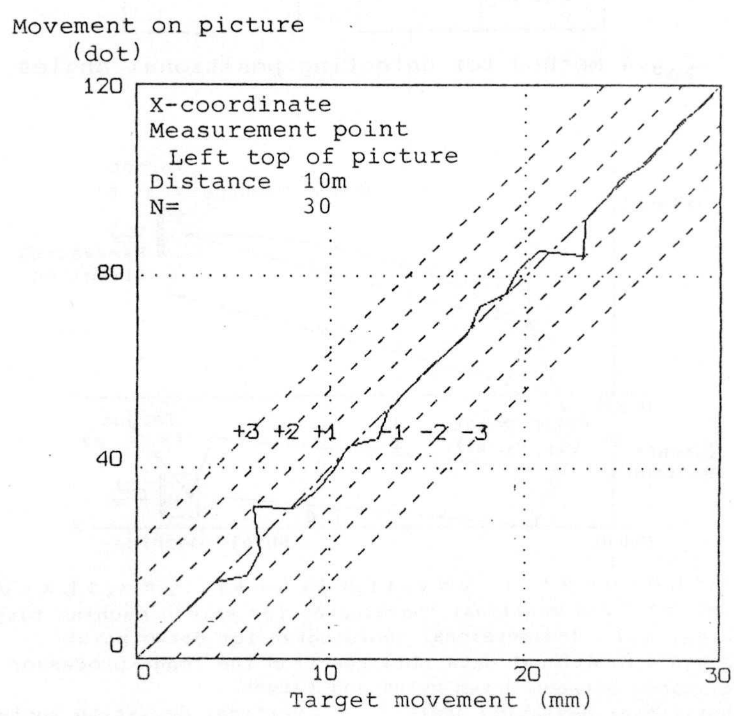


Fig.7 Locational detection accuracy (X-coordination)

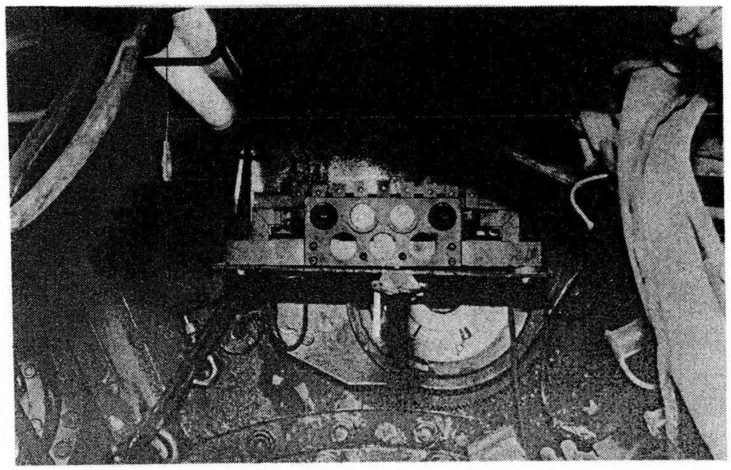


Photo 5 Target mounted on shield machine

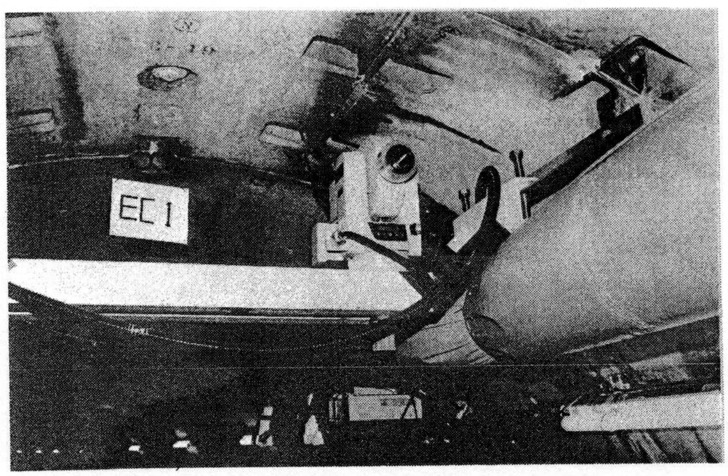


Photo 6 Detector mounted on segment

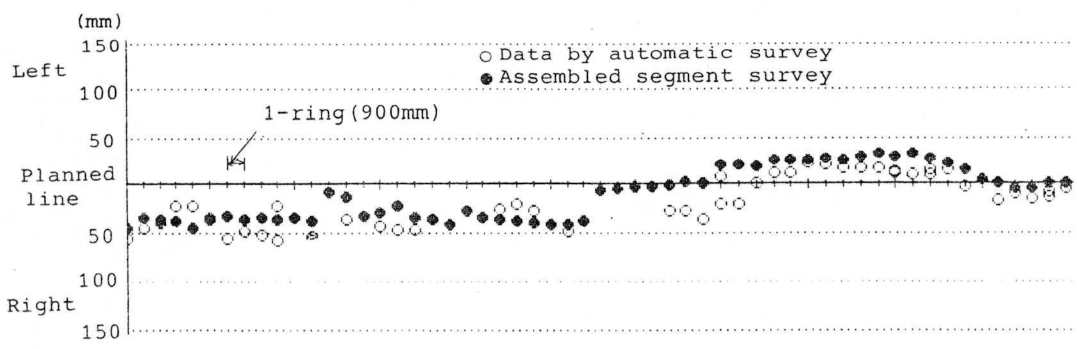


Fig.8 Trace by automatic survey system and results of assembled segment survey