LASER MARKING SYSTEM BASED ON 3D CAD MODEL

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ABSTRACT: In many cases of renovation work, it is very difficult to gain sufficient information about the existing building such as the positions and dimensions of the frame, interior and equipment because of incomplete or missing drawings. As a result, it is necessary to fabricate the parts on the construction site. We have been developing a system for measuring existing buildings precisely using a 3D laser scanner before renovation work, fabricating the parts in factories and assembling them on site. This system will increase productivity and eliminate construction waste. The system requires a function for positioning of the parts and marking precisely on the site. Our developed marking system determines positions from 3D-CAD data and indicates them with a motor-driven Total Station. The position data is produced from objects such as points and lines stored in a design file, and is saved as a marking data file. The Total Station reads the data file and marks the positions by laser automatically and precisely.
This report describes the function to produce the position data file and to mark the positions with the Total Station. It also shows the results of a field test at an actual construction site. This research was carried out with a grant from the Ministry of Land, Infrastructure, Transport and Tourism.

Keywords: *Renovation Work, 3D CAD, 3D Laser Scanner, Total Station, Marking*

1. INTRODUCTION

In many cases of building renovation work, it is difficult to obtain sufficient information about the existing building because the as-built drawings are either missing or inadequate. This makes it difficult to design the renovation work according to the figures, positions and sizes of the existing building, and so productivity decreases and much surplus material is generated because parts must be processed on site. We have been developing a production system for measuring the components of an existing building such as the frame, interior finishes, and equipment by using a 3D laser scanner, designing based on the data by 3D CAD, and then fabricating the parts in factories and marking their positions based on the drawings on site. This system will enable efficient, ecological construction without on-site fabrication of parts and the associated waste[1)].

The accurate positioning function based on drawings is very important in this system. Traditional marking work on the construction site is inefficient and has limited accuracy due to manual procedures such as using a scale, plumb bob and laser instrument. In contrast, in civil engineering work various information technologies such as the total station, 3D CAD and GPS have been developed and many research papers have been published[1][2][3]. We have developed a marking system for extracting position data from a 3D CAD model designed based on data measured by a 3D laser scanner and projecting them efficiently and accurately onto the construction site with a motor-driven total station. Obviously, this is also effective for newly construction works.

This report describes a function for extracting positions and making marking data, and then explains a method of pointing with a laser and marking with an original device for marking with a motor-driven total station. The result of experiment for confirming the marking accuracy and that of usage on an actual construction site are also described.

2. MAKING THE MARKING DATA FROM 3D CAD MODEL

2.1 Outline of the Function

This function extracts the position information of parts from the 3D CAD drawing and makes the marking data. The system uses a 3D model viewer[2)] which is low-cost and can be easily run on a laptop computer on site. The working drawings are opened as reference files and the position information of parts is registered in a new file for drawing (called "marking file" below).

2.2 Details of the Function

(1) Registration of base lines

As shown in Figure 1, a base line is copied and registered on the marking file as a base line object by clicking on it in the reference file. The base line object is a line segment which has a base line name as an attribute, and can be edited such as moving, extending and contracting.

(2) Placing reference lines

Offset lines, vertical lines and horizontal lines are made automatically from the base line and the intersection of a base line with a wall or post. An example of placing offset lines is shown in Figure 2 and one of placing horizontal lines in Figure 3. A pair of offset lines is made automatically on both sides of the base line. Here, the distance from the base line and the height need to be input.

(3) Placing marking objects

Marking objects are placed at the positions for marking based on the reference file. The list of marking objects is shown in Table 1. Each object has a tag attribute for confirming the contents consistently. An example of placing a square object is shown in Figure 4.

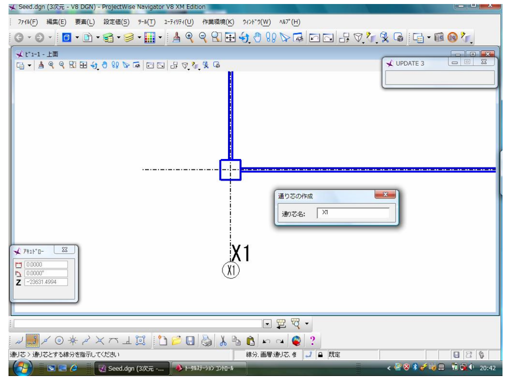

Fig.1 Registration of the Base Line

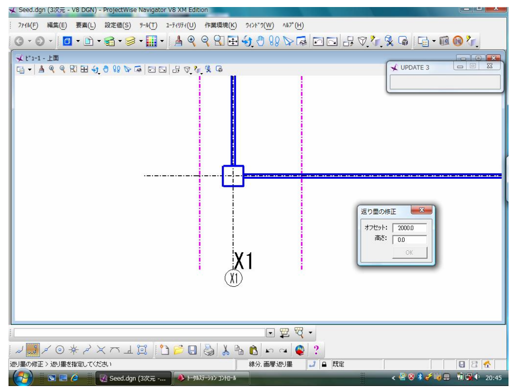

Fig.2 Allocation / Relocation of the Reference Line

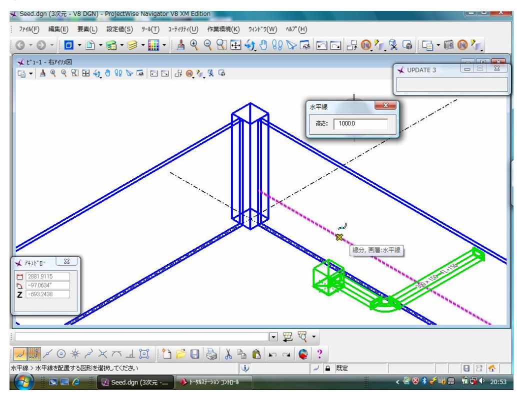

Fig.3 Allocation of the Horizontal Line

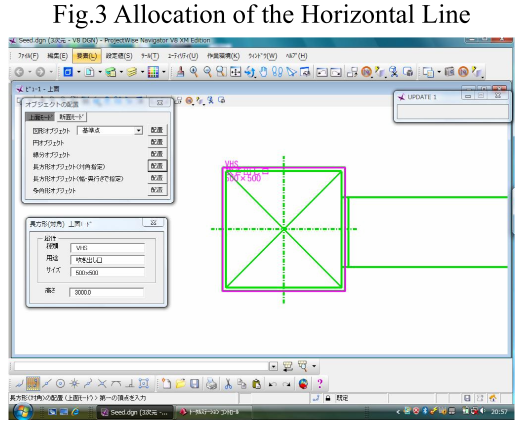

Fig.4 Allocation of the Rectangle Object

Table 1 Summary of marking objects

No.	Name	Applications
1	Point	Anchor, Insert, etc.
2	Circle	Sleeve, Circular diffuser, etc.
3	Line	Partition, etc.
4	Rectangle	Rectangle sleeve, Diffuser, etc.
5	Polygon	Polygonal sleeve, etc.

Table 2 Marking points and number of objects

No.	Name	Marking Point and Number
1	Point	One point
2	Circle	Center of circle (One)
3	Line	Start and end of the line (Two)
4	Rectangle	Four vertexes
5	Polygon	Vertexes (more than five)
6	Reference line	Intersection with other reference lines or edges of the frame (plural)

(4) Output marking data

The line and point objects registered and placed in the marking file are transformed to the marking point data andsaved as data files with each object. The number of marking points depends on the type of object as shown in Table 2. Marking data consists of coordinate data and unit normal vector of the surface on which the objects are placed.

3. MARKING AND POSITIONING FUNCTION

3.1 System Configuration

The system configuration is shown in Figure 5. The motor-driven total station[3)] can automatically radiate the laser at an arbitrary point, except for midair positions, with the angle control function and laser range finder. This system can be operated by one person with a remote controller using wireless LAN. The target is a self-contained prism with a level and is set on the reference point for measuring the self-position of the total station in the field coordinate system. The marking unit is used for accurately marking the point radiated by the laser.

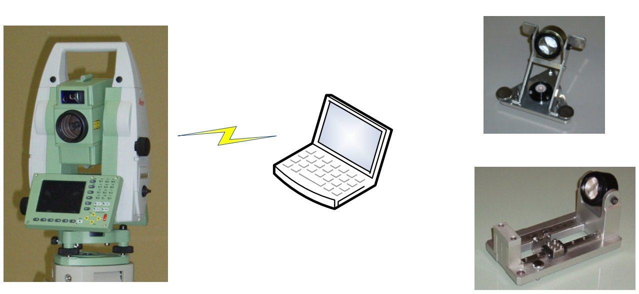

Fig.5 System Configuration

3.2 System Functions

(1) Initialization

Initialization involves measuring the position and direction of the total station. As shown in Figure 6, the position in XY coordinates is calculated using the horizontal distances between the total station and each of two reference points at which a target is set and the angle between them. The x axis of the coordinate system of total station is defined the direction to the origin of the field coordinate system as shown in the figure. The height is calculated from measurements of each reference points of height, distance and vertical angle as shown in Figure 7. Here, TS means total station in the figures of this paper.

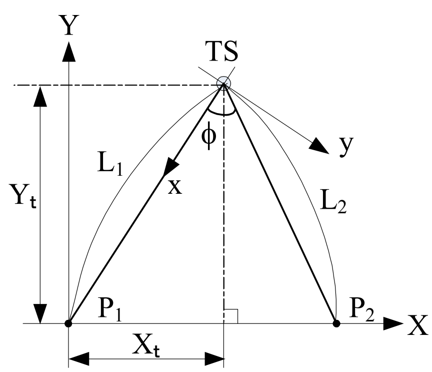

Fig.6 Measuring TS Position in XY Coordinate

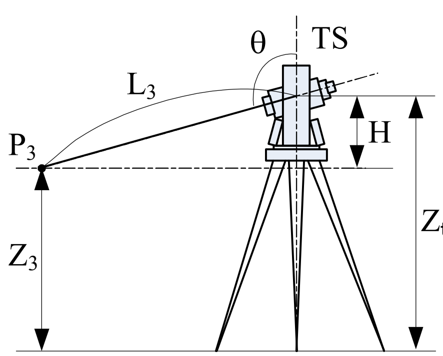

Fig.7 Measuring TS Height

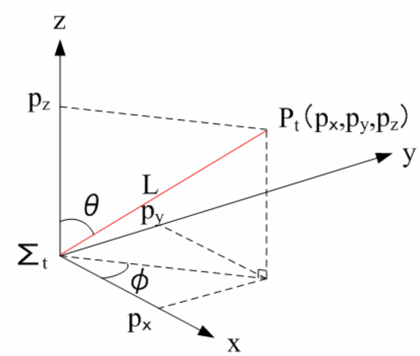

Fig.8 Point on the Local Coordinate System

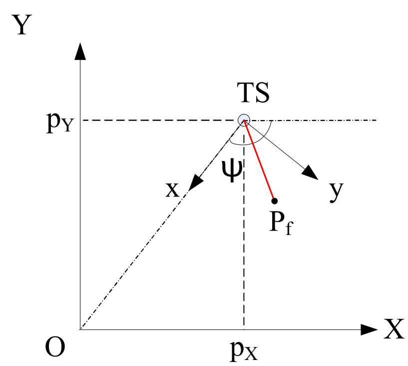

Fig.9 Transformation to the Field Coordinate System

(2) Marking function

This function is used for positioning and marking with the angle control and laser radiation of the total station. As shown in Figure 8, the total station calculates the coordinates of measuring point P_t with the horizontal and vertical angles, ϕ and θ , and the distance L in the coordinate system of the total station, $\sum_t$. As shown in Figure 8, the coordinates of P_t are transformed to the field coordinate system with the rotational angle around the Z axis, ψ, and the position of the total station, T $[X_t,Y_t,Z_t]^T$. By this inverse calculation, it is possible to calculate the horizontal and vertical angles for radiating the laser.

However, this pointing method has two problems:

1) The laser is radiated at an incorrect point if the target object such as a floor, ceiling or base is different from the drawing.
2) The laser spot becomes longer depending on the incident angle, making it hard to specify the point.

Regarding the first problem, our system can measure the coordinates of the radiation point and correct the position.

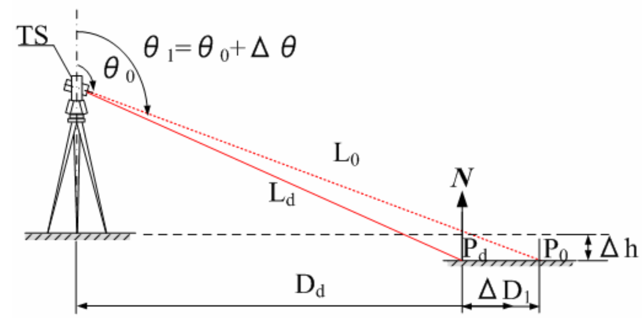

Fig.10 Correcting the Indicating Position

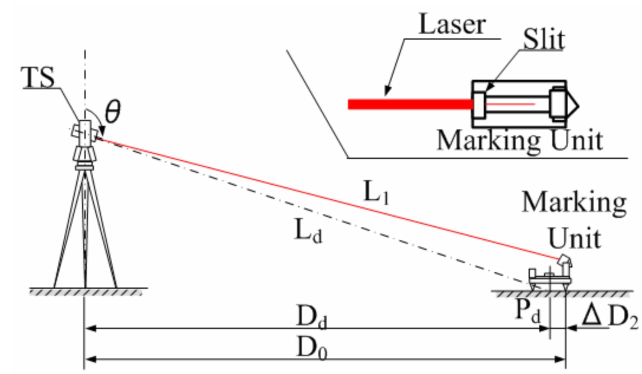

Fig.11 Marking Principle with the Marking Unit

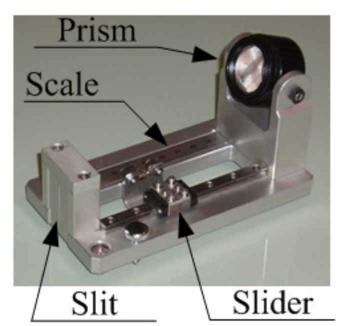

Fig.12 Marking Unit

As shown in Figure 10, if the floor height of the target point is different from the designed value, the laser is radiated at the incorrect point. This system measures the distance L_0 and calculates the coordinates of the radiated point P_0. The corrected value of the vertical angle ΔD_1 is calculated from the difference between P_0 and P_d. The total station radiates the laser at the corrected angles and measures the point again. This cycle is repeated until the difference from the target point becomes within acceptable tolerance. In adjusting the position, the normal-direction component of the coordinates is ignored. Therefore, the marking data made from the 3D CAD includes not only the

3D coordinates but also the unit normal vector of the radiated surface.

The developed marking unit solves the second problem. As shown in Figure 11, the unit has a prism to accurately measure the horizontal distance D_0 from the total station. As shown in Figure 12, the unit is set on the laser spot after radiation and the total station measures the distance D_0. The system figures out the difference ΔD_2 from the horizontal distance D_d to the target point P_d. The operator can specify the marking point by adjusting the position of the slider with the mounted scale.

The marking unit has a manual level adjuster and direction adjuster with a slit for setting horizontally and directly to the total station.

4. COOPERATION WITH 3D CAD

4.1 Making Parameters for Initializing

For initialization, it is necessary to input information about two reference points, such as the distance from the origin on the X or Y axis and the direction of plus or minus. It is very important to avoid errors in the initialization because such errors will affect all marking positions. This system has a function for making the data file of the reference points on 3D CAD visually.

As shown in Figure 13, the field coordinate system is set by specifying the origin and the direction of the X axis on 3D CAD. Here, the Z axis is always vertical. Next, the data file of the two reference points is made by specifying the two points referenced on site on CAD. The total station reads this file automatically and uses it for calculating during the initialization.

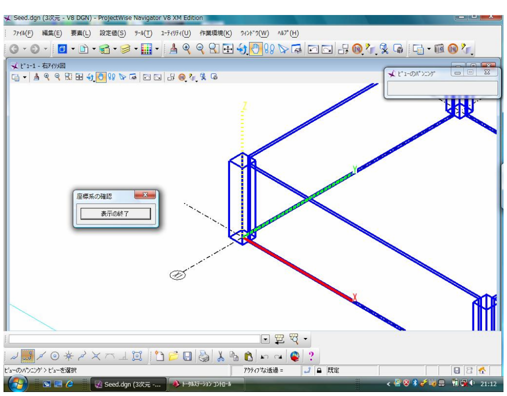

Fig.13 Configuration of the Field Coordinate System

4.2 Managing the Marking Work

The system creates a file of the marking points for which marking has been finished. The manager can confirm the progress of the marking by the change in color of the finished points on CAD without going to the site.

5. EXPERIMENTS

5.1 Confirming the Marking Accuracy

Six target positions from No. 1 to 6 for marking were set on the experimental site as shown in Figure 14. The errors from the target positions are shown in the figure. It is confirmed that the accuracy of marking is less than about 2 mm inside a circle with radius 15 m. These errors are calculated as the difference between the measuring result of the marking point with two transits (T_1 and T_2) and the target point.

5.2 Field Test

In order to confirm the applicability to the construction site and the efficiency, we used this system at an actual construction site for marking the inserts on the site of a large office building, which has 27 floors above ground and 4 below and a total floor space of about 140,000 m^2. The marking data was made by locating the point objects at the insert positions referenced from the drawing of the inserts on the 3D model viewer. Using the system, the workers could mark more than 1,000 points a day, which is about three or four times faster than the traditional method.

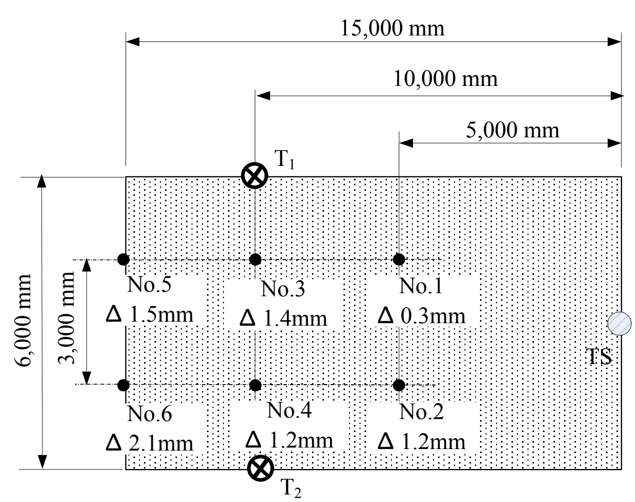

Fig.14 Experimental Field and the Result

It was also confirmed that the system prevents human error because there is no need to read the drawings and measure with a scale on site.
The situation of marking is shown in Figures 15 and 16.

6. CONCLUSION

In this study, we developed a system for creating the marking data from the position information of each part extracted from the 3D CAD model and marking with a motor-driven total station, and confirmed that it is possible to mark with an accuracy of less than 2 mm. Field tests at an actual construction site confirmed that the system has a sufficient applicability for real site, to increase the productivity and prevent human errors.

Fig.15 Field Test on the Construction Site (No.1)

Fig.16 Field Test on the Construction Site (No.2)

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Note:

1) This study was carried out as a subsidized project by The Ministry of Land, Infrastructure, Transport and Tourism.
2) Projectwise Navigator XM Edition (Bentley)
3) TCRP1205+ (Leica Geosystems)