Development of Virtual Survey Marking System for Remote Control of Construction Machinery Ⅱ

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ABSTRACT

The authors are developing the Virtual Survey Marking System (VSMS) for use in remote control construction of structures such as erosion control dams. Tests of the performance of this system in slope grading operations were recently conducted at Mt.Fugen at Unzen in Nagasaki Prefecture. In these tests it was possible to perform slope grading with a maximum precision of approximately 86% when the design slope gradient of the virtual reference marks was 1:1(100%). In the future we intend to improve the method of displaying the virtual reference marks in order to achieve a higher degree of precision. To be specific, we intend to investigate a method of display in which the results of measuring the excavated surface configuration are used as feedback.

1 Introduction

Remote control technology for construction machinery enables the safe performance of construction operations in dangerous areas and can be employed as a means of reducing arduous operations. In Japan, genuine remote control construction by remote control of construction machinery is being performed for disaster prevention measures at Mt.Fugen at Unzen in Nagasaki Prefecture.

The authors are developing the Virtual Survey Marking System(VSMS) as a technology to support remote control construction. VSMS is a system to generate virtual reference marks by computer graphics, synthesize these with stereo camera images for machine operation and show this to the machine operator as a combined stereo image for the remote control construction of structures such as erosion control dams. Basic experiments performed up to the present have confirmed that this system is effective in positioning a construction machine and performing excavation.[1]

This paper describes the experimental system which was newly developed for practical use and reports the results of performance tests conducted at Mt.Fugen construction works.

2 System composition

VSMS is composed of a stereo camera, a virtual reference mark formation block, an image synthesis block and a stereo image display block.[1] The stereo camera is mounted in a fixed position in the operator's cabin of the construction machine and the other blocks are located in the remote control room.

The stereo camera provides a three-dimensional image for machine operation, and the virtual reference mark formation block uses design information to generate virtual reference marks by graphics computer. The image synthesis block combines the three-dimensional image and the computer generated virtual reference marks into a three-dimensional synthesized image which is shown to the operator by the stereo image display block.

Because the position and attitude of the stereo camera change when the construction machine moves, the image acquisition range of the stereo camera also changes. On the other hand, because the virtual reference marks represent design information, they must always be displayed in the proper position even though the stereo camera image changes. To achieve this, it is necessary to measure the position and attitude of the construction machine in real time and correct the positions on the monitor screen at which the virtual reference marks are generated.

For this reason, the system was revised so that data on the position and attitude of the construction machine can be measured in real time as shown in Figure 1.

The virtual reference mark formation block in the remote control room was revised so as to compute the amounts of correction corresponding to the changes in construction machine position and attitude to enable display of the virtual reference marks in the proper positions for the operation at all times.

The following paragraphs describe the composition of devices on the construction machine and the virtual reference mark formation block which were newly improved in order to add the above described function to the system.

2.1 Devices on the construction machine

In addition to the stereo camera, a GPS(Global Positioning System) unit and a triaxial gyroscope were mounted on the construction machine. The RTK(Real Time Kinematic) GPS unit is used to measure the absolute position of the construction machine, and the laser type triaxial gyroscope is used to measure the roll, pitch and yaw of the construction machine.

The measured data on position and attitude is transmitted through a notebook computer and by radio to the main body of the VSMS equipment(virtual reference mark formation block) in the remote control room. The stereo camera image also is transmitted in the same way by radio to the remote control room.

2.2 Virtual reference mark formation block

The virtual reference mark formation block generates virtual reference marks by graphics computers based on design information. As shown in Figure 1, in this system, position and attitude data transmitted from the construction machine is received by the master graphics computer and transmitted to the slave graphics computer by means of a serial cable. The graphics computers generate virtual reference marks based on the received data on position and attitude of the construction machine. The virtual reference marks for the left and right eyes are generated, including binocular parallax, by one of the two graphics computers dedicated respectively to each eye, but it makes no difference to which eye the master computer(or the slave computer) is dedicated.

In order to generate the virtual reference marks, the coordinates of the points of sight of the stereo camera and data on the lines of sight need to be known. The virtual reference mark formation block computes the amount of correction to the coordinates of the points of sight and the lines of sight of the stereo camera from the data on the position and attitude of the construction machine.

The design information which forms the basis of the virtual grading reference marks is based on the site coordinate system which is separately established at each site. Therefore, it was decided that the input data for generation of virtual reference marks would be input on the site coordinate system. As shown in Figure 2, the position of the stereo camera on the site coordinate system and the lines of sight can be obtained by converting the GPS reception data to the site coordinate system.

The principal components of the subsystem on the construction machine and of the virtual reference mark formation block are shown in Table 1. The flow of system processing is shown in Figure 3.

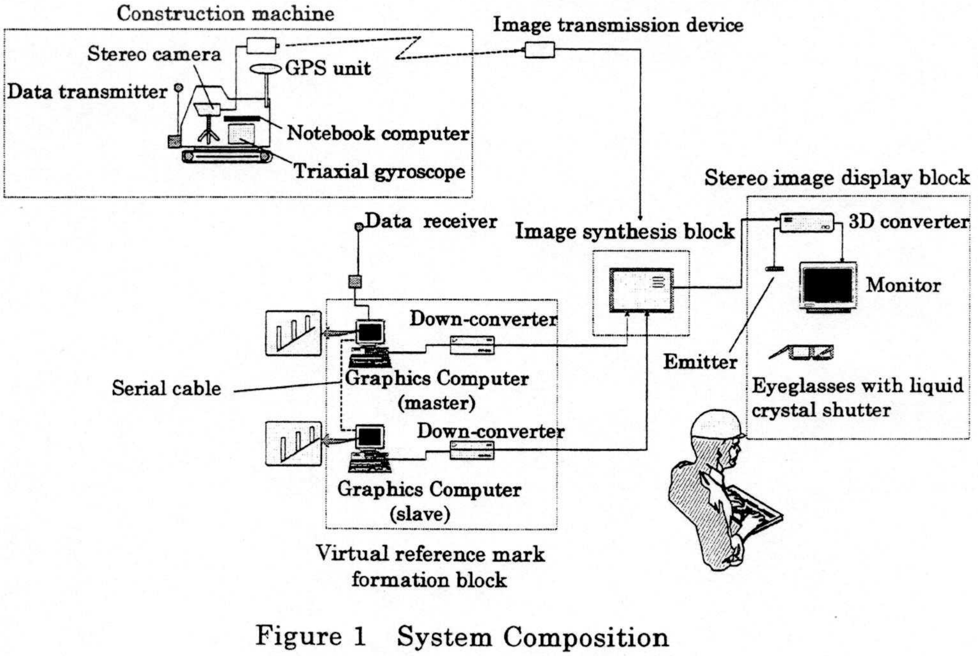

Figure 1 System Composition

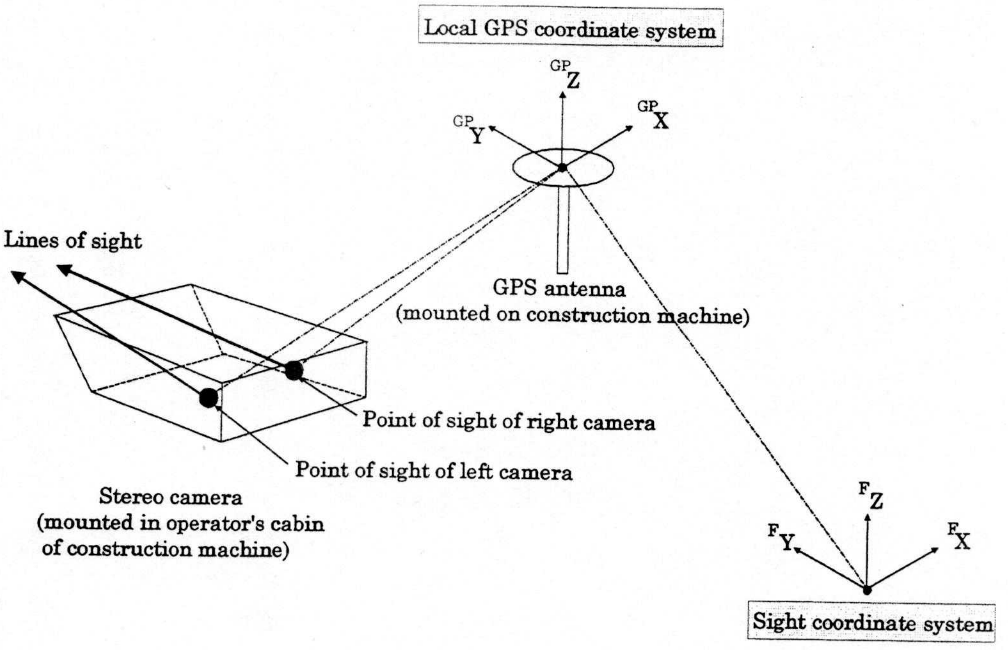

Figure 2 Coordinate System

Table 1 List of Principal Component Devices

Subsystem on the construction machine	Stereo camera
	GPS unit
	Triaxial gyroscope
	Image transmitter
	Position and attitude data transmitter
Virtual reference mark formation block	Graphics computers (master and slave)
	Position and attitude data receiver

3 Test results

3.1 Test method

Tests in slope grading operations were performed using this system at the Mt.Fugen construction site at Unzen in Nagasaki Prefecture. As shown in Photo 1, design gradients for slope cutting were shown by virtual reference marks on an embankment(slope gradient of approximately 20°) and slope cutting was performed according to these marks. The construction machine used in these tests was a $1.6m^3$ hydraulic shovel which was equipped for remote control. The virtual reference marks can be displayed in three patterns, as in Figure 4. The tests were performed in two parts ; Test 1 in which the design gradient was held constant and the pattern was changed , and Test 2 in which differing design gradients were displayed using the same pattern. The test arrangement is shown schematically in Figure 5.

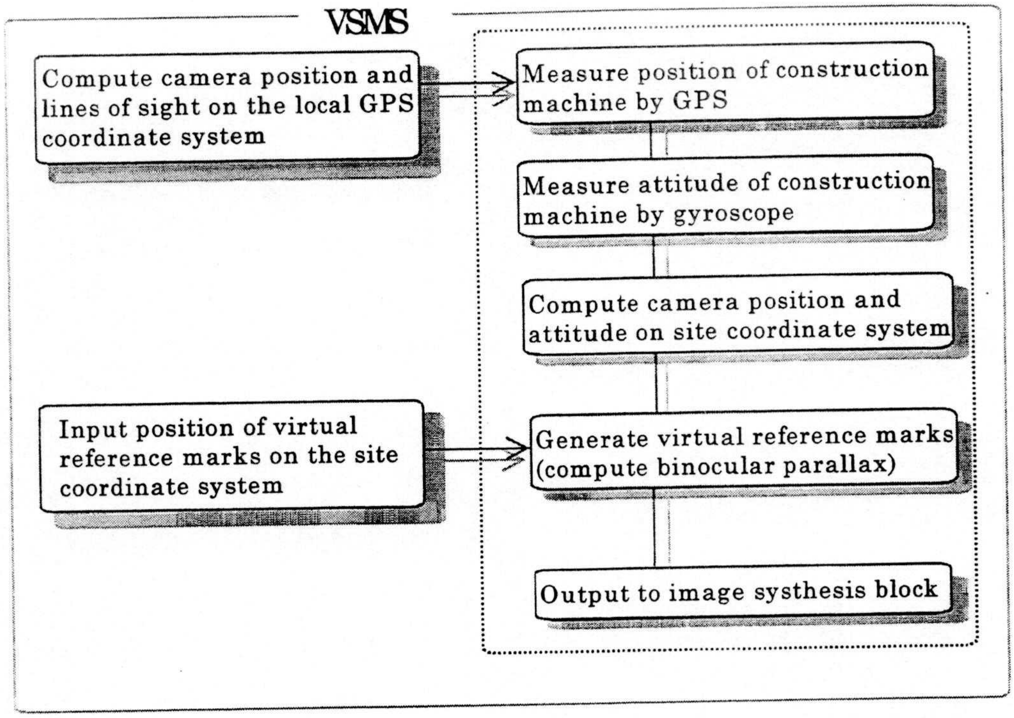

Figure 3 Flow of System Processing

Photo 1 Display of Virtual Reference Marks

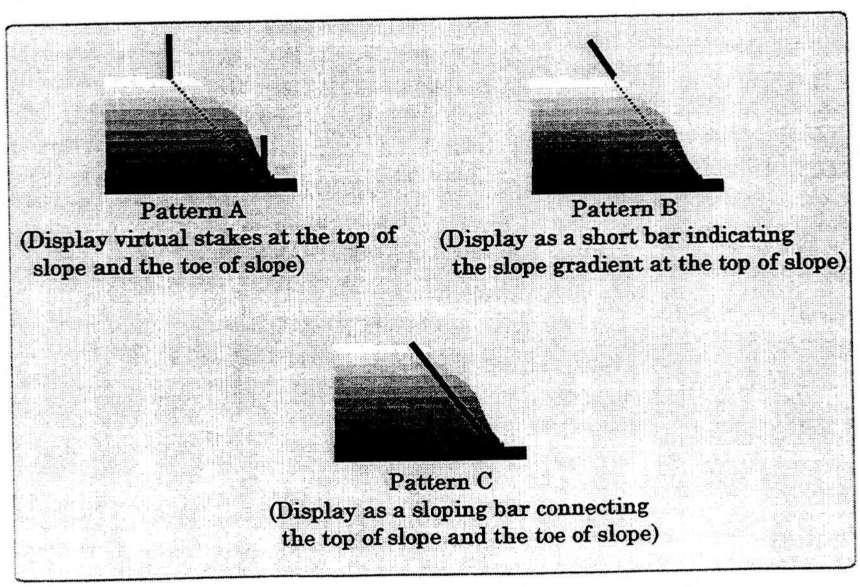

Figure 4 Virtual Reference Mark Patterns

In Test 1, the design gradient of 1v:1h (45°) was displayed by the three patterns of virtual reference marks. Six test areas were established on an embankment slope as shown in Figure 6, and virtual reference marks in the patterns shown in Table 2 were displayed in the respective test areas. The machine operator performed slope cutting while viewing the virtual reference marks displayed in each test area. After completing the operation in each area, the construction machine was moved to the next area.

Following completion of the test, the face of the cut slope was measured by total station instrument as shown in Figure 7, and the slope gradient was computed.

In Test 2, the pattern was selected which had produced results closest to the design gradient in Test 1. Test areas were established in the same way as in Test 1, and the design gradients shown in Table 3 were displayed by virtual reference marks in the respective areas. Slope cutting and measurement were performed in the same way as in Test 1.

The test operation is Shown in Photos 2 and 3.

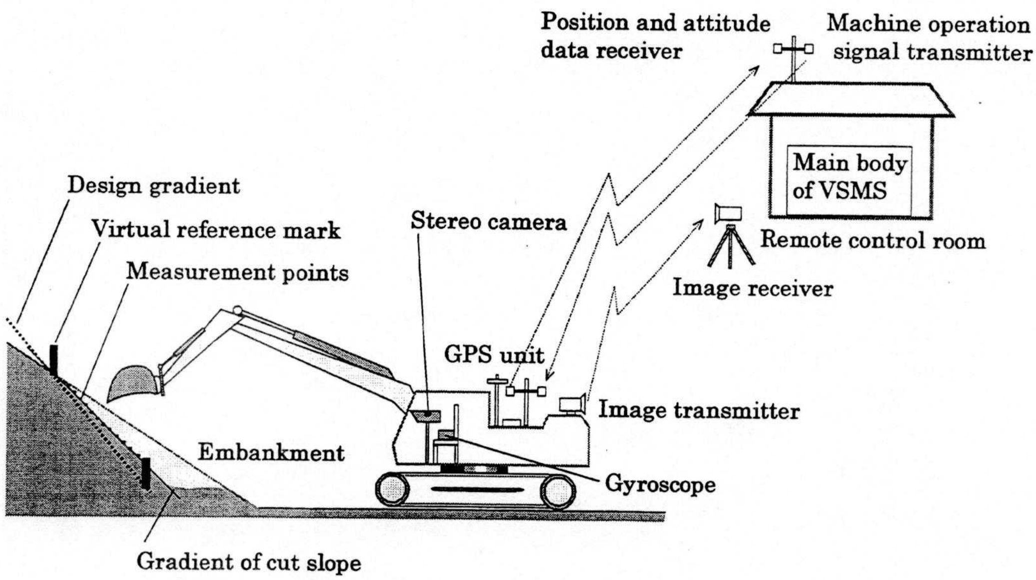

Figure 5 Test Arrangement (Virtual Reference Marks in Pattern A)

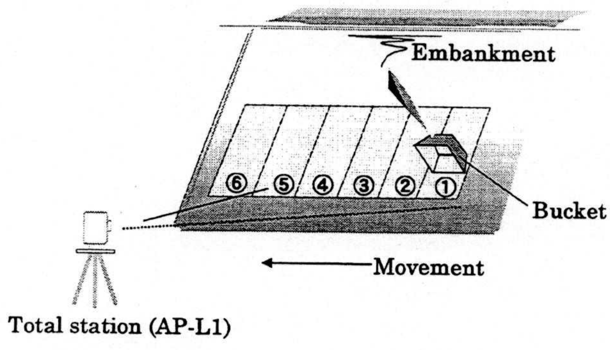

Figure 6 Operation Test Areas

Table 2 Test Areas and Virtual reference mark Pattern Displayed

Test area	1	2	3	4	5	6
Pattern displayed	A	B	C	A	B	C

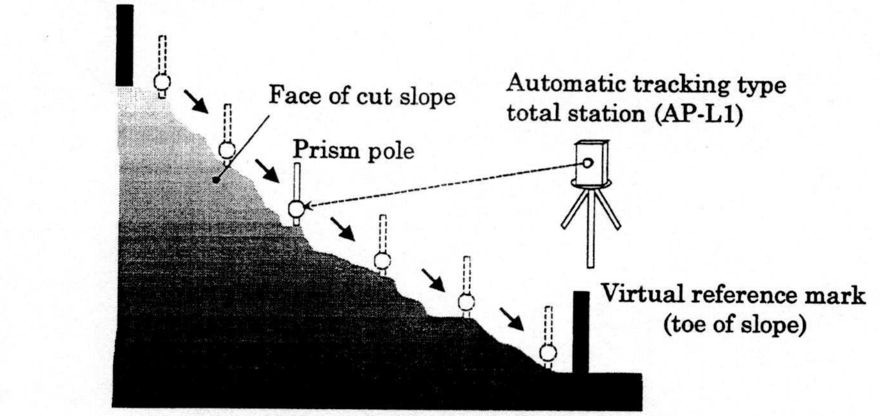

Figure 7 Cut Slope Measurement method

Table 3 Test Areas and Design Gradient (Test 2)

Test area	1	2	3	4	5	6	7
Design gradient(v:h)	1:1	2:1	1:1	1.5:1	2:1	1:1	1.5:1

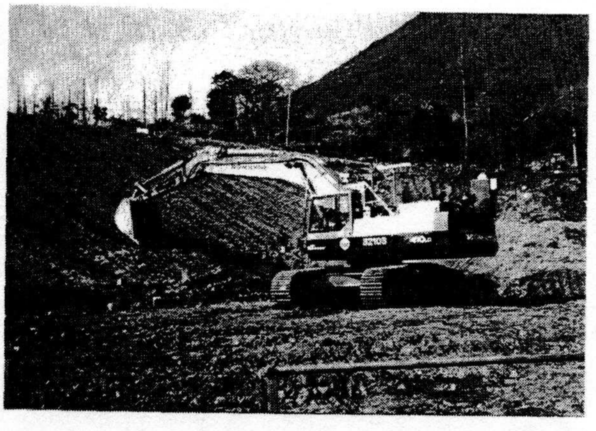

Photo 2 Test Operation
(Slope Cutting Operation)

Photo 3 Test Operation
(Remote Control Room)

3.2 Test results

The results of Test 1 are shown in Table 4. "Ratio" in the table is the ratio (expressed as a percentage) of the gradient (expressed in degrees) of the cut slope to the design gradient.

Consequently, a ratio closer to 100% indicates a cut slope which is closer to the design gradient. From the table, the pattern having the highest ratios is pattern A (67% maximum).

The results of Test 2 are shown in Table 5. Because pattern A had the highest ratios in the results of Test 1, this pattern was used to display the virtual reference marks in Test 2. The maximum ratio obtained in Test 2 was 86% (78% average), a result exceeding that of Test 1. Also,

Table 4 Test 1 Results

Test area	Desplay method	Design gradient[a]	Result [b]	Ratio [b/a × 100]
①	Pattern A	1v:1h(45°)	1v:2.32h(23.24°)	51.6%
②	Pattern B	1v:1h(45°)	1v:2.45h(22.19°)	49.3%
③	Pattern C	1v:1h(45°)	1v:2.60h(20.98°)	46.6%
④	Pattern A	1v:1h(45°)	1v:1.71h(30.19°)	67.0%
⑤	Pattern B	1v:1h(45°)	1v:2.13h(25.13°)	55.8%
⑥	Pattern C	1v:1h(45°)	1v:2.54h(21.42°)	47.6%

Table 5 Test 2 Results

Test area	Desplay method	Design gradient[a]	Result [b]	Ratio [b/a × 100]
①	Pattern A	1v:1h(45°)	1v:1.45h(34.58°)	76.8%
②	〃	2v:1h(63.4°)	2v:1.73h(49.00°)	77.2%
③	〃	1v:1h(45°)	1v:1.51h(33.39°)	74.2%
④	〃	1.5v:1h(56.3°)	1v:1.71h(48.68°)	86.4%
⑤	〃	2v:1h(63.4°)	2v:2h (44.95°)	70.9%
⑥	〃	1v:1h(45°)	1v:1.30h(43.32°)	83.3%
⑦	〃	1.5v:1h(56.3°)	1.5v:1.59h(43.32°)	76.9%

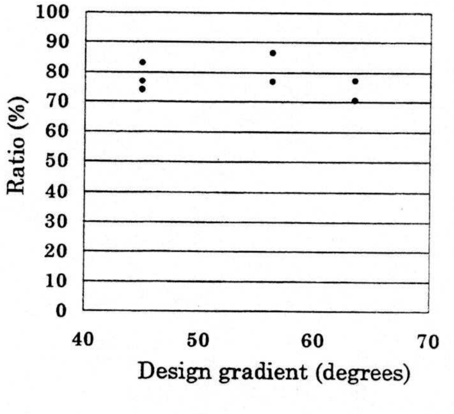

Figure 8 Design Gradient vs Ratio

Figure 8 shows a dispersion diagram of the test results with the design gradient on the x-axis and the ratio on the y-axis. From Figure 8, a clear correlation can not be found between design gradient and ratio.

4 Observations

Because grading reference marks can not be placed by actual surveying in remote control construction, the objective of this system is to enable its application to slope grading works and other operations performed by remote control in which precision is required in finished shape. Through these tests it was confirmed that slope grading can be performed with a maximum precision of 86% using this system to display virtual reference marks.

The test results show that slope cutting was performed in all cases to a gradient which is more gentle than the design gradient. This is believed to be a result of the fact that operators in general tend to perform slope cutting to a more gentle gradient in order to avoid over cutting, and that the operator in these tests took care to excavate on a gradient which was more gentle than the design gradient because of the necessity of turning the bucket at the toe of slope, an inherent condition of the tests.

Also, the fact that overall test precision was higher in Test 2 than in Test 1 is thought to be a result of the operator's having acquired feeling for the operation.

Technology such as VSMS to heighten operability in real space by superimposing virtual space information on real space is called AR (Augmented Reality) and is considered to be a field of application of VR (Virtual Reality). In AR, because the virtual object is always displayed transparently over the real object, it is known that the depth relationship between virtual objects and real objects is affected. That is called contradiction between binocular parallax and masking.

In these tests, the virtual reference marks were displayed as shown in Figure 9. In pattern A, the base part of the virtual reference mark at the toe of slope is buried in the embankment. Also, in pattern C, the whole virtual reference mark is buried. However, as shown in Figure 10, a point which is closer to the points of sight has a larger binocular parallax, and a point which is farther from the points of sight has a smaller binocular parallax.

Consequently, the buried part, which is within the embankment and is displayed with a smaller binocular parallax than that of the embankment, by nature should not be seen due to masking, but in fact it can be seen transparently. The same can also be said for parts which are exposed above the slope.That is, at the top of slope in patterns A and B, the surface of the slope, which by nature should be hidden by masking behind the virtual reference mark which stands in front and is displayed with a larger

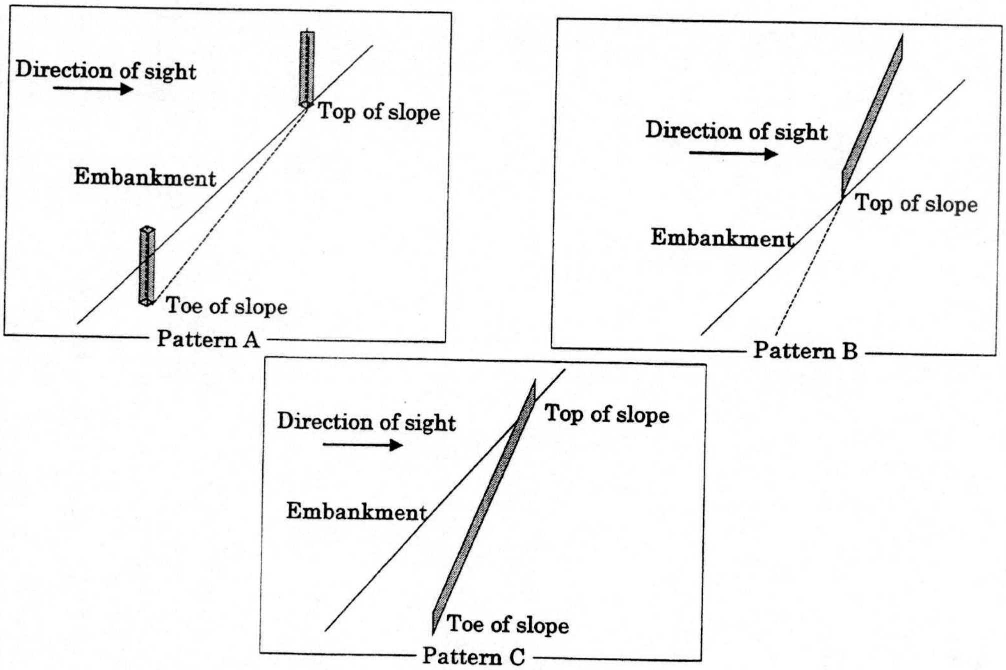

Figure 9 Display of Virtual Reference Marks

binocular parallax than that of the embankment, can in fact be seen transparently.

This feeling of sensory disorder is thought to have had an effect on perception of the virtual reference marks. However, for a simple operation such as machine positioning in which attention is given to the position of the base of the virtual reference mark such as at the top of slope in pattern A, the fact that position can be readily perceived has been confirmed by the previous test[1] and the present tests.

5 Conclusions

The authors are developing VSMS for use in remote control construction of structures such as erosion control dams. An experimental system aimed at practical use was newly developed and tests of the performance of this system in slope grading operations were performed. In these tests it was possible to perform slope grading with a maximum precision of 86% when the design slope gradient of the virtual reference marks was 1:1 (100%). The principal cause of this error is believed to be a sensory disorder in perception of the synthesized stereo image. Especially, in a case such as VSMS in which virtual space information is superimposed on real space, it is thought that binocular parallax and masking have an influence on perception.

In order to further improve the precision of the system, it is necessary to improve the method of displaying the virtual reference marks in such a way as to reduce this sensory disorder. To be specific, we believe that an effective method will be to obtain feedback of the results of measuring the excavated surface configuration and display this as a comparative cross sectional image.

Reference

[1]Y. Miyauchi, et al. "Development of Virtual Survey Marking System for Remote Control of Construction Machinery,"
Proceedings of The 13th ISARC pp.571-580.1996

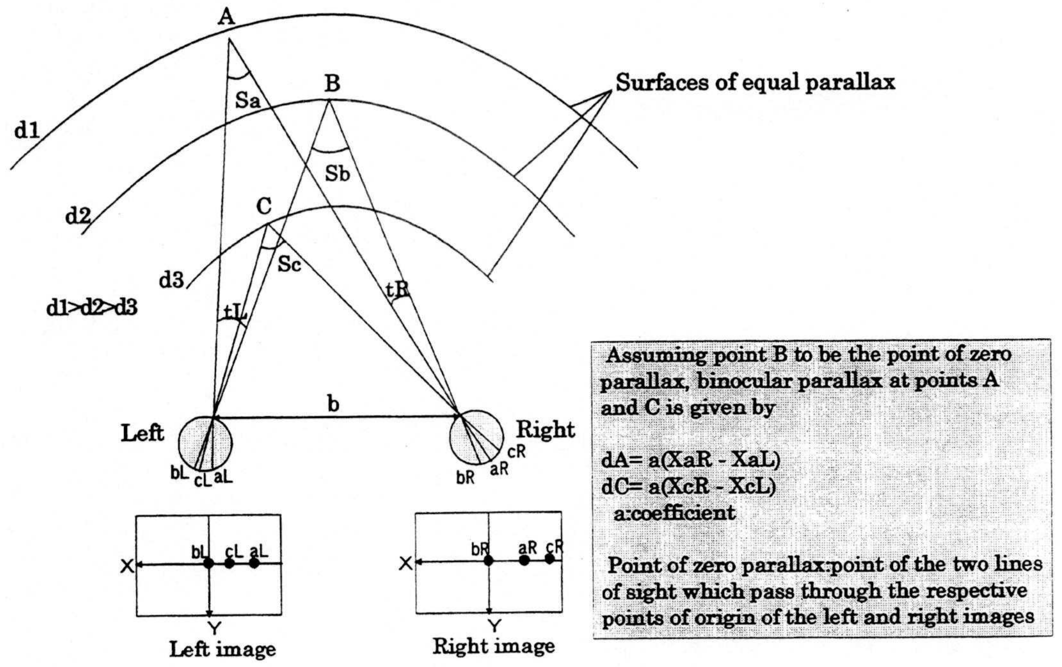

Figure 10 Binocular Parallax