CONTROL SURVEY USING THE ACCELEROMETER AND GYRO

Akira YAMAMOTO
Product Development Dept.,
Yamayo measuring tool CO., LTD,
2-23-13, Adachi, Adachi-ku, Tokyo, 120-0015, Japan
E-mail: k2yamayo@intacc.ne.jp

Yasuyuki SHIRAI
Dep. Precision Eng., Associate Professor, Chiba Institute of Technology
E-mail: shirai@cc.it-chiba.ac.jp

Atsuro TAKEMOTO
Dep. Computer Center, Associate Professor, Chiba Institute of Technology
E-mail: atakemoto@cc.it-chiba.ac.jp

Toshio KOIZUMI
Dep. Civil Eng., Professor, Chiba Institute of Technology
E-mail: koizumi@ce.it-chiba.ac.jp

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ABSTRACT

As one of the fundamental study themes to make a real-time imaging technology develop, a development of device to exactly compute the position of a moving camera with installed platform and so on in real time can be considered. Authors have considered it effective to apply the inertial navigation system as the device. In this study, the authors developed the device which measures the position of a moving object in 3-dimensions using the accelerometer and the gyro which are used as an inertial navigation system. In this study, while analyzing experimentally the features of this device, the authors tried an application to a survey as a concrete application to 3-dimensional position measurement.

1. INTRODUCTION

The inertial survey is the one that the technology of the inertial sensor such as Inertial Navigation System (INS) for the aircraft and Inertial Guidance System (IGS) of the space rocket was applied, and the measurement method to obtain the relative position between arbitrary points based on the change in the acceleration and the angular velocity of the movable body which accelerometer and the gyro detected based on dynamics. Therefore, this method can never compare with a current measurement method to request the position measuring the angle and the distance with a Theodolite, a Electronic distance meter and GPS, and never be controlled by weather and visibility, and do the reconnaissance of a necessary point comparatively freely in use for all spaces like in the air, on the ground, in the earth, and in water.

When an antiaircraft sign is set up, three dimension coordinates value is obtained by the traverse survey and the leveling as a control surveying, however, if the control surveying can be easily done with an inertial device, the labor and time to do photogrammetry will be reduced accordingly.

In this study, we examined to apply this inertial survey to the control surveying.

2. EQUIPMENT TO USE

2.1 Inertial sensors

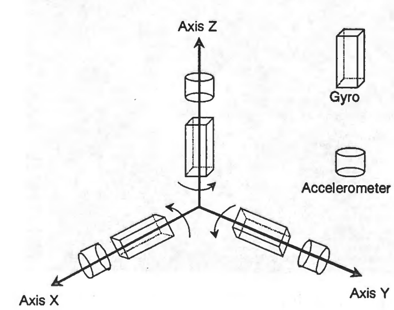

Figure 1 Coordinate system and sensor

In this research, we used piezoelectric model vibration gyro ENV-05A type made by Murata Mfg. Co., Ltd. as the vibration gyro and used accelerometer JA-5VC1 type made by Japan Aviation Electronics Industry., Ltd. as the accelerometer. And, this accelerometer and the gyro were installed as three axes were orthogonal as shown in Figure 1.

2.2 Inertial survey device

2.2.1 Four-wheel truck type inertial survey device

This device is installing the inertial device in four-wheel truck. It is used on the flat place which does not have much ups and downs, when making stable motion like straight movement. A personal computer, and A/D conversion board are installed on the upper part of this truck, and the amplifier of an accelerometer, the power supply of a gyro, and a battery are installed on the lower part of this truck. Therefore, it is enabled to survey also in the place like the outdoors without the exchange power supply. Although a truck type is stable, it has difficulty to rotate in one point by four-wheel truck and has disadvantage for measurement (application to a traverse survey etc.) which needs rotation. Therefore, it is thought that this device is suitable for the measurement by the straight movement like the distance survey on the plane.

2.2.2 Monocycle type inertial survey device

This device is installing the inertial device in the monocycle for the rotation in one point which becomes possible and is the weakest point in four-wheel truck type. Figure 2 shows the device.

Figure 2 Monocycle type inertial survey device

The device block was set up on sideward of the tire of the monocycle. And, the device can be centered to the survey point by hanging the plum bob down right under the block. The reason to set up the device block sideward of the tire is because it is thought that the monocycle rotates right under the tire when it rotates by one point, so unless the device block is set up near the tire, the error factor of the centrifugal force etc. when rotating is included. A personal computer, A/D conversion board, amplifier of accelerometer and the power supply of a gyro are installed in the open space of the monocycle. However, when measuring in the place without the exchange power supply like the outdoors, the man who moves a monocycle do measurement by carrying a battery on the back.

2.2.3 Handy type inertial survey device

This device was manufactured so that measuring in a difficult place (place with the height difference, place where there are much ups and downs were violent and etc.) to measure in the monocycle type and the truck type might be possible. The battery etc. was made possible to be carried on the back like a monocycle type. This device can be not only movable anywhere but also accurately centered in comparison with four-wheel truck type and the monocycle type if there is space where one person can pass in comparison with four-wheel truck type and the monocycle type. However, when the inertial survey was done, axis x and axis y of the device block were needed to be horizontal and axis z to be perpendicular to the ground respectively as condition for an initialization, and this initialization was easily able to be done comparatively in four-wheel truck type and the monocycle type so far. However, a special plinth was used so as to make the initialization because it was difficult for this device to satisfy the initialization as the device was handled by person's hand.

3. APPLICATION TO ENGINEERING WORKS MEASUREMENT

3.1 Distance measurement with four-wheel truck type inertial device

Experiment in distance measurement was made using four-wheel truck type device. In the experiment, there moved about 10m on an almost smooth passage of the third floor (tiled) in the fourth pavilion of Chiba Institute of Technology (nine story RC structural building). This device was installed in the direction where the detection axis of accelerometer installed in the direction of axis x becomes direction of progress. And the experiment was made by installing an inertial block so that it might become as level as possible. And, the gap between the attainment point and 10m point was measured with the rule. The actual

Table 1 Distance measurement experiment result

		axis X[m]	axis Y[m]	axis Z[m]	Resultant[m]	Error[m]	Accuracy
TEST1	M D	9.984	-0.011	0.000	9.984		
	C D	9.491	0.213	-0.093	9.494	0.490	1/20
TEST2	M D	9.994	-0.006	0.000	9.994		
	C D	9.488	0.220	-0.088	9.491	0.503	1/19
TEST3	M D	9.989	0.036	0.000	9.989		
	C D	9.292	0.344	-0.210	9.301	0.688	1/14
TEST4	M D	9.985	0.028	0.000	9.985		
	C D	9.361	0.283	-0.188	9.367	0.618	1/16
TEST5	M D	10.069	-0.004	0.000	10.069		
	C D	9.339	0.266	-0.253	9.346	0.723	1/13

※M D:Moved distance, C D:Calculation distance experiment was aimed to understand the adaptability to the range measurement with the truck type device. Table 1 shows the result. Axis X is a value of the direction of progress, axis Y is a value of the horizontal direction, axis Z is a value of the vertical direction, and the result is shown by the resultant of three axes. The accuracy of the distance is 1/13-1/20. It is thought that the reason why the error of some ten cm appears in axis Y and axis Z with a little amount of the movement is because the initialization that axis X is a direction of progress and axis Z is vertical directions were not accurately done. Figure 3 shows the difference of the coordinate system of initialization and the movement.

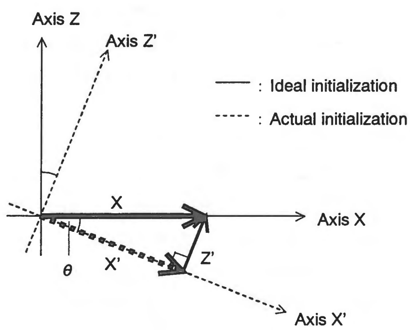

Figure 3 Difference of coordinate system

We explain here by the plane X-Z for easiness. The faction of the ideal initialization is assumed to be plane X-Z, the faction which actually is set up is assumed to be plane X'-Z', the inclination of each faction is assumed to be θ, and moved distance is assumed to be X. When X moves, as the calculation distance is calculated not in the faction of the ideal initialization but in the faction of an actual setting, X'Z' is calculated. The same thing can be said with the plane X-Y. The distance of each axis caused the above-mentioned error, however, if the distances are compared by the resultant, the error caused by the difference of the coordinate system is deleted.

3.2 Traverse survey and leveling with monocycle type inertial device

The traverse survey and the leveling were done with a monocycle type inertial survey device as an application to the engineering works measurement. As the accelerometer and the gyro were installed to become three axis orthogonalization, the traverse survey can determine the horizontal position of the survey point by the value of axis X and axis Y. The leveling calculates height with axis Z, and the horizontal position is obtained in the value of the resultant of the axis XY. That is, as three dimension position is calculated, this device can calculate the result of the traverse survey and the leveling at the same time. In this initialization, plane x-y is set horizontal against the ground level.

The experiment place was made surrounding the pond in front of the fourth pavilion of Chiba Institute of Technology (Figure 4). Figure 5 shows the outline of the experiment place.

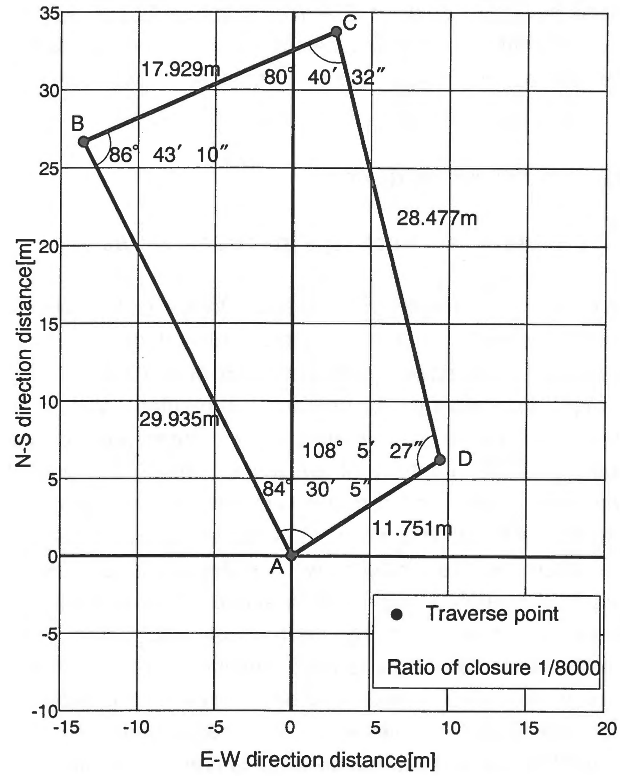

Figure 4 Traverse point

Figure 5 Outline of the experiment place

The maximum difference of elevation of the four points is about 30cm. The ratio of closure was 1/8000 in the measurement with the Theodolite and the Electronic distance meter. And, the ratio of closure in each experiment was calculated by the following expressions.

$$\text{Ratio of closure} = \frac{\text{Error of closure[m]}}{\text{Total length of calculated traverse line[m]}} \tag{3.1}$$

Error of closure : Gap when returning from original point A to point A (AA')

Here, A' indicates point which does not shut at starting point A.

When the error of x and y of point A and A' is set as Δx and Δy

$$AA' = \sqrt{\Delta x^2 + \Delta y^2} \tag{3.2}$$

The survey point was measured by the ring in the leveling with the automatic level, and the error of closer was 0.001m.

In the experiment, point A was a starting point (original point) as shown in Figure 4. And in point A, the spacer was inserted into the leg part behind the monocycle, so that inertial device might become level as much as possible, and it was checked with the level. The bubble tube sensitivity of the level used is 1'. And the initialization was done by using the azimuth magnetic needle so that the detection axis of accelerometer of axis x might point the north. It seems that some gaps are caused at each experiment because it is done by using the azimuth magnet to set axis x for the north. Here, the reason to turn axis x for the north is to know the direction of the traverse point when the traverse survey is done. As a result, traverse point measured with Theodolite and Electronic distance meter can be compared with value calculated by inertial survey.

3.2.1 Traverse survey

Table 2 shows the result of the traverse survey with an inertial device.

Table 2 Traverse survey experiment result

	Straight line distance between each point[m]				Total length distance L[m]	Close combination difference[m]	Ratio of closure
	A-B	B-C	C-D	D-A'			
M V	29.935	17.929	28.477	11.751	88.092		
TEST1	32.028	20.549	30.382	12.507	95.465	5.380	1/18
TEST2	31.928	15.848	33.583	11.377	92.735	5.689	1/16
TEST3	28.044	20.079	26.111	14.416	88.650	4.400	1/20
TEST4	31.444	20.062	34.547	12.658	98.711	7.009	1/14
TEST5	31.651	19.142	32.632	12.276	95.702	7.966	1/12
Average	31.019	19.136	31.451	12.647	94.253	6.089	1/15

* Only 11.751 is a value between D-A. , M V:Measurement value

The measurement value is a calculated one based on the value measured with the Theodolite and the Electronic distance meter. The ratio of closure was calculated by the above-mentioned type 3.1. The measurement value is a value measured with the Electronic distance meter. Figure 6 shows the result of the traverse point and the traverse experiment done by inertial survey. The movement was in order of A→B→C→D→A. It is now understood that the ratio of closure by the inertial survey is about 1/12-1/20 according to Table 2. The result can be said not too good as a whole. We think that the reason why such a result was found is that a time error was accumulated because the movement for return from point A point A was so rapid. Additionally, it is thought that the reason is that initialization (The inertial block was horizontally set.) was not done accurately. If initialization is not accurately done (Initial posture inclines.), the value output from the inclined amount of accelerometer becomes small. When the value of accelerometer is analyzed (integration), the average value at geostationary is subtracted as a bias value. Therefore, if initial posture inclines the output value which is possible to be inclined is subtracted as a bias value as well. Therefore, the error is caused because the analysis was done by using the value outputted according to the inclination. Moreover, when inclined, the coordinate transformation value reaches the value of the direction of each axis in the inclined coordinate system. Therefore, it is thought that the gap in the value with the traverse point is caused because they cannot be compared under the same condition when they are compared with the traverse point. As coordinates conversion is very much influenced with the value by the gyro, the value of the acceleration by which coordinates conversion was carried out will become not so good one if data obtained from the gyro is not so accurate.

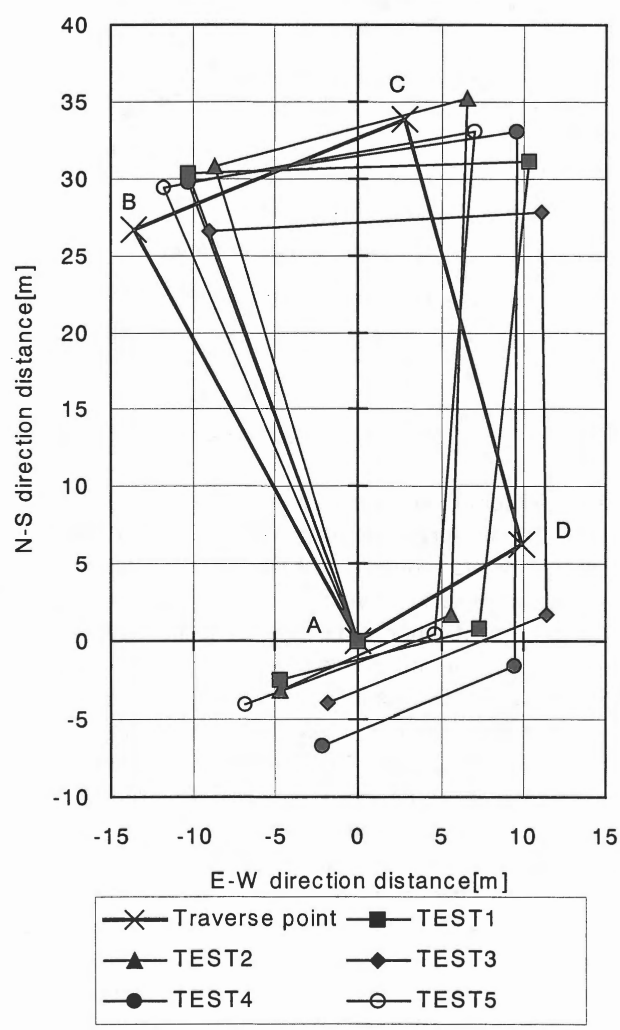

Figure 6 Result of traverse survey

3.2.2 Leveling

The result of the leveling is shown in Table 3.

Table 3 Leveling experiment result

Unit [m]

	Coordinates value of point B		Coordinates value of point C		Coordinates value of point D		Coordinates value of point A'	
	Axis X (direction of N-S)	Axis Z (direction of gravity)	Axis X (direction of N-S)	Axis Z (direction of gravity)	Axis X (direction of N-S)	Axis Z (direction of gravity)	Axis X (direction of N-S)	Axis Z (direction of gravity)
M V	26.668	-0.396	33.892	-0.402	6.318	0.030	0.000	0.000
TEST1	30.337	-0.020	31.082	-1.197	0.847	-1.656	-2.503	-2.112
TEST2	30.719	-0.926	35.264	1.388	1.694	-0.818	-3.190	-2.022
TEST3	26.571	0.345	27.868	-1.479	1.759	-1.144	-4.000	-1.578
TEST4	29.724	0.094	33.031	-0.220	-1.517	-1.837	-6.678	-2.752
TEST5	29.378	0.158	33.016	0.147	0.476	0.325	-4.081	-0.035

※M V:Measurement value

Table 3 indicates the coordinates value of the plane X-Z of each traverse point. The true value in Table 3 is a value measured with the automatic level. Figure 7 shows the result.

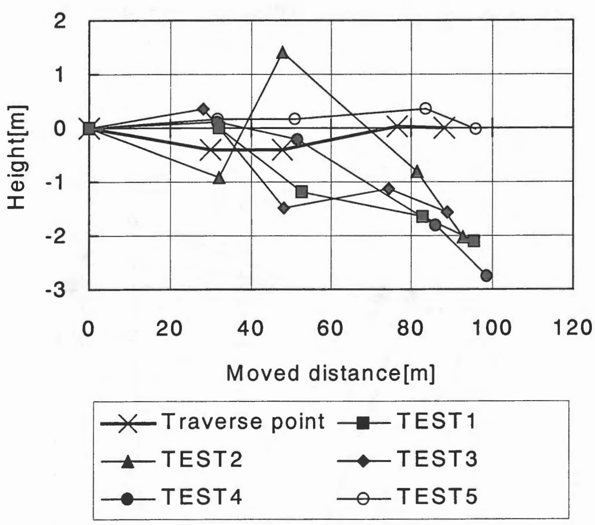

Figure 7 Result of leveling

The gap (error) with the survey point is larger than that of the traverse survey as indicated in Figure 7. Here, the amount of the movement of the vertical direction to the movement time is smaller compared with the amount of the movement of horizontal direction to the movement time. Therefore, it is thought that the error of the leveling is larger than that of the traverse survey. Figure 8 shows the result of the movement tracks. Movement was in order as A→B→C→D→A. The tendency described in the consideration of Figure 7 appears clearly according to Figure 8. When moving from point A to B, actual movement leaves at point A, then at once descends through the difference of elevation of about 30cm, and moves at a smooth place up to point B afterwards. According to tracks by the inertial survey of Figure 8, it is closer to actual movement in the place descending by about 30cm, but the part where it moves at a smooth place until reaching point B accumulates the error, and the tracks are quite different from actual movement.

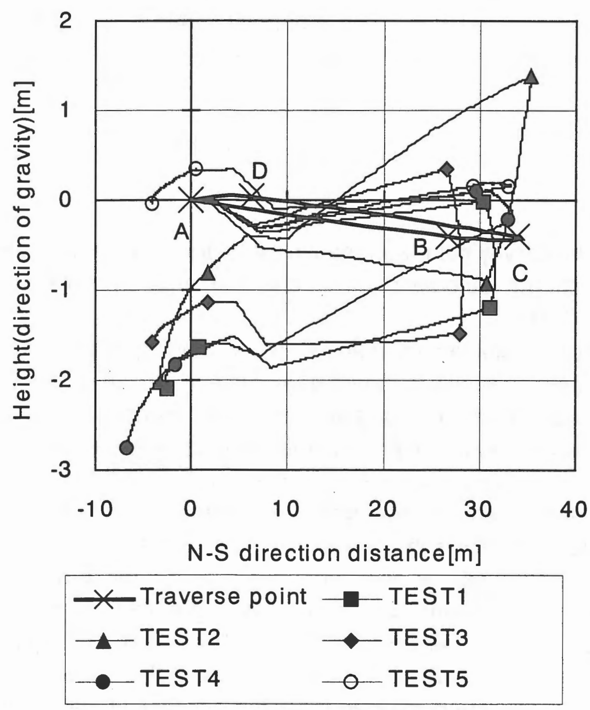

Figure 8 Leveling (movement tracks)

The accumulation of the error is a little in TEST4 and TEST5, because a straight line distance is short, even though the movement from point B to C is of an almost smooth place.

In the movement from point C to D, it actually leaves at point C and moves at a smooth place then goes up by about 30cm moves some meters reaches point D. According to tracks of Figure 8 we are supposed to move at a smooth place but as the error is accumulated, the tracks are descended. However, the tracks are showing almost an actual motion only for the place going up.

The movement from point D to A' (point which returned to point A) is the same as the one from point B to C, and moved distance is of the straight line is short and the accumulation of the error is small.

From the above-mentioned point of view, it is thought that if the place with some difference of elevation is moved without taking much time in the leveling by the inertial survey, a value close to an actual one can be calculated. However, it is understood that the error accumulates when time is taken for measurement at the place where is not so many differences of elevation and a preferable result is not obtained.

3.3 Plane-table survey with handy type inertial device

In the experiment, the shape of the pond was measured in the traverse point with the inertial device (Figure 5). Original point O (point C in previous traverse experiment) was set up by the pond, the device block as initialization on point O was put on the Transit plinth, and it was installed so that the detection axis of accelerometer x axially might turn to north by the azimuth magnetic needle.

And the block in hand was moved from point O to the corner (8 points in all) of the pond, it was put on the corner, and the measurement was ended there. And after returning to point O again and performing the same initial setup, and measurement was made up to the next survey point. Thus after measurement for 1 point was finished one by one, again it returned to point O. And after performing the initial setup, the experiment was made by the method of measuring even the following point.
Figure 9 shows the experiment result.

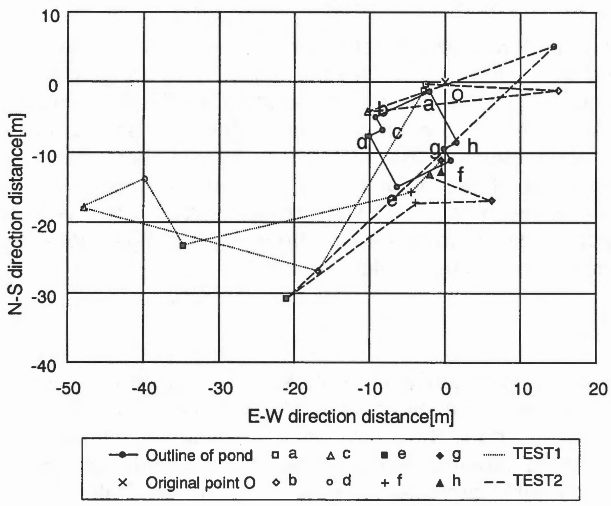

Figure 9 Plane-table survey result

The original point in figure is point O. And the characters from a to h indicates the corner (measured point) of the pond. The shape of the pond cannot be expressed at all according to Figure 9. The measurement result of point a which is the nearest to point O is plotted in about the point a, but the measurement result in other points is not stable, and contains a big error. The dotted line is TEST1, and the short dashes line is TEST2. Even though the plane-table survey made movement of the device distance with the traverse survey, the calculation result became quite different from each other. Different points to be enumerated between the range measurement experiment and the plane-table survey experiment are that the device block was installed in the truck in the range measurement experiment, but it was moved in hand in the plane-table survey. Therefore, it is thought that the reason why the error was greatly calculated by the actual experiment is became the device block was moved in hand.
When moving with the device block in hand like in the experiment at this time, movement becomes complex and when data is analyzed, a quite different result is obtained. When moving with the device block in hand even if the device block is moved as slowly as possible (In the actual experiment, it was moved as slowly as possible.) a minute movement when moving with the device block in hand or minute vibration and the impact when walking surely join accelerometer and the vibration gyro. Such movement can be thought not as the acceleration to the movement but only useless. Therefore, it is thought that the shape of the pond was not able to be shown because of a lot of the errors calculated with a lot of such useless operations.
From the above-mentioned, we think it necessary for devising the external force error factor like the vibration and the impact not to join accelerometer and the gyro, and shortening the movement time when moving with the inertial device in hand.

4. SUMMARY

The measurement with the inertial device can be said as that the ratio of the error which accumulates differs by time. When the distance is calculated, the error accumulates in proportion to the second power because acceleration of time is double integrated. Therefore, it is considered that development examination is needed so that the measuring method of which we stop measurement while measuring and begin measurement again can be performed, in order to lessen the influence of the error by time in measuring with inertial device. It seems that more accuracy or more improvement will be obtained if this method can be used. However, the measuring method of which the measurement is stopped on the way, and the measurement is started there again is quite difficult at present because relation between initialized coordinate system and coordinate system of which measurement was started again on the way becomes unclear.

What was confirmed with this research result is as follows.

(1) When we do the inertial survey, we think that relative accuracy of the result obtained by movement (The distance is longer and the difference of elevation is larger.) with some amount degree's of movement improves.
(2) It is necessary to examine the method not to join the outside power like the vibration and the impact, etc. to inertial device.
(3) Measuring time should be shortened as much as possible. Moreover, it is thought examining the measurement method is necessary so that ending the measurement on the way (If possible, an already-known point is desirable.) and starting the measurement from the place again can be done.
(4) The gyro with better performance than the vibration gyro used by actual experiment should be inquired to use.
(5) Centering to survey point should be accurately done.

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