FUNDAMENTAL STUDY ON REAL TIME MEASUREMENT OF ALTITUDE DATA WITH ACCELEROMETER AND VEHICLE SPEED SENSOR

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ABSTRACT

The background of this research is in the easy measurement of the difference of elevation of the surface of the earth in the developing countries. The leveling is being measured by generally using the level and GPS now. However, there are times when the measured range is wide-ranging and in the urban area and the mountain where the electric wave does not reach easily, are difficult in the level and GPS. Then, if the difference of elevation can be measured by installing the inertia l device in the vehicle, the leveling of the large area easily becomes possible. Because a inexpensive gyro had the fault with low accuracy in a past inertial survey, the method of not using the gyro was examined. Then, this study developed the method of obtaining the difference of elevation by using the accelerometer and the vehicle speed sensor.

1 INTRODUCTION

One of the most important assignments in mobile mapping is to measure in real time the altitude of a platform with camera and others mounted thereon at a higher accuracy. GPS is one of the effective means for positioning the platform. However, the GPS is rather poor in the altitude defining. Further, it is difficult to use the GPS in mountains and urban areas that are beyond the radio wave range. Though the inertial photogrammetry using accelerometers and gyros has been studied, the accuracy of the inertial survey does depend largely on the gyro. Any gyros with high accuracy are exceedingly expensive. Their availability is much limited. In this paper we are going to introduce a methodology we developed that will allow us to obtain, at lower cost, altitude data with rather high accuracy using accelerometers and vehicle speed sensor. Only the gravitational acceleration of the earth acts on any accelerometers at rest installed on three orthogonal axes: X, Y, and Z. When displaced on a slanting surface, however, the resultant of the acceleration accompanying the displacement is calculated out as a resultant force of the acceleration acting on the accelerometers on the respective axes. Further, this resultant force is computed as the resultant of the gravitational acceleration of the earth, vertical and horizontal accelerations. The acceleration of the platform in its progressing direction is calculated as the resultant of its vertical and horizontal accelerations. From these, the vertical acceleration becomes the function of the resultant force of triaxial accelerometers, the acceleration in the progressing direction, and the gravitational acceleration of the earth. The computation of the acceleration in the progressing direction will therefore allow us to calculate out the acceleration in the perpendicular direction and accordingly the height of the slanting surface. The acceleration in the progressing direction was calculated in our study using a vehicle speed sensor. According to the theory thus far described, we attempted an experiment on an actual road with some level differences to verify and justify the theory. The experiment used an automobile and a bicycle-drawn cart, both provided with sensors to describe the longitudinal sectional drawings of the road. The results were compared with those by direct leveling. The road on which the experiment was conducted was a road with asphalt pavement, approximately 160 m in horizontal distance and about 6 m in level difference. Three sorts of comparisons were made between the accelerometer and vibration gyro, accelerometer and fiber optical gyro, and accelerometer and vehicle speed sensor. The descending order of accuracy was the accelerometer with vehicle speed sensor, with fiber optical gyro and with vibration gyro. The experiment could demonstrate the justification of the theory the authors have proposed. This enabled us to manufacture equipment that measures in real time the altitude of a moving platform by means of accelerometers and vehicle speed sensors. We will delve into accumulated errors of measurement when this equipment displaces over a wide range of distance and over a longer time.

2 PRINCIPLE

The vehicle speed sensor speed detection in the progressing direction is installed in the vehicle where the accelerometer was installed in three axis (x, y, and z axis) orthogonalization. And, the element received when it is ascended and descended to turn is calculated in consideration of the progress acceleration and the centripetal acceleration calculated from the vehicle speed sensor. And, the vertical acceleration is requested by considering gravity acceleration and a synthetic acceleration. The speed of each wheel in a right and left same axis measured, and the centripetal acceleration is calculated according to the speed difference by a private difference.

Here, it thinks of case to have descended by drawing the circular arc on a slope constant as shown in Figure 1. First of all, gravity acceleration, the progress acceleration, the centripetal acceleration to centrifugal force, the horizontal acceleration, and the vertical acceleration are caused in the movable body. A synthetic acceleration is a synthetic acceleration of three axes obtained from the accelerometer. Here, the element which is the unknown is a horizontal acceleration and a vertical acceleration. Because the element which wants to be requested is a vertical acceleration, the next expression is set up from Pythagoras' theorems and the horizontal acceleration is deleted.

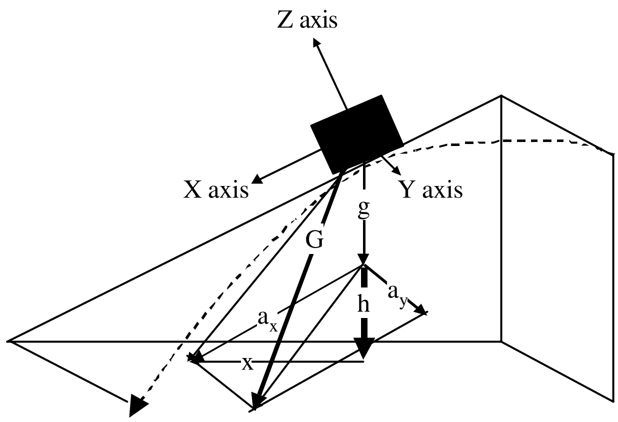

Figure 1. Principle figure

$$\begin{cases} G^2 = (g+h)^2 + x^2 + a_y^2 \\ a_x^2 = h^2 + x^2 \end{cases} \qquad (1)$$

$$\therefore h = \frac{G^2 - a_x^2 - a_y^2 - g^2}{2g}$$

Here it is:
G:Synthetic acceleration
g:Gravity acceleration
h:Vertical acceleration
x:Horizontal acceleration
a_x:Progress acceleration
a_y:Centripetal acceleration
“h” is calculated from expression 1. The combination of the vehicle speed sensor and the acceleration meter was calculated based on this.

3 EXPERIMENT DEVICE

Figure 2 shows the experiment device. In the actual experiment, the accelerometer and the gyro were installed in three axes orthogonalization respectively as an inertia device on a rear car made of aluminum, and they were set up x axially as a direction of progress. The accelerometer used for this measurement is the JA-5V accelerometer of Japan Aviation Electronics Industry., Ltd. which is shown in Figure 3. And, the vehicle speed sensor which was able to obtain the rotational frequency of the tire was installed on both wheels and two magnets were installed in the tire. The vehicle speed sensor used for this measurement is the ND-PG1 vehicle speed sensor of Pioneer Electronic CO., Ltd. which is shown in Figure 4. These data was taken with the personal computer through the A/D conversion board. Because the results at the combination of the accelerometer and the gyro are compared, the gyro is installed.

Figure 2. Experiment device

Figure 3. Accelerometer

Figure 4. Vehicle speed sensor

4 EXPERIMENT

4.1 Horizontal movement experiment

To confirm the theory and the actual experiment device shown in Section 2, the experiment moved almost horizontally by about 10m on the passage in front of the Koizumi laboratory of the third floor in the fourth building of Chiba Institute of Technology was done. The experiment device was stabilized as much as possible, and at this time, it was pulled and moved by the speed level where the person walked.
The accelerometer, the vibration gyro, and the vehicle speed sensor were installed in the experiment. Table1 shows the experiment result of the combination of accelerometer and vibration gyro. Table2 shows the experiment result of the combination of accelerometer and vehicle speed sensor.

Table 1. Result of accelerometer and vibration gyro

		Actual measurement	Measurement value				
	Time[s]	Way[m]	Way[m]	Horizontal distance[m]	Difference of elevation[m]	Way error[m]	Way accuracy
Experiment 1	23.1	10.012	10.384	10.377	-0.222	0.372	1/27
Experiment 2	16.7	10.035	10.148	10.147	-0.042	0.113	1/89
Experiment 3	17.8	10.078	10.172	10.171	-0.103	0.094	1/107
Experiment 4	16.8	10.030	10.035	10.034	-0.069	0.005	1/1940
Experiment 5	16.6	10.036	10.215	10.214	-0.056	0.179	1/57
Average	18.2	10.038	10.191	10.189	-0.099	0.153	1/66

Table 2. Result of accelerometer and vehicle speed sensor

		Actual measurement	Measurement value				
	Time[s]	Way[m]	Way[m]	Horizontal distance[m]	Difference of elevation[m]	Way error[m]	Way accuracy
Experiment 1	23.1	10.012	9.979	9.956	0.053	0.056	1/179
Experiment 2	16.7	10.035	9.979	9.970	0.031	0.065	1/155
Experiment 3	17.8	10.078	9.979	9.980	0.056	0.098	1/103
Experiment 4	16.8	10.030	9.979	9.972	0.058	0.058	1/173
Experiment 5	16.6	10.036	9.979	9.984	0.051	0.052	1/194
Average	18.2	10.038	9.979	9.972	0.050	0.066	1/153

The combination of accelerometer and vehicle speed sensor became a result with good about two double accuracy than the combination of accelerometer and vibration gyro. As a result, the theory when horizontally moving in the theory shown in Section 2 was able to be proven though there was a difference in accuracy.
Moreover, it is thought that the reason is that there was very no vibration at all as a reason with fairly good accuracy.

4.2 Outdoor experiment

The experiment alternately did going up and descending, on the asphalt pavement road of the difference of elevation about 5.5m and about 164m in the way under the Maronie bridge in Narashino City, Chiba Pref. The experiment place was measured at the total station and it was assumed to be a true value at this time. Figure 5 and Figure 6 show the plan and the running through chart of the experiment place.

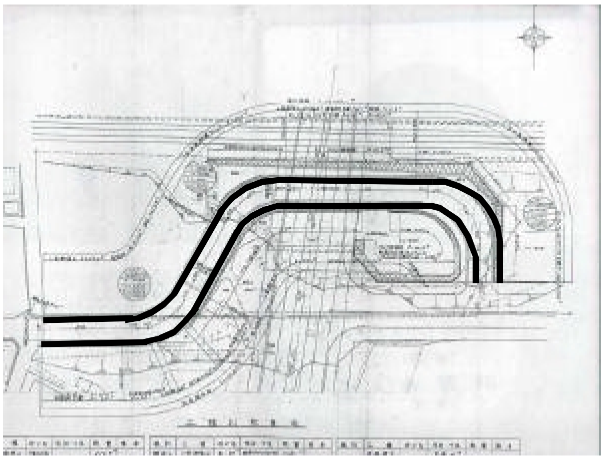

Figure 5. Plan of the experiment place

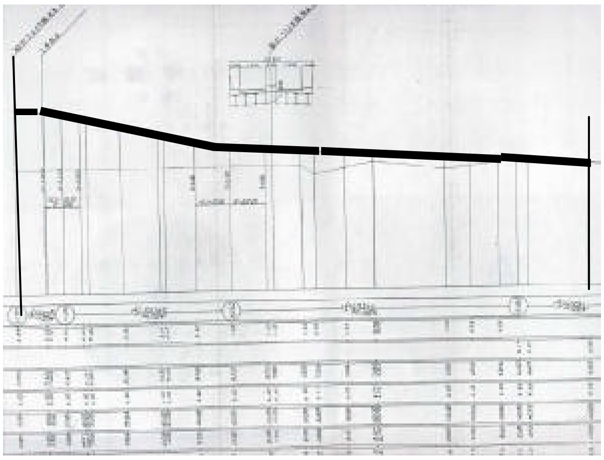

Figure 6.Running through chart of the experiment place

The comparison of obtaining a difference of elevation, a way, and the horizontal distance examination was done from method of using accelerometer and gyro, and method of using accelerometer and vehicle speed sensor. The device had turned on a empty of former power supply for about 12 hours of the day before. And, the power supply was turned on in the experiment place at that day and the experiment was done about 15 minutes later. Two kinds (a vibration gyro and a fiber optical gyro) were followed concerning the gyro. The appearance of the experiment place is shown and the experiment scenery is shown in Figure 7 and in Figure 8.

Figure 7. Appearance of the experiment place

Figure 8. Experiment scenery

Table 3-5 and Figure 9-14 show the experiment result. As a result, a way and the horizontal distance became good results for the difference of elevation in combination with the vehicle speed sensor. And, the difference of elevation became a good result for the way and the horizontal distance in combination with the gyro.
Because the vehicle speed sensor obtained the output value by the contact of ground and the tire and the value was able to be obtained directly, a good result was obtained in the measurement of the distance in the combination of the accelerometer and the vehicle speed sensor. However, the progress acceleration and the centripetal acceleration are calculated from the accelerometer and the vehicle speed sensor, and it is thought that the error was greatly caused at the stage of the calculation of the vertical acceleration because calculations process is one step more in the measurement of the difference of elevation.

Table 3. Result of accelerometer and vibration gyro

		Time[s]	Way[m]	Horizontal distance[m]	Difference of elevation[m]	Way error[m]	Horizontal distance error[m]	Difference of elevation error[m]	Way accuracy	Horizontal distance accuracy	Difference of elevation accuracy
Descent	Actual measurement	-	163.969	163.824	-5.459	-	-	-	-	-	-
	Experiment 1	118.6	245.834	244.115	-23.892	81.865	80.291	18.433	1/2	1/2	1/1
	Experiment 2	109.6	283.894	283.731	-4.755	119.925	119.906	0.704	1/1	1/1	1/7
	Experiment 3	111.3	158.645	158.022	-11.184	5.324	5.802	5.725	1/30	1/28	1/1
	Experiment 4	133.8	221.468	221.329	-6.665	57.499	57.505	1.206	1/2	1/2	1/4
	Average	118.3	227.460	226.799	-11.624	66.153	65.876	6.517	1/2	1/2	1/1
Ascent	Actual measurement	-	163.969	163.824	5.459	-	-	-	-	-	-
	Experiment 5	119.8	98.537	98.230	2.735	65.432	65.594	2.724	1/2	1/2	1/2
	Experiment 6	100.4	177.085	176.830	6.836	13.116	13.006	1.377	1/12	1/12	1/3
	Experiment 7	131.4	219.453	219.236	7.154	55.484	55.412	1.695	1/2	1/2	1/3
	Average	117.2	165.025	164.766	5.575	44.677	44.670	1.932	1/3	1/3	1/2

Table 4. Result of accelerometer and fiber optical gyro

		Time[s]	Way[m]	Horizontal distance[m]	Difference of elevation[m]	Way error[m]	Horizontal distance error[m]	Difference of elevation error[m]	Way accuracy	Horizontal distance accuracy	Difference of elevation accuracy
Descent	Actual measurement	-	163.969	163.824	-5.459	-	-	-	-	-	-
	Experiment 8	124.4	230.091	229.956	-5.811	66.122	66.132	0.352	1/2	1/2	1/115
	Experiment 9	106.3	248.277	248.137	6.966	84.308	84.313	12.425	1/1	1/1	1/1
	Experiment 10	111.9	197.283	197.214	1.275	33.314	33.390	6.734	1/4	1/4	1/1
	Experiment 11	107.3	173.523	173.112	-11.265	9.554	9.288	5.806	1/17	1/17	1/1
	Average	112.5	212.293	212.105	-2.209	48.325	48.281	6.329	1/3	1/3	1/1
Ascent	Actual measurement	-	163.969	163.824	5.459	-	-	-	-	-	-
	Experiment 12	112.7	167.363	167.263	2.973	3.395	3.439	2.486	1/48	1/47	1/2
	Experiment 13	111.9	158.169	157.923	7.850	5.800	5.902	2.391	1/28	1/28	1/2
	Experiment 14	116.4	208.224	207.863	11.468	44.255	44.038	6.009	1/3	1/3	1/1
	Experiment 15	114.0	314.700	314.641	3.817	150.731	150.816	1.642	1/1	1/1	1/3
	Average	113.8	212.114	211.922	6.527	51.045	51.049	3.132	1/3	1/3	1/1

Table 5. Result of accelerometer and vehicle speed sensor

		Time[s]	Way[m]	Horizontal distance[m]	Difference of elevation[m]	Way error[m]	Horizontal distance error[m]	Difference of elevation error[m]	Way accuracy	Horizontal distance accuracy	Difference of elevation accuracy
Descent	Actual measurement	-	163.969	163.824	-5.459	-	-	-	-	-	-
	Experiment 8	124.4	168.510	164.067	3.683	4.541	0.242	9.142	1/36	1/675	1/1
	Experiment 9	106.3	168.510	170.410	-5.541	4.541	6.586	0.082	1/36	1/24	1/66
	Experiment 10	111.9	164.850	166.384	-13.806	0.881	2.560	8.347	1/186	1/64	1/1
	Experiment 11	107.3	167.082	167.294	-17.125	3.113	3.469	11.666	1/52	1/47	1/1
	Average	112.5	167.238	167.039	-8.197	3.269	3.214	7.309	1/50	1/50	1/1
Ascent	Actual measurement	-	163.969	163.824	5.459	-	-	-	-	-	-
	Experiment 12	112.7	166.224	163.766	3.366	2.255	0.058	2.093	1/72	1/2800	1/2
	Experiment 13	111.9	166.224	171.388	-4.754	2.255	7.564	10.213	1/72	1/22	1/1
	Experiment 14	116.4	166.224	165.838	13.207	2.255	2.014	7.748	1/72	1/82	1/1
	Experiment 15	114.0	166.222	164.604	0.323	2.253	0.779	5.136	1/72	1/210	1/1
	Average	113.8	166.223	166.399	3.035	2.254	2.604	6.297	1/72	1/62	1/1

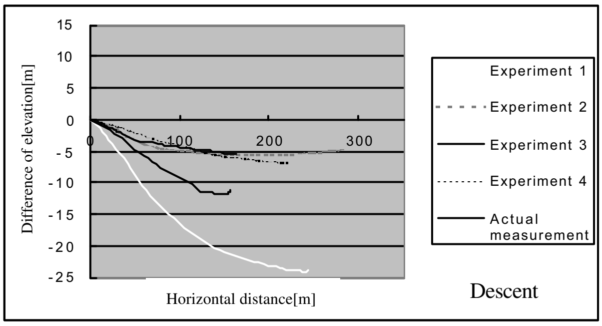

Figure 9. Running through chart (With vibration gyro)

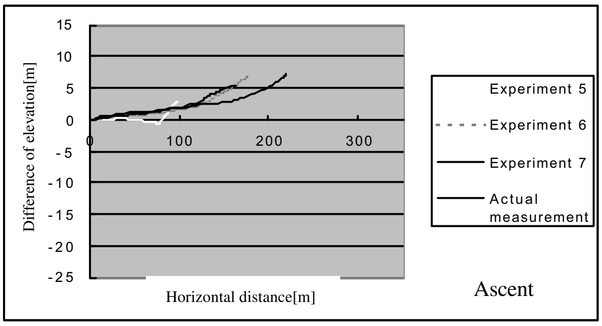

Figure 10. Running through chart (With vibration gyro)

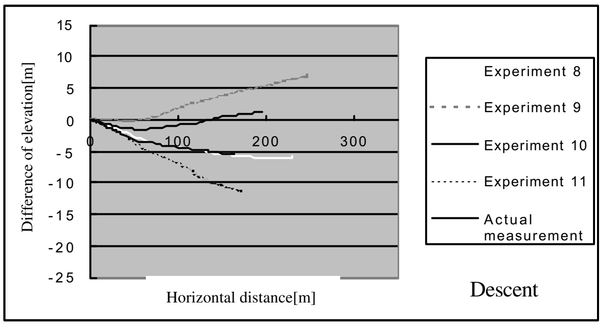

Figure 11. Running through chart (With fiber optical gyro)

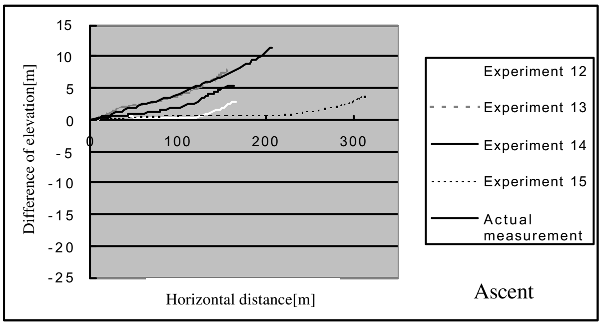

Figure 12. Running through chart (With fiber optical gyro)

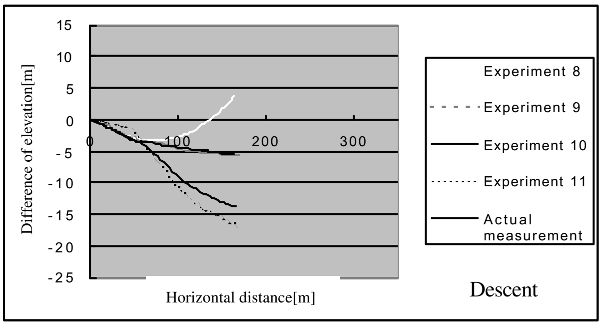

Figure 13. Running through chart (With vehicle speed sensor)

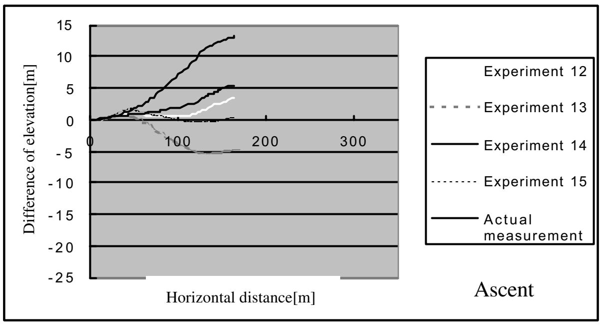

Figure 14. Running through chart (With vehicle speed sensor)

The posture correction by which the posture which has changed hourly first of all by calculations process is horizontally mended is done to accelerometers and gyros of x, y, and z axis in the measuring accuracy of the difference of elevation in the combination of the accelerometer and the gyro. And, the difference of elevation is obtained from the acceleration of Z axis which shows the direction of height afterwards, and it is thought that the error of other axes is not received easily because the value of the accelerometer of z axis is a main element.
However, it is thought that the error was greatly caused compared with the difference of elevation to consider two or more axes such as X and Y axes in the measurement of the distance.

5 CONCLUSIONS

This study aimed at the development of the method of obtaining the difference of elevation by using the accelerometer and the vehicle speed sensor. The research result is brought together as follows.

In the distance measurement, the combination of vehicle speed sensors became a result in which accuracy is better than the combination of gyros.

The combination of gyros became a result with comparatively good accuracy about the measurement of the difference of elevation.

It is thought that accuracy was comparatively good because the movement time was short concerning the horizontal movement experiment. Moreover, it is thought that accuracy was not good because the experiment time was longer than the horizontal movement experiment concerning the large area leveling.
Moreover, the following are thought as development in the future:

The reexamination of theoretical formula and the correction element such as other sensors are added.

The gap between acceleration obtained from the accelerometer and acceleration obtained from the vehicle speed sensor is lost, and is matched for beginning to move for increasing the number of pulses obtained for the tire one surroundings.

Because an unstable operation of the vehicle speed sensor was seen when beginning to move, the vehicle speed sensor is selected.

The shake is prevented reinforcing a rear car because it is thought that strength shortage of the stand is seen for a rear car made of aluminum, and the shake when moving became a error source.
It is thought that accuracy is improved by these. If a more efficient device is developed because the individual equipment used by this research has evolved every day, and the inertia device comes to be put to practical use, it is possible to use in not only the field of engineering works but also various fields, and a large influence will be produced in a present measurement form.

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