FUNDAMENTAL RESEARCHES INTO THE DEVELOPMENT OF INERTIAL PHOTOGRAMMETRY USING ACCELEROMETER AND GYRO

Atsuro TAKEMOTO[*], **Toshio KOIZUMI**[**], **Yasuyuki SHIRAI**[***], **Ichiro ADACHI**[****], **Akira YAMAMOTO**[*****]
[*]Computer Center, Associate Professor, Chiba Institute of Technology, Japan
atakemoto@pf.it-chiba.ac.jp
[**]Dep. Civil Eng., Professor, Chiba Institute of Technology, Japan
koizumi@ce.it-chiba.ac.jp
[***]Dep. Precision Eng., Associate Professor, Chiba Institute of Technology, Japan
shirai@pf.it-chiba.ac.jp
[****]Dep. Civil Eng., Professor, Chiba Institute of Technology, Japan
adachi@pf.it-chiba.ac.jp
[*****]Product Development Dept.,Yamayo measuring tools CO., LTD.,
2-23-13, Adachi, Adachi-ku, Tokyo, 120-0015, Japan
k2yamayo@inatacc.ne.jp

Working Group V/2

KEY WORDS: Inertial navigation system, Photogrammetry, Exterior orientation element, Accelerometer, Gyro, Control points.

ABSTRACT

When the position and inclination (exterior orientation element) of a camera at the time of photography are searched for by conventional photogrammetry, the standard point ground coordinates must be known, and time and labor are needed for the survey or installation work. Information on the position and inclination of a camera is obtained by installing an accelerometer and a gyro in the camera. This study is a fundamental study in which the accelerometer and the gyro were used, and the information about the position and inclination of a camera at the time of photography was acquired, and was examined in connection with the application to the photogrammetry of an inertial navigation system. The gyro used a vibration gyro and a fiber optical gyro. By this experiment, we could get various basic data required in order to make it apply to the photogrammetry. Moreover, by searching for the position and inclination of a camera with the accelerometer and the gyro, and treating as an exterior orientation element of a camera, simple photogrammetry could be performed.

1 INTRODUCTION

Use of an accelerometer and gyro, which belong to an inertial sensor, allows us to compute distance and angle. The gyro and accelerometer mounted on a camera make it possible to calculate the position and inclination of the camera when it is photographing. This study describes a fundamental study in which the photogrammetry using a camera with inertial sensors mounted is defined as an inertial photogrammetry. If the position and inclination of the camera, which are the exterior orientation elements, are found without the terrestrial control point, they will come to largely contribute to the simplification and convenience of the phtogrammetry. This time they were adapted to terrestrial photogrammetry. We used an inexpensive vibration gyro, though lower in accuracy, and a fiber optical gyro having moderate performance. The accelerometer employed is the servo type. Three gyros and accelerometers were installed on three orthogonal axes: X, Y, and Z respectively, to build up an inertial equipment. The camera used is a digital camera with 2.11 million pixels. Before proceeding to our experiments, examined were the characteristics of the vibration gyros, fiber optical gyros and accelerometers. A number of plastic plates, approximately 20 cm x 20 cm, were installed as objects in the experiment chamber. The coordinates of these objects were measured precisely with "Total Station."
The photographing was worked out with the cameras provided with accelerometers and gyros, which were either hand-held or on a carriage. The base-height ratio was 1/1.9 to 1/2.4. The standard deviations of the average values measured by the inertial photogrammetry with vibration gyro on carriage were 0.010 m in the planar direction (X, Y) and 0.036 m in the depth direction (Z). The same deviations with the fiber optical gyro turned out to be 0.011 m in planar direction (X, Y) and 0.039 m in depth (Z). In the inertial photogrammetry with the camera hand-held, the standard deviations were 0.016 m in planar direction and 0.100 m in depth with the vibration gyro, and 0.015 m and 0.087 m respectively with the fiber optical gyro. The measurement time is about ten seconds.

What was aimed at in our study was a development of a photogrammetry that does not require any control point. This methodology differs from the main stream of general research method that uses GPS and gyro. Conclusions derived from this study may be summarized as follows:
(1) Mounting the accelerometers and gyros on a camera makes it possible to compute the position and inclination of the camera when photographing, allowing thus for a photogrammetry without any ground control point.
(2) In general, the performance of the gyro has a great influence on the survey results. However, the influence on accuracy by the difference of the performance of the gyro was not caused. It is thought that the reason for this cause is that the measurement time was short.
(3) Although our photogrammetry may be insufficient at the current stage from the accuracy viewpoint, we think it will become an effective surveying means with some improvements added.

2 COMPOSITION OF THIS SYSTEM

In the system of the photogrammetry done with an inertial device, a gyro and an accelerometer which were installed at right angles to each other were equipped with a camera in this study. Data from gyro and accelerometer is converted from analogue into digital through the A/D conversion board, and is taken into the personal computer. Then, the position and the inclination of camera at the time of taking a picture are calculated.
On the other hand, the photograph taken with the camera is measured using a digitizer, and a analysis of the photograph is performed in the position and the inclination of a camera which were obtained from the gyro and the accelerometer.

2.1 Inertial device

2.2.1 Vibration gyro: The vibration gyro used for this measurement is the ENV-05A piezo-electric vibration gyro of Murata Mfg. Co., Ltd. which is shown in Figure 1.

2.2.2 Fiber optical gyro: The fiber optical gyro used for this measurement is the JG-35FD fiber optical gyro of Japan Aviation Electronics Industry., Ltd. which is shown in Figure 2.

2.2.3 Accelerometer: The accelerometer used for this measurement is the JA-5V accelerometer of Japan Aviation Electronics Industry., Ltd. which is shown in Figure 3.

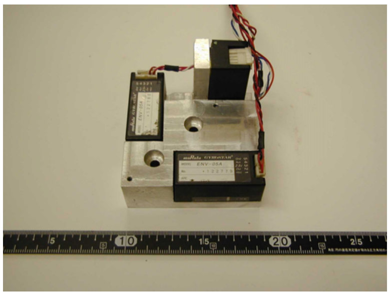


Figure 1. Vibration gyro

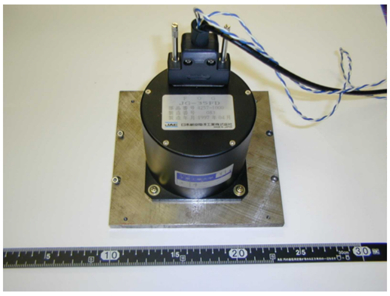


Figure 2. Fiber optical gyro

Figure 3. Accelerometer

2.2 Inertial camera

The experiment device equipped with the inertial device in the camera is defined in this study as an inertial camera. The inertial camera made for this study is shown in Figure 4. The camera used is a digital camera with 2.11 million pixels. The gyro and the accelerometer which are installed at right angles to each other are equipped with the camera. As a result, the three dimension position and the inclination of the camera when taking a picture are required.

Figure 4. Inertial camera

3 THREE DIMENSIONAL (3-D) MEASUREMENT WITH INERTIAL CAMERA (INDOOR EXPERIMENT)

Experiment for three dimensional measurement with inertial camera was carried out indoors as follows.

3.1 Installation of object (point of measurement and control point)

Figure 5 shows the subjects of measurement points and control points. These subjects measure 20cm×20cm, and are made of plastic board. The three-dimensional positions of subjects were located by the method of intersection and resection by utilizing a Total Station.

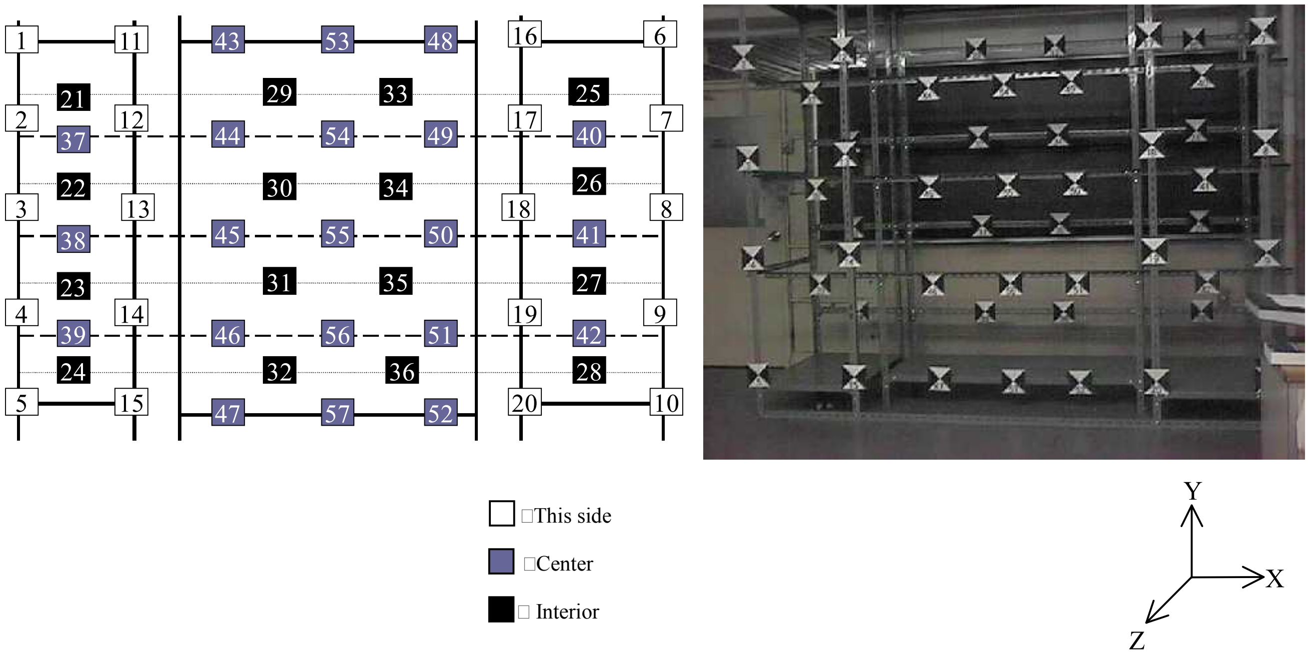


Figure 5. Subjects of measurement points and control points

3.2 Photographing

The experiment was carried out under the photography conditions shown in Figure 6. Experimentation was carried out for three cases as follows.
Experiment 1: Photographing distance is 4.3m, Base-height ratio is 1/2.4 (on a carriage)
Experiment 2: Photographing distance is 3.3m, Base-height ratio is 1/1.9 (on a carriage)
Experiment 3: Photographing distance is 4.3m, Base-height ratio is 1/2.4 (hand-held)
As for movement and photography of camera, photograph is taken by moving truck after determining the position of the truck in the front of a photographic subject in advance. In the experiment, the shutter of a camera is pressed at point O first, and after operating the inertial device, the camera is moved from point O to point A and then, the shutter is the pressed again to take 1 set of stereo photograph. Furthermore, inertial camera has to be moved on to point O where measurement by the inertial device is finished.
As for the synchronization of both taking data from the inertial device and taking a picture, the method of inputting the electric signals at time of taking a picture was examined. However, since there is the passage of a certain period of time even though the electric signals was instantaneously input, synchronization of taking a picture and taking data was found

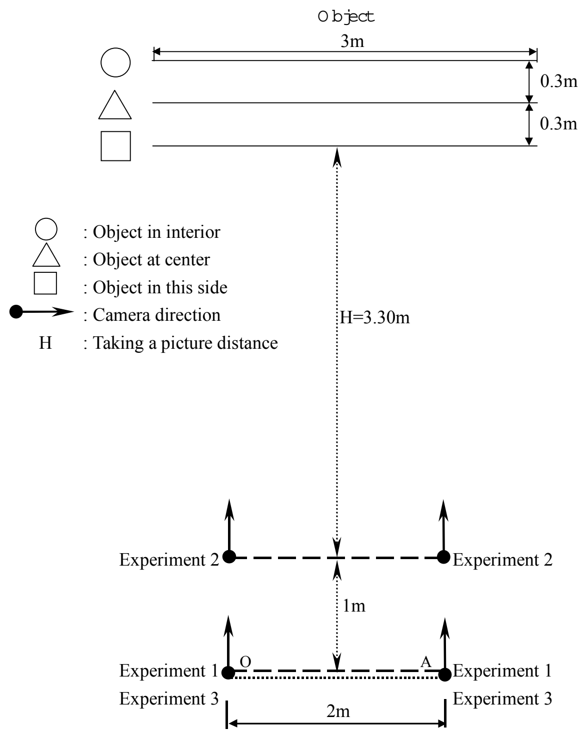
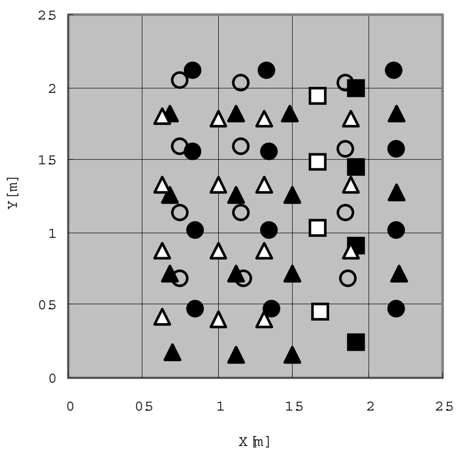


Figure 6. Photography condition

difficult at this stage. Then, in this study, a photograph was taken by making movement of the camera stop at time of photographing. By doing this, signal output from the inertial device is the one under the condition of no motion of camera and through the signal it is confirmed of no motion in the camera. The position where the inertial device had stopped was decided by the data obtained while no movement was confirmed by eyes, and the data analyzed considering as the place where inertial device stopped and the position of taking a picture were the same.

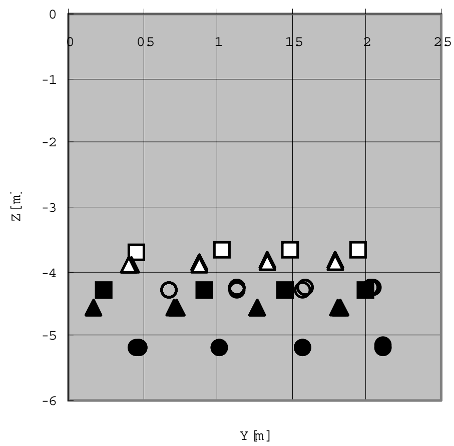
3.3 Result of analysis

For the accuracy test, the authors compared values of the three-dimensional measurement by utilizing photograph and Total Station. Proces s of analysis is shown as follows.
The interior orientation element of the camera was provided for by using the control points shown in Figure 5 first. Next, the orientation of the camera was done based on the interior orientation element and the exterior orientation element which had been obtained with the inertial device. The photographic coordinates were measured by a digitizer whose resolution is 0.020mm. The measurement points and the control points are not the same, but the points from case 1 to case 3 are the same points. The X-Y plan of an analytical result of experiment 1 is shown in Figure 7, and the Y-Z plan is shown in Figure 8. Result of analysis are shown in Table 1. From these results, the standard deviations of the average values measured by the inertial photogrammetry with vibration gyro on carriage were 0.010 m in the planar direction (X, Y) and 0.036 m in the depth direction (Z). The same deviations with the fiber optical gyro turned out to be 0.011 m in planar direction (X, Y) and 0.039 m in depth (Z). In the inertial photogrammetry with the camera displaced in hand, the standard deviations were 0.016 m in planar direction and 0.100 m in depth with the vibration gyro, and 0.015 m and 0.087 m respectively with the fiber optical gyro. The cause of the error will be an insufficiency of the accuracy of measurement of the external orientation element obtained from the inertial device, and a gap of the lens center of the camera and the center of the inertial device, etc.



□ : Actual measurement (interior) □ : IPS (interior)
□ : Actual measurement (center) □ : IPS (center)
□ : Actual measurement (this side) □ : IPS (this side)

Figure 7. X-Y plane (Experiment 1)



□ : Actual measurement (interior) □ : IPS (interior)
□ : Actual measurement (center) □ : IPS (center)
□ : Actual measurement (this side) □ : IPS (this side)

Figure 8. Y-Z plane (Experiment 1)

Table 1. Result of analysis

		Experiment 1				Experiment 2				Experiment 3			
		Actual measurement	Normal*1	IPS (Vib)*2	IPS (Fog)*3	Actual measurement	Normal*1	IPS (Vib)*2	IPS (Fog)*3	Actual measurement	Normal*1	IPS (Vib)*2	IPS (Fog)*3
Photographing distance H [m]		4.300				3.300				4.300			
Base length B [m]		2.000				2.000				2.000			
Base-height ratio B/H		1/2.4				1/1.9				1/2.4			
Measurement error*4	X [m]		0.003	0.189	0.186		0.002	0.084	0.086		0.003	0.127	0.129
	Y [m]		0.003	0.110	0.111		0.003	0.108	0.109		0.003	0.127	0.127
	Z [m]		0.032	0.787	0.777		0.024	0.579	0.583		0.036	0.783	0.794
Standard deviation of Measurement error	X [m]	0.013	0.001	0.021	0.022	0.010	0.001	0.007	0.007	0.013	0.001	0.014	0.016
	Y [m]	0.013	0.001	0.008	0.008	0.010	0.001	0.006	0.006	0.013	0.002	0.017	0.015
	Z [m]	0.028	0.006	0.059	0.062	0.017	0.004	0.012	0.016	0.028	0.005	0.100	0.087
σ_Z/Z			1/136	1/5	1/5		1/138	1/5	1/5		1/119	1/5	1/5

*1 Normal: Normal photogrammetric method
*2 IPS (Vib): Inertial photogrammetry system (Using vibration gyro)
*3 IPS (Fog): Inertial photogrammetry system (Using fiber optical gyro)
*4 Measurement error: Absolute value of measured value by photogrammetry from measured value by Total station
Calculate equation of actual measurement $\sigma_{X,Y} = (H/f) \cdot \sigma_p$, $\sigma_Z = (H^2/f) \cdot (1/b) \cdot \sigma_p$, $f = 0.0065$m, $\sigma_p = 0.020$mm

4 THREE DIMENSIONAL (3-D) MEASUREMENT WITH INERTIAL CAMERA

Experiment for three dimensional measurement with inertial camera was carried out outdoors as follows.

4.1 Installation of object (point of measurement and control point)

The object where 50 plastic sheets (17cm×17cm size) assumed to be point of measurement and control point were attached was made and affixed around the pond in front of the sixth building of Chiba Institute of Technology, as is shown in Figure 9.

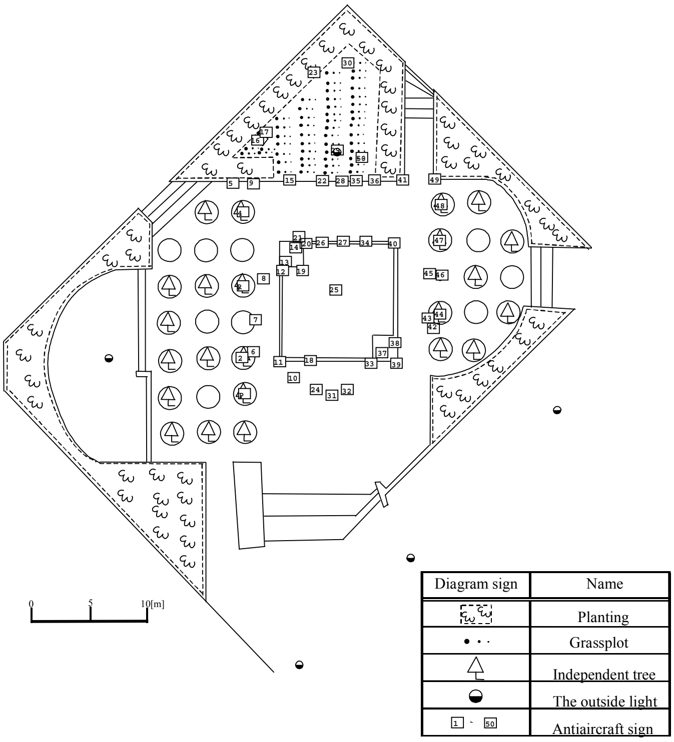


Figure 9. Object

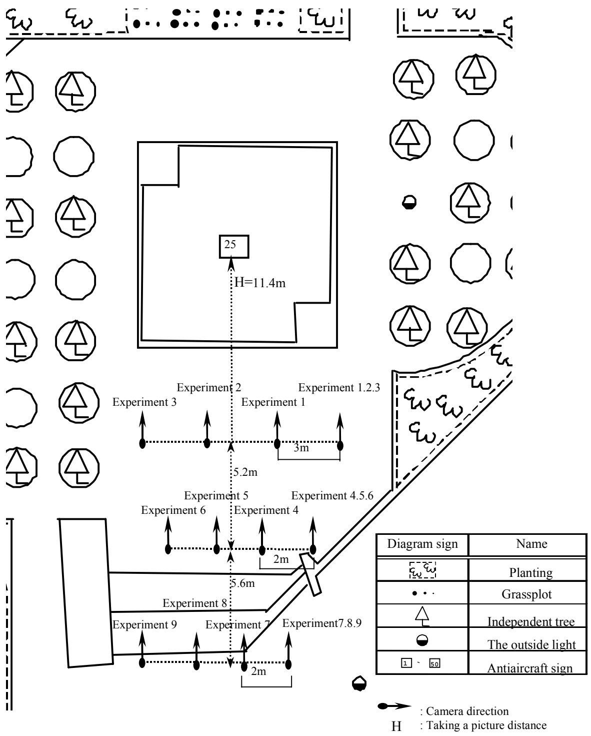


Figure 10. Photography condition

4.2 Photographing

The experiment was carried out under the photography conditions shown in Figure 10.
The experiment was performed nine times under the following conditions:
Experiment 1: Taking a picture at a distance of 11.4m and base-height ratio 1/3.8
Experiment 2: Taking a picture at a distance of 11.4m and base-height ratio 1/1.9
Experiment 3: Taking a picture at a distance of 11.4m and base-height ratio 1/1.3
Experiment 4: Taking a picture at a distance of 16.6m and base-height ratio 1/8.3
Experiment 5: Taking a picture at a distance of 16.6m and base-height ratio 1/4.2
Experiment 6: Taking a picture at a distance of 16.6m and base-height ratio 1/2.8
Experiment 7: Taking a picture at a distance of 22.2m and base-height ratio 1/11.1
Experiment 8: Taking a picture at a distance of 22.2m and base-height ratio 1/5.6
Experiment 9: Taking a picture at a distance of 22.2m and base-height ratio 1/3.7
The experiment method was done as well as the indoor experiment.

4.3 Result of analysis

Photography was performed almost horizontally to the photographic object. The measured value by the total station was set as true value and it was compared with the value measured from the photograph. In the analysis, first of all, the interior orientation element of the camera was determined based on control point taken a picture. Next, the orientation of the camera was done based on the obtained interior orientation element, the position and the inclination of camera when taking a picture obtained from inertia device. As for measuring the point on photograph, the coordinates were measured with the digitizer. The analysis followed the control point set up in the object and the point which had been arbitrarily selected from the object. A part of the pond was shown in the outline drawing based on the experiment result. The outline drawing of the result of experiment1 is shown in Figure 11.

5 CONCLUSIONS

At present, the error of external orientation element obtained from inertial device is larger than that from photographic analysis. Regarding this, the gap between lens center and inertial device center and detection accuracy of inertial device, etc. are considered as a cause of the error.

Because as point O is a point of taking a stereo picture in the actual experiment, frequency of movement of the inertial device is low. The error increases along with time due to the feature of the inertial device. Under the constant speed of moving inertial device, it will take more time according to the longer distance of movement and in this respect, range of error will increase. However, if it is made to move too quickly, an excessive vibration etc. will occur. If it is made to move slowly, it will cease to obtain effective acceleration and angle velocity by the relation with the resolving power of device. As for plenty of elements in relation to the error and time, the clear relationship between them cannot be understood yet despite its being grasped in outline.

Effective range is seemed within about 3-4m which is possible to move the inertial device in this stage.

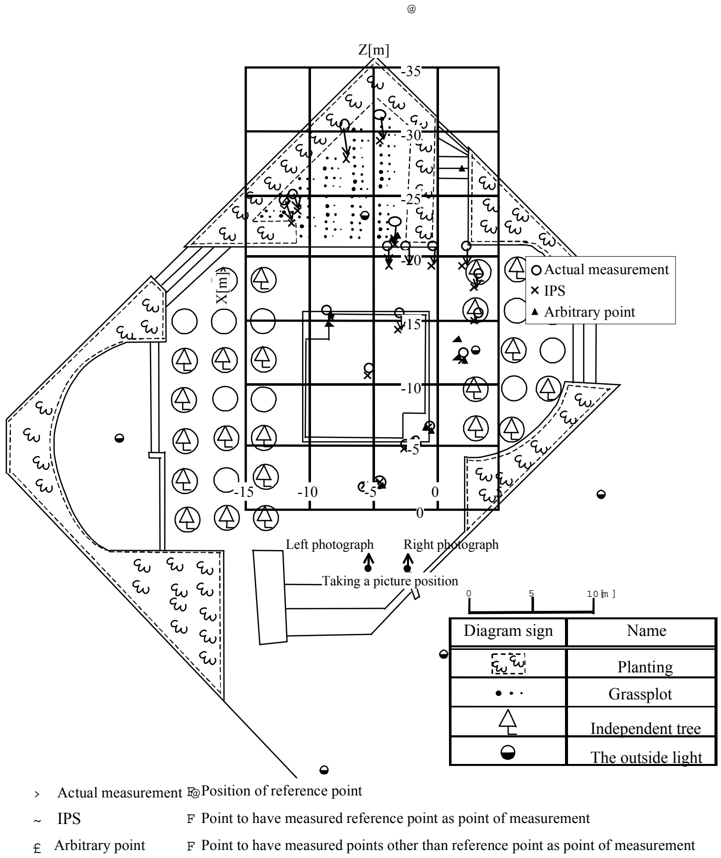


Figure 11. Outline drawing (Experiment 1)

This study is the one having aimed at the development of photogrammetry which does not need the control point. As for this method, it is what development was carried out through a new aspect in the use of the accelerometer and the gyro, besides the method by the GPS and the gyro that is generally the main current of the present research.

The result of this study is summarized below.

(1)The position and the inclination of camera when taking a picture were calculated by installing the accelerometer and the gyro in the camera, and owing to this it was confirmed that an exterior orientation element was obtained through the experiment.

(2)The method adopted in this study has some merits in comparison with the method by GPS, and enables to perform photogrammetry without control point in the buildings, undergrounds, mountains, etc, where electric waves do not reach.

(3)Improvement for accuracy is further necessary on the device through, sufficient materials have been obtained as a basic research for future study.

REFERNENCES

Aoki, T., 1996, Fundamental Study on Inertial Surveying. In: International Archives of Photogrammetry and Remote Sensing, Vienna, Vol.XXXI, Part B1, pp.6-12.

Nakano, T., 1998, Fundamental Study on the Development of the Photogrammetry Using Inertial Navigation Syatem. In: International Archives of Photogrammetry and Remote Sensing, Hakodate, Vol.XXXII, Part 5, pp.258-261.