# キネマティックGPSアンテナの傾斜による測定精度特性について

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# Characteristics of the Measurement Accuracy by the Inclination of Kinematic GPS Antenna

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It is possible to measure by KGPS to an accuracy of about 2 cm. As there are many merits to measure by KGPS and its application is coming to be of wide range in use. One of the ways of using KGPS is to calculate the angle of inclination of moving subjects. If the angle of inclination of the hull can be easily measured by KGPS with a high accuracy, the application to the field of fisheries can be considered. For this application, it is necessary to evaluate and detail the measurement accuracy of the angle of inclination by KGPS.

In this paper, we analyzed the measurement accuracy when the antenna inclines, since the antenna of KGPS also inclines when the moving subject inclines. Besides, we also analyzed the angle of inclination calculated by making the pitching and rolling antenna as the reference station.

As a result, the measurement accuracy to the angle of inclination and the reduction of accuracy became clear, and the measurement for moving subjects was found to be efficient.

Key words : Kinematic GPS, Antenna, Inclination, Accuracy, Ship motion

## 1 Introduction

The evaluation of the GPS (Global Positioning System) measurement accuracy has been conducted for various uses. Today, based on the evaluation, GPS is practically used in many fields.

On application to fisheries, for instance, GPS is utilized for gaining the accurate position of fishing reefs, and the shape measurement of the fishing boat and fishing gear. Moreover, if the angle of inclination is measured by GPS, it would be possible to correct the error of the depth measurement caused by the hull inclination and to measure the hull inclination that varies due to the fishing gear and catch while the fishing boat is being operated. These measurements would not only become basic data for the design of fishing boats and fishing gear, but also contribute to improve safety at sea caused by the hull inclination.

One of the techniques to measure these inclinations is considered to be the Kinematic technique that enables the measurement of the angle of inclination with a high accuracy. It is possible to measure the angle of inclination by a clinometer, but the measurement by Kinematic GPS (KGPS) has the merit the position and the speed can be simultaneously measured. Though this kind of experiment and the result of this analysis has been reported in the past[1)], it does not refer to the measurement accuracy when the antenna itself inclines.

Therefore, it was decided to evaluate and analyze on the characteristics of the measurement accuracy when the antenna inclines and the pitching and rolling antenna should be a reference station in order to measure the angle of inclination by KGPS. As a result, it was succeeded to evaluate how far the reduction of the measurement accuracy would be due to the angle of inclination of antenna.

## 2 Experiment

In order to analyze the measurement accuracy when the antenna inclines, 3 experiments were conducted. In this paper, it is decided the station of the previous position by

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Kinematic technique as a reference station, the station with an uninclined antenna as a fixed station and the station with an inclined antenna as an inclined station. The receiver used here for each station is 1 frequency type, Ashtech GG-24.

## 2.1 Experiment to compare the measurement accuracy of the fixed station and the inclined station

As shown in Fig. 1, we set up a fixed station and an inclined station 100.9cm apart from the reference station. Each station simultaneously stored raw data in a computer every 0.2seconds. The antenna at the inclined station was made to be inclined about an angle of 10degrees, 20degrees and 30degrees every 30minutes and the raw data was stored. Then, we conducted the measurement calculation by the post processing software with the Kinematic technique. By comparing the measurement results of the fixed station with the inclined station, the measurement accuracy when the antenna inclined was analyzed. The date of the experiment was May 25, 2004.

## 2.2 Measurement experiment of the angle of inclination made at two inclined stations

When the antenna is fixed on an onboard subject, the antenna also inclines by the inclination of the onboard subject. Then, as Fig. 2 indicates, one reference station and two inclined stations were set up, and the experiment was

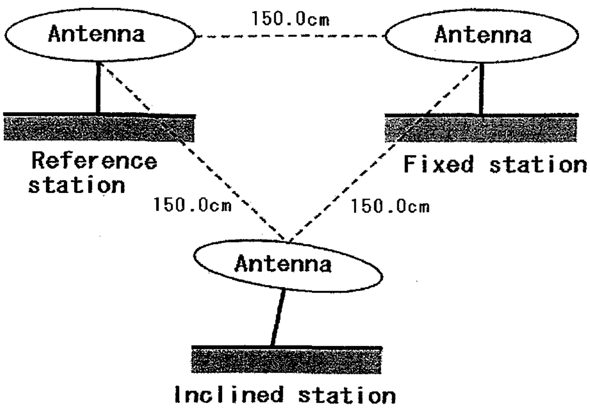


**Fig. 1.** Composition of the experiment to compare the measurement accuracy of the fixed station and the inclined station.

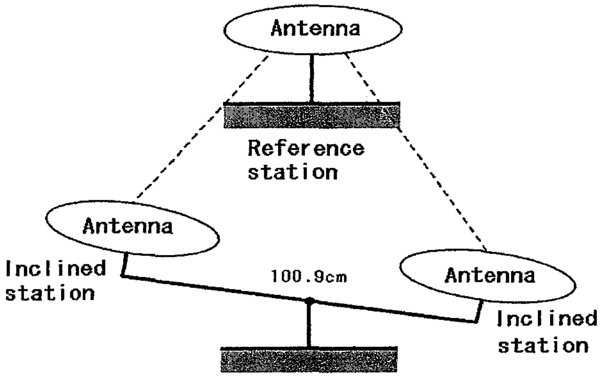


**Fig. 2.** Composition of the experiment of the angle of inclination made at 2 inclined stations.

conducted which assessed the angle of inclination caused by two stations. In the same way as the experiment of Section 2.1, the raw data was stored in the computer every 0.2 seconds, the antenna at the inclined station was made to be inclined at 0 degree, 10degrees, 20degrees and 30degrees every 30minutes.

The angle of inclination was calculated by the following two methods. One is that after getting the relative vector of each inclined station from the reference station, the angle of inclination was calculated from the distance of each inclined station (the length of actual measurement) and the difference of the z element (the height direction). The following equation is for the angle of inclination $a_1$.

$$a_1 = \sin^{-1}(\Delta z / L_1) \cdots\cdots\cdots (1)$$

Here, $\Delta z = z_1 - z_2$

$z_1$, $z_2$ : the z element for each inclined station

$L_1$ : the length between the antennas at the inclined stations (100.9cm).

The other method is that by making the one inclined station out of two as a reference station, the relative vector of the other inclined station was calculated. The following equation is of the angle of inclination $a_2$ by this method.

$$a_2 = \sin^{-1}(z_3 / L_1) \cdots\cdots\cdots (2)$$

Here, $z_3$ : the z element of the relative vector seen from an inclined station at one side.

By comparing $a_1$ with $a_2$, we analyzed the accuracy of the angle of inclination from the reference station and the angle of inclination was calculated by making one inclined station as reference. The date of the experiment was June 15, 2004.

### 2.3 Measurement experiment of the angle of inclination at the inclined station which pitches and rolls

In the case of measuring onboard, the ship usually pitches and rolls. Then, as shown in Fig. 3 , we set up two inclined stations which repeat inclining on a regular cycle. The inclination was manually operated at almost a fixed cycle up to about 30degrees up and down. The experiment was conducted four times, and raw data was stored in the computer every 0.2seconds over a period of about 10 minutes. The calculation of the angle of inclination is the same as Section 2.2. However, when one side of the moving inclined station is a reference, that position is calculated by point positioning. When the relative vectors at each station are short, even if there is an error which point positioning makes at reference position, it is known that there is almost no influence on the relative vector[2]. By this experiment, it is possible to analyze the measurement accuracy of the angle of inclination when making the inclined station which pitches and rolls as a reference. The date of the experiment was July 29, 2004.

## 3 Results and discussion

### 3.1 Characteristics of the measurement accuracy by an inclined antenna

Fig. 4 shows the result of the experiment at Section 2.1. It shows the ratio of the standard deviation of the inclined station against the standard deviation resulted from the direction of the three axes at the fixed station. By the way, Table 1 shows the standard deviation at the fixed station. The standard deviation of 3 axes direction at the inclined station seems to increase as the gradient increases, compared that of at the fixed station

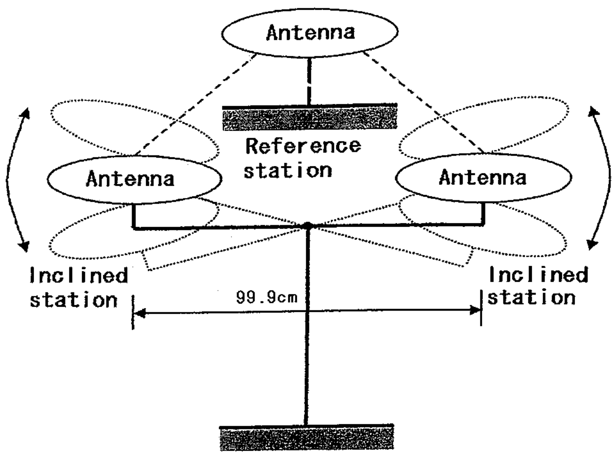


**Fig. 3 .** Composition of the experiment of the inclination at the inclined station which pitches and rolls.

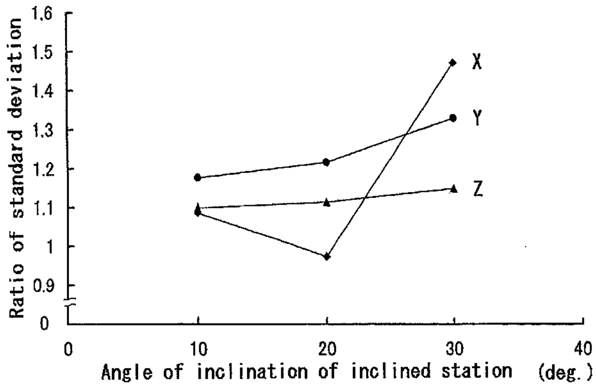


**Fig. 4 .** Measurement accuracy by the inclined antenna.

Then, since it would be estimated that the number of captured satellite signals and PDOP (position dilution of precision by the satellite location) would change as the antenna inclines, the average and the standard deviation are shown in Table 2 . According to this table, though when the angle of inclination is 10degrees, PDOP is getting worse, there is almost no difference between the fixed station and the inclined station at different angles. However, as Fig. 5 shows, the change of the number of captured satellite signals by time series was more recognizable at the inclined station. Along with the influence of Multipass, this is also considered as a cause which influences the accuracy of 3 axes direction at the inclined station.

Though it depends on the surrounding environment of the setting place, it is recognized that when the gradient

**Table 1 .** The standard deviation at the fixed station.

| Fixed station | 0° (10° ) | 0° (20° ) | 0° (30° ) |
|---|---|---|---|
| x (cm) | 0.22 | 0.29 | 0.37 |
| y (cm) | 0.28 | 0.30 | 0.30 |
| z (cm) | 0.69 | 0.71 | 0.84 |

( ) : Angle of inclination of inclined station

**Table 2 .** The average and the standard deviation of the number of satellite and PDOP.

| Angle of inclination | | 10° | | 20° | | 30° | |
|---|---|---|---|---|---|---|---|
| Station | | Inclined station | Fixed station | Inclined station | Fixed station | Inclined station | Fixed station |
| PDOP | Average | 1.66 | 2.07 | 1.43 | 1.43 | 1.35 | 1.35 |
| | Standard deviation | 0.155 | 0.232 | 0.067 | 0.067 | 0.058 | 0.057 |
| Number of satellite | Average | 7.9 | 7.9 | 9.0 | 9.0 | 8.6 | 8.6 |
| | Standard deviation | 0.95 | 0.94 | 0.04 | 0.04 | 0.76 | 0.75 |

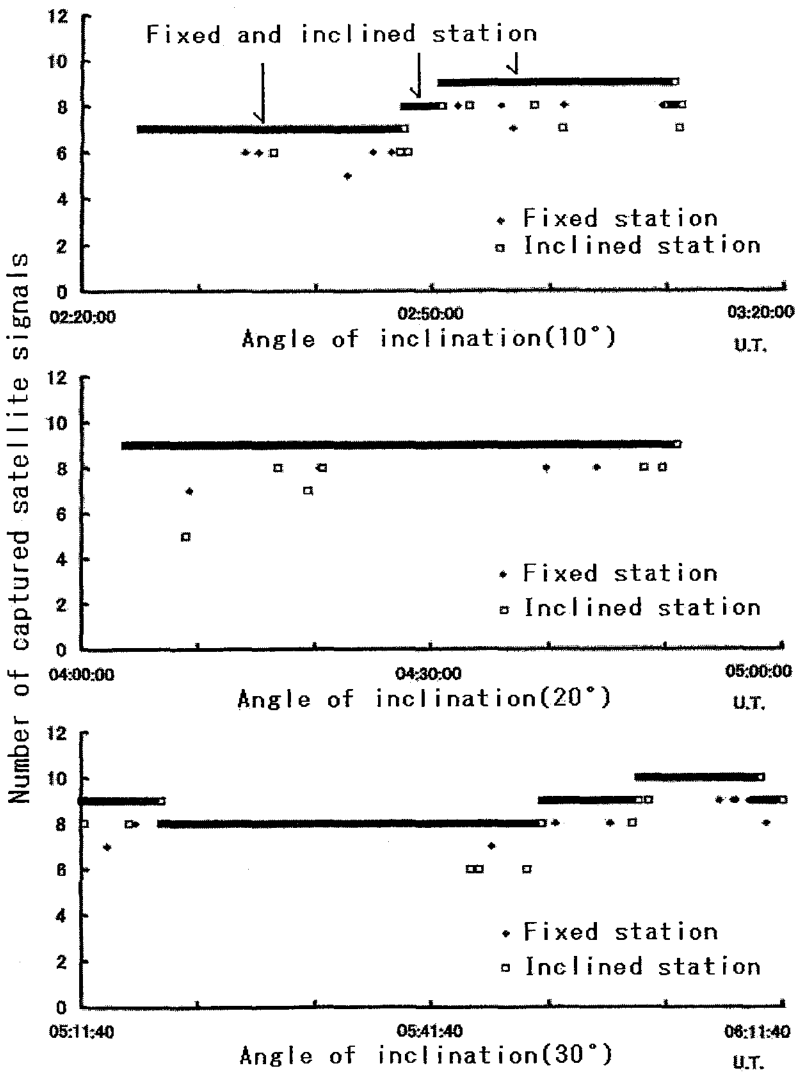


**Fig. 5 .** Number of captured satellite signals.

becomes nearly 30degrees, the accuracy is reduced to about 50% at the x-axis. The accuracy of the z-axis used for the measurement of the angle of inclination is reduced by only 15% at the gradient of 30degrees. In order to minimize the reduction of the measured accuracy caused by the antenna inclination, it is needed a device which makes no inclination of the antenna itself if the pedestal setting on the antenna inclines.

### 3.2 Characteristics of the measurement accuracy of the angle of inclination calculated by two inclined stations

#### 3.2.1 Angle of inclination calculated by the static inclined station

The angle of inclination was calculated using the method of Section 2.2. Fig. 6 shows the result of the angle of inclination which gained from a reference station using equation (1), and of the angle of inclination gained by making one side of the inclined station as reference using equation (2).

When the gradient is 0 degree, the difference of the measurement accuracy of the two inclined stations seen from the reference station is only 0.1cm on the Y-axis, so it is safe to say that the two receivers at the inclined station have almost the same measurement accuracy. There is a tendency that the larger the gradient becomes, the worse becomes the measurement accuracy of the angle of inclination calculated by equations (1) and (2), whose value is from about 0.3to 0.5degrees. According to the approximate curve in the figure, there is almost no difference in the accuracy under 25degrees of the angle of inclination. Therefore, the degree of reduction in accuracy is hardly changed even if the angle of inclination is calculated by making one side of the inclined station as reference.

This means that when calculating the angle of inclination onboard, it is not necessary to set up a static reference station on land. Therefore, this has a big merit that it does not need to consider the length of the baseline from the reference station onboard.

Next, the accuracy of the angle of inclination depends on the accuracy of the z element of the relative vector. Then, Fig. 7 shows an example of the measurement consequence to z element at two inclined stations seen in time series. Though this is the case of a gradient of 10 degrees, there seems to be the same change of error. However, the correlation coefficient is 0.49, and there is almost no correlation. This is the same as the report[3] of the result of the experiment at the fixed station. Accordingly, it would be correct to consider that the errors at each inclined station are independent.

#### 3.2.2 Angle of inclination calculated by making one side of pitching and rolling inclined station as reference

In Sections 3.1 and 3.2.1, we conducted the basic analysis of the measurement accuracy when an antenna inclined, and clarified the changes in accuracy. In this section, the angle of inclination was calculated under the state of an antenna repeating inclination periodically, then the characteristics of the measurement accuracy were analyzed.

According to the experiment formation in the Fig. 3, an example of the results of the experiment is shown in Fig. 8 (a) and (b). (a) is the angle of inclination calculated from the reference station, and (b) is the angle of inclination calculated from one side of the inclined station. These

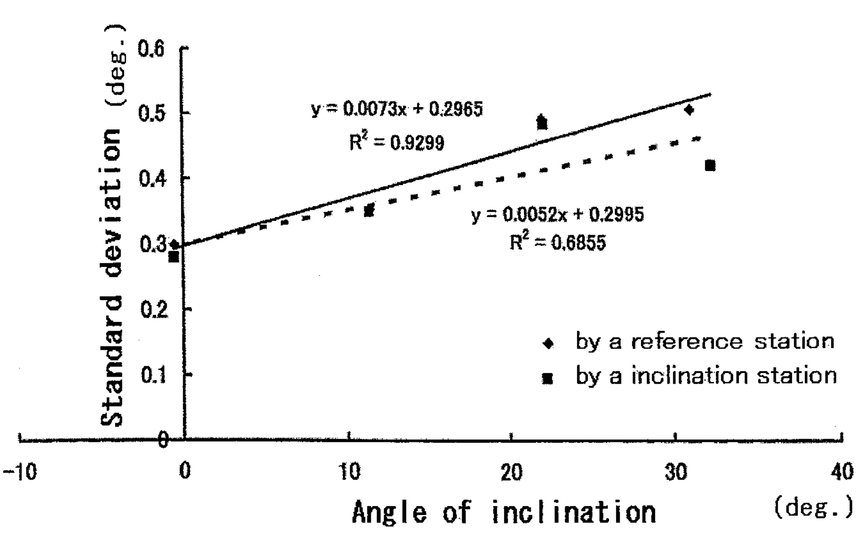


**Fig. 6 .** Measurement accuracy of the angle of inclination which was gained from the reference station and gained by making one side the inclined station.

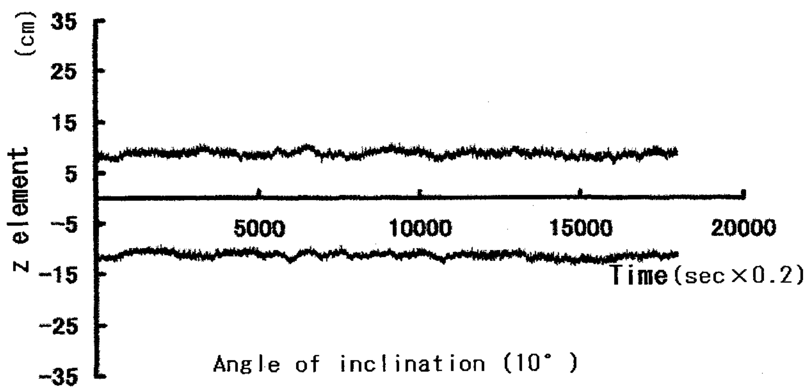


Fig. 7. An example of the measurement consequence to the z element at two inclined stations.

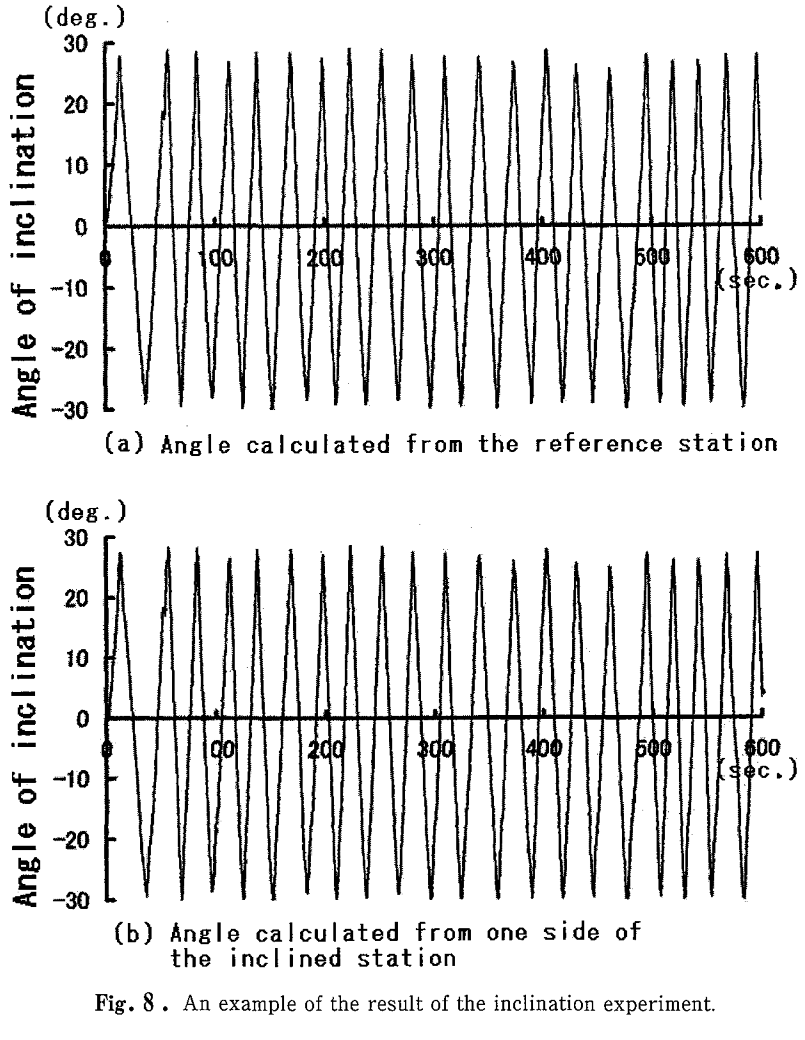


Fig. 8. An example of the result of the inclination experiment.

are the results for a period of 10 minutes, and the average of one cycle is about 30 seconds. In the result of (b), the inclined station as reference is moving. Therefore, the error of (b) was considered larger than that of (a), then we got the difference as (a) as standard. Table 3 shows that result. The average of the difference is about 0.5 degrees, and the standard deviation is about 0.15 degrees. In addition to that, the difference was compared when the angle of inclination was under 15 degrees and more than 15 degrees. That result is shown in Table 4. Only by a little

**Table 3.** The comparison of the inclination experiment.

| | |
|---|---|
| Average | 0.53 ° |
| Standard deviation | 0.146 ° |
| Number | 3000 |
| Max | 1.97 ° |

**Table 4.** The comparison of the result of the high angle and low angle of inclination.

| | −15°≦A≦15° | A<−15°, 15°>A |
|---|---|---|
| Average | 0.51° | 0.54° |
| Standard deviation | 0.138° | 0.151° |
| Number | 1477 | 1523 |
| Max | 1.77° | 1.97° |

A : Angle of inclination

though, the smaller the angle of inclination becomes, the lesser the difference becomes. Though depending on the measurement subject, these results on the accuracy seems to be quite enough in quality generally.

Accordingly, if the angle of inclination is calculated by making one side of pitching and rolling antenna as reference, there is no problem for practical purposes.

## 4 Conclusions

To sum up the observations of this experiment, the following statements can be made. Here, these are the results of the experiment when the distance between the antennas is about 1 m and the angle of inclination is less than 30degrees.

(1) If the antenna inclines about 30degrees, the angle of inclination can be calculated at a measurement accuracy of about 0.5degrees.

(2) Even if the antenna inclines, there is almost no influence on the number of captured satellite signals and PDOP.

(3) The inclination of the antenna becomes a cause of the reduction of the measurement accuracy, but the degree of the accuracy reduction to the $z$ element, which is needed for the measurement of the angle of inclination, becomes about 15% at a gradient of 30degrees, which is less than that of the x and y element.

(4) In order to increase the measurement accuracy, there should be a device which does not incline the antenna even if the pedestal setting on the antenna inclines.

(5) The angle of inclination calculated by making one side of the inclined station as reference has hardly changed with the degree of reduction of the measurement accuracy of the angle of inclination calculated by data of the reference station.

(6) Even if the angle of inclination is calculated by making one side of pitching and rolling antenna as the reference, there is almost no influence on the measurement accuracy. However, further analyses are needed with more rapid cyclical oscillations.

Hereafter, when conducting a pitching and rolling experiment, we are considering to investigate the measurement accuracy making a device which can set up the cycle and the angle of inclination that is mechanically and precisely operated.

## References

1) H. Namie, A. Yasuda and T. Okamura : Application of Real-Time Kinematic GPS to Clinometer, The Journal of Japan Institute of Navigation, 94, pp. 125-129 (1996).

2) K. Okuda, K. Motomura and S. Inoue : Degradation in the Accuracy of Baseline Vectors due to Errors in KGPS Reference Station Data, Fisheries Engineering, 40, No. 1, pp. 201-208 (2003).

3) K. Okuda, J. Kawasaki and K. Motomura : Characteristics of Kinematic GPS Measurement Accuracy over a Short Baseline Length, Journal of National Fisheries University, 53(1), pp. 1-8 (2005).

# キネマティックGPSアンテナの傾斜による測定精度特性について

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KGPSは約2cmの精度で測定することができる。KGPSによる測定は多くの利点があるので，その利用範囲は広まりつつある。移動体の傾斜角度を求めることもその利用方法の一つである。KGPSによって船体の傾斜角度を高精度で簡単に測定することができれば，水産分野への応用が考えられる。そのためには，KGPSによる傾斜角度の測定精度を明らかにして把握する必要がある。

本論では，移動体が傾斜するとき，KGPSのアンテナも傾斜するので，アンテナ傾斜による測定精度について解析を行った。 また，動揺するアンテナを基準として計算した傾斜角度についても解析した。

その結果，傾斜角度に対する測定精度とその劣化精度を明らかにすることができ，移動体での測定が有効であることが分かった。