実測によるキネマティックGPSの短基線長測定精度特性

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Characteristics of Kinematic GPS Measurement Accuracy over a Short Baseline Length

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Recently applied technology using kinematic GPS has become increasingly important. In the field of maritime navigation and pilotage, GPS based compasses have become of practical use, and hull oscillation device are currently being manufactured. With these devices, the reference point continuously changes as it is onboard the vessel. Therefore, the position is figured with the differential or point positioning GPS every time it is calculated. The accuracy of the case when it is applied for the compass with this technique is shown in the manual of the manufacturer, and is theoretically detailed. However, the quantitative accuracy by actual measurements of the measurement point from the reference point over a very short baseline length of one to several meters has not been published. Therefore, the actual measurement was surveyed under the condition that intervals of the baseline length were set every one-meter up to six meter. Then, the characteristics of the measurement accuracy were analyzed, and the general expression was quantitatively shown for the accuracy by the baseline length of the measurement point seen from the reference point.

1 Introduction

Recently, there is much research and developments using GPS in various fields. Not only for position fixing, but also the compass and the hull oscillation device based on GPS are manufactured for use in maritime navigation and pilotage.

The technique of kinematics is applied to the principle of this measurement, and it requires several receivers. Using the data received from the satellites with these receivers at the same time, the direction and oscillation value of the hull are determined. At the moment, the distance (baseline length) of each receiver has been shown to influence the measurement accuracy[1,2]. Though the measurement accuracy deteriorates when the baseline length gets long, it is relatively better to make the distance of each receiver long especially in the case of using GPS for the compasses and the oscillation detection device of the hull that the baseline length becomes less than several meters. That is why the change of the measurement point is surveyed from the reference point on this occasion. However, there are hardly any reports on the quantitative analysis of the measurement error when the baseline length is extremely short.

Then, the authors measured the distance of each receiver making intervals of one meter up to approximately six meters. And next, we analyzed quantitatively the relations of the measurement error to the distance of each receiver. As a result, we derived the general expression on the accuracy of the measurement point from the reference point, and analyzed the character of the measurement error as well.

These results of the analysis will be guidelines and basic data, in the case of the measurement of the hull position of an operating fishing boat using kinematic GPS and calibration of data such as the measurement of the precise depth of water.

2 Measurement accuracy and factor by kinematic method

The measurement accuracy by the kinematic method is decided by the factors such as the precision of the satellite orbit information, the radio wave propagation route in the

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ionosphere and the troposphere, the phase character of the antenna, the receiver internal error, the disturbance wave and baseline software.

Generally, the following formula shows the measurement accuracy considering the above factors[3].

Accuracy = (0.5~1.0cm) + (0.5~2.0ppm) × baseline length

Where, the unit of accuracy is cm and baseline length is m. 0.5-1.0cm as a constant term could be the measurement accuracy by this formula since the baseline length is several meters long and it is short in this experiment. The main factors of this term are the internal error of the receiver and the error caused by the antenna, and this value depends on the length of the measuring time. Therefore, this experiment was conducted for a fixed period of 24 hours for each pattern of satellite location so that the character of the measuring accuracy could be analyzed as well as the proof of this formula.

And, the horizontal measurement accuracy of the baseline length over a scale of km has been given in the empirical formula by Okuda et al.[1].

3 Method of experiment and analysis

Considering the difficulties of taking long distance due to the inboard structure, and making the several receivers as a unity type, the distance between the receivers was set at a maximum of 6 m. 3 receivers were prepared in the experiment, and the distance between each receiver was set at about 1 m as shown in Fig. 1. After the receivers were placed at ①, ②, ③ and data simultaneously recorded over a 24 hour period, the receivers were moved to positions ①, ④, ⑤ and then ①, ⑥, ⑦ over 24 hour periods, respectively and data received. Accordingly, data from (①, ②, ③), (①, ④, ⑤) and (①, ⑥, ⑦) were received under the same environmental conditions.

Raw data from the satellite were stored in a personal computer with each receiver in one-second interval. And, the measurement calculation took the way of post processing software conducted after all the data were received. The receivers used in the experiment are Ashtec GG24 (1 wave type).

The measurement calculation was conducted as ① as the reference point, and from② to ⑦ as the measurement points. Therefore, the measurement accuracy can be analyzed in intervals of 1 m from the reference point. And, because the measurement will be done at the moved onboard the vessel, the measurement calculation adopted the method of relative measurement from the reference point. The position of the reference point is not the absolute position, but the position of the point positioning GPS in this method. Though the accuracy of the point positioning GPS has about a 10m error with the radius of 95% circular error probable, it has been proved that there is minimal error in the baseline vector when the baseline length is several m[4].

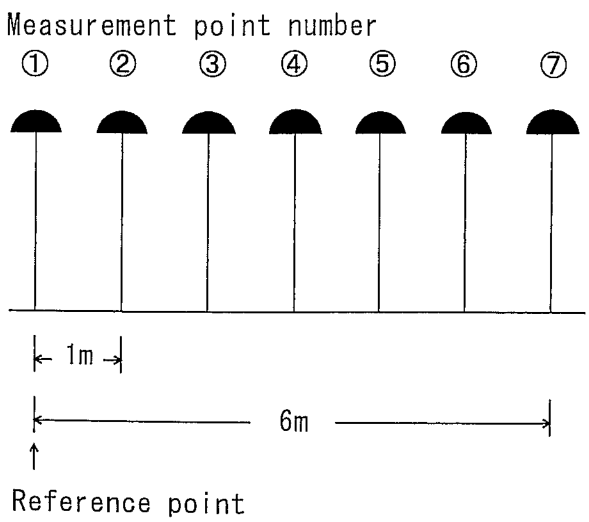

Fig. 1. Composition of the experiment, showing the position of the reference point and 6 measurement points.

And, the output of the result of the measurement calculation by post-processing is the measurement time, PDOP (position dilution of precision by the satellite location), the vector of the x, y and z element, the number of satellites used for the measurement calculation and the reliability of the raw data etc.

The experiment outline is shown in Table 1.

4 Results and discussion

4.1 Vector error for each baseline length

Table 2 shows the results of the measurement calculation in each experiment. And, Fig. 2 shows the measurement distribution when the baseline length is 1 m as an example. The mean vector length from the reference point in each experiment became the same length (unit:mm) measured using a tape measure at the time of the experiment. The standard deviation of the baseline vector for each baseline length is about 0.8cm, and this value is within the measurement accuracy as mentioned in Section 2. There is no correlation between the standard deviation for each measurement point and the baseline length, and the standard deviation had about the same accuracy. Namely, there is no difference in the accuracy of the baseline vector at this degree of short baseline length. And the number of data in Table 2 is less than the total for 24-hour (86400) due to the removal of unreliable raw data in the experiment. The causes of occurrence of these unreliable raw data are the environment and of hardware like the receivers used in the experiment. Especially, it is considered that faults caused by the radio wave propagation occurred in the experiment.

Table 1. Specifications of the experiment

Date of experiment (U.T.)	Measurement point number	Baseline length(cm)	Height from reference point (cm)	Position of reference point
2002 5/20 10:00～	②	100.4	1.5	
5/21 10:00	③	199.3	−0.5	34° 4.'15330N
5/21 11:00～	④	300.7	1.4	130° 53.'57685E
5/22 11:00	⑤	397.7	0.6	Height of antenna
2003 3/04 05:00～	⑥	497.2	1.4	: 71.997 m
3/05 5:00	⑦	599.3	1.6	

Table 2. Results of the measurement calculation

Measurement point number	Number of data	Average : upper Standard deviation : lower (cm)					
		Length of the baseline vector	x	y	z	PDOP	Number of available satellite
②	69174	100.43	97.73	−23.07	1.53	1.46	8.36
		0.79	0.26	0.36	0.68	0.39	1.38
③	71344	199.34	190.96	−57.16	−0.47	1.46	8.26
		0.83	0.28	0.35	0.71	0.39	1.32
④	69367	300.71	292.70	−68.91	1.43	1.47	8.26
		0.81	0.27	0.37	0.68	0.41	1.33
⑤	71195	397.72	386.38	−94.28	0.62	1.47	8.31
		0.81	0.27	0.35	0.69	0.41	1.38
⑥	69544	497.21	488.17	−94.37	1.43	1.50	8.18
		0.79	0.25	0.32	0.68	0.41	1.29
⑦	66415	599.32	586.22	−124.61	1.56	1.46	8.34
		0.76	0.26	0.31	0.65	0.38	1.20

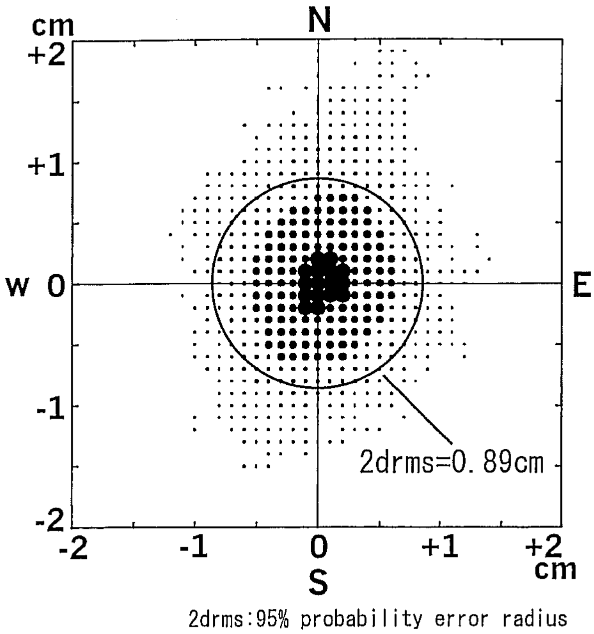

Fig. 2. Measurement distribution when the baseline length is 1 m.

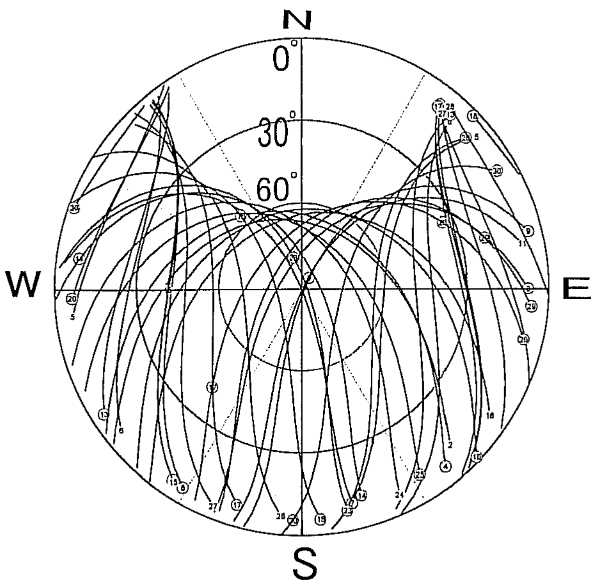

Fig. 3. Satellite location. (2003 3/4 05:00 ~ 3/5 05:00)
Note : The numbers on the figure are the satellite number.

Comparing the standard deviation of the 3 elements of each experiment, the z element (height direction) is the biggest one in all the experiments, and the y element (latitude direction) is the next. As for this cause, there is something to do with the location of the satellites. The satellites are only in the sky above the measurement point, and the data can be got only from the sky. As the measurement calculation uses the distance between the satellite and the measurement point, its result greatly affects the z element. And, the correction error of the radio wave propagation delay by the ionosphere and the atmosphere influences the z element as well. The difference of the accuracy of the x (longitude direction) and the y element is also influenced by the satellite location. Since the inclination of the satellite is 55° , the satellite is hardly seen in the north direction in the Northern Hemisphere. Fig. 3 is an example of a satellite trace over a 24 hour period as seen from the measurement point in the experiment. The center indicates the measurement point, and the circumference shows an elevation of 0° . According to this figure, no satellite appeared at the elevation less than about 60° within the range of direction from about 320° to 40° . This is the reason for the difference of the accuracy of the x and y element. This indicates that the size of the measurement error differs because the crossing angle of the position line also differs, and it is caused by the satellite location as mentioned above. Therefore, when the baseline length is several m, the standard deviation of the y element is bigger than that of the x element. However, when the unit of length becomes km, the x element is bigger than the y element[1]. Though it is possible to consider as the reason for this is the influence of the precision of the correction data, which is transmitted from the reference point to the measurement point, the precise reason for this is not clear.

4.2 Correlation of the 3 elements in the baseline vector

In Section 4.1, we mentioned that the accuracy of the baseline vector from the baseline length 1 to 6 m became almost the same value. In this section, the subject is the correlation between the 3 elements is examined. For example, Fig. 4 shows a time series diagram of the error of the 3 elements when the baseline length is 1 m. This figure clarifies the variation of the error between the 3 elements diachronically. It is said that the standard deviation of the baseline vector becomes smaller than that of the 3 elements[5]. This is because the error to negate the error in another element appears when the error appears in either one of the vector elements, and it is considered that there is a correlation between the errors of the 3 elements. That is, as shown in Fig. 4, the y or z element has the error to negate the big error of the x element. Consequently, the standard deviation of the length of the vector becomes smaller than those of each individual element. However, the error of the 3 elements is likely to tune each other at a glance of Fig. 4. That is, when a large error appears, there might be a large error in all 3 elements. Then, the result that the coefficient of correlation was calculated with the combination of each element is shown in Table 3. According to this table, there is no correlation between the 3 elements in each experiment. And, there is no contradiction between the standard deviation of the length of the vector and that of the 3 elements in this experiment. Therefore, when the baseline length is several m, the errors of the 3 elements are concluded to occur independently.

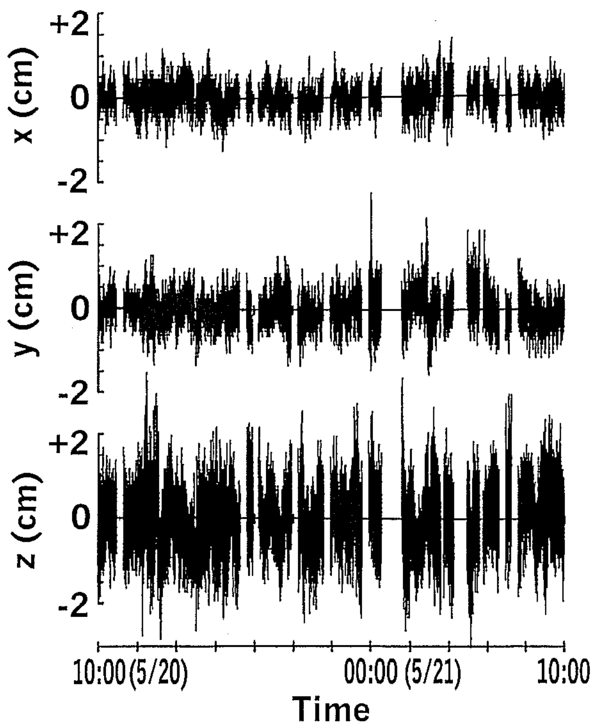

Fig. 4. Time series figure of the error when the baseline length is 1 m.

Table 3. Correlation by combination of each element

Measurement point number	Cofficient of correlation		
	x-y	x-z	y-z
②	0.14	−0.00	−0.14
③	−0.02	−0.03	−0.06
④	0.01	−0.02	−0.10
⑤	0.01	−0.00	−0.03
⑥	0.02	0.07	−0.13
⑦	0.08	0.03	−0.08

4.3 Correlation character by the baseline length of each element

As mentioned above, there seems to be no significant difference between the standard deviations of the baseline vector length with the baseline length. This section will discuss about the analysis of interrelation between each element with the baseline length. If there is any correlation in each element, the measurement can be done in high precision using the differential method. And, if not, the error of each receiver appears to happen independently, and it would correspond to the consideration given in Section 4.2.

In the experiment, as ①②③, ①④⑤ and ①⑥⑦ in Fig. 1 were received at the same time, correlations of the error of each element were computed when the baseline length is 1 m and 2 m, 3 m and 4 m, and 5 m and 6 m. The results are shown in Table 4. According to the correlation coefficient, it is hard to determine whether or not there is a clear correlation of the 3 elements with the baseline length. For example, the difference between the errors of 1 m and those of 2 m is shown by the time series in Fig. 5. The statistics of the difference in these errors are shown in Table 5. This statistic is the value which the error of the baseline length 1 m was deducted from that of 2 m, 3 m from 4 m, and 5 m from 6 m. This method is based on the technique of the differential, and it can be regarded that the results are the measurement accuracy after the differential of the baseline length 2 m, 4 m and 6 m. This accuracy does not almost change with the results shown in Table 2. Therefore, it seems that the error of each receiver is independent, and the causes could be the internal error of the receiver and the characteristic error of the antenna.

Table 4. Correlation of error of measurement point received at the same time

Measurement point number	Number of data	Coefficient of correlation		
		x	y	z
③-②	59975	0.38	0.43	0.48
⑤-④	64153	0.54	0.56	0.55
⑦-⑥	61908	0.49	0.46	0.52

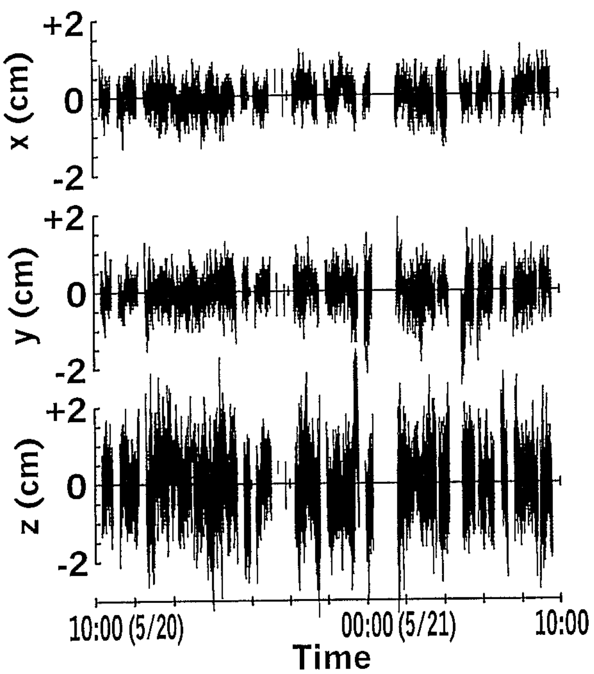

Fig. 5. Time series figure of the difference of the error (baseline length 2 m − 1 m).

Table 5. Difference of error of measurement point received at the same time

Measurement point number	Standard deviation (cm)		
	x	y	z
③-②	0.30	0.36	0.71
⑤-④	0.26	0.32	0.64
⑦-⑥	0.26	0.32	0.65

Table 6. Accuracy of measurement point seen from the reference point

Measurement point number	Standard deviation (degree)	
	Horizontal direction	Position direction
②	0.25	0.45
③	0.13	0.24
④	0.09	0.16
⑤	0.06	0.12
⑥	0.05	0.09
⑦	0.04	0.08

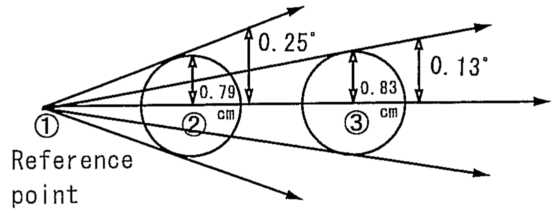

Fig. 6. Model type of the accuracy seen from the reference point.

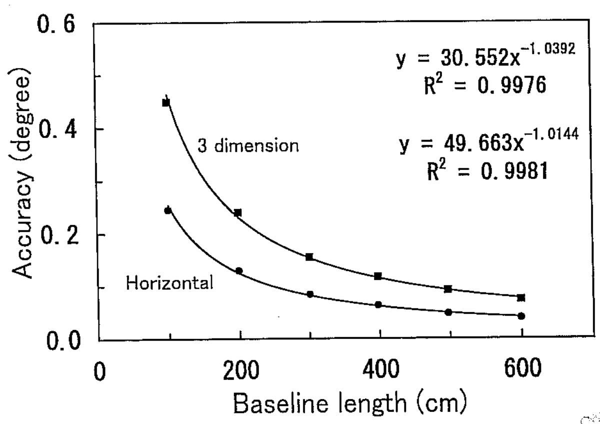

Fig. 7. Measurement accuracy seen from the reference point.

4.4 Measurement accuracy by the baseline length

The results from which the measurement accuracy by the baseline length was calculated in the angle seen from the reference point is shown in Table 6, and its model type is shown in Fig. 6. Since there is almost no difference in the measurement accuracy by the baseline length, the angle of the measurement accuracy of the receiver point seen from the reference point ① gets smaller with increased distance from ①. Therefore, when GPS is applied to the compass and the hull oscillation detector device, it is quantitatively found that the accuracy improves as the baseline length is increased. These relations are shown in Fig. 7. The y-axis indicates the measurement accuracy seen from the reference point, and the x-axis the baseline length. The measurement accuracy of the horizontal direction is for the measurement such as the direction. The accuracy of the 3 dimensions added to the vertical direction is for the measurement such as the oscillation of the hull. The approximate curves were calculated to find the accuracy quantitatively by the plot point in the figure. We considered the power of a number approximation is suitable for this curve by the tendency of the plot point. The approximate curve and the expression are shown in the figure.

Among the variables in the expression, y is the measurement accuracy (unit :degree) seen from the reference point, and x the baseline length (unit :cm). And R^2 is the correlation coefficient squared. It is proved that the accuracy very much improves at 2 m and more though there are many cases that the baseline length is set at 1 m due to the limited space availability onboard and the length of the frame between the antennas.

These expressions can provide the fundamental data to take the baseline length into consideration according to the examination environment and the necessary accuracy.

5 Conclusion

The following are the conclusions from the results and the discussion of the measurement accuracy characteristics on the short baseline length.

(1) There was no correlation between the standard deviation of the 3 elements and the baseline length. And, the difference of the standard allocation of the 3 elements is caused by the characteristics of the principle and the satellite location. As the other cause, though the correction information was considered, it was not proven.

(2) There was no correlation of the 3 elements for each baseline length.

(3) Because the error of the short baseline length is caused by the characteristics of the receiver, the accuracy does not improve even if the technique of the differential is used on the results by the technique of the kinematic.

(4) As the measurement accuracy hardly changes in the short baseline length, the longer the baseline length is, the more the accuracy of the measurement point seen from the reference point improves. We could obtain an approximate expression of these relations.

(5) A filter process will be needed to remove measurement results that have big errors caused by the radio wave propagation in even the technique of kinematic.

From now on, the application of the kinematic GPS will very much increase in various fields. This time, we were able to show the measurement accuracy of the short baseline length quantitatively as well as the analysis of the characteristics of the accuracy. The above-mentioned results can be important data when the kinematic GPS is used in the inclination measurement of the hull during port arrival and departure and fishing boat operations, the measurement of the settlement of the hull in a shallow water area and the calibration of various sensors for hull oscillation.

In future, further analysis of the measurement accuracy is expected when the receiver is oscillated.

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実測によるキネマティックGPSの短基線長測定精度特性

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船舶の分野で，キネマティックGPSを使った応用技術は，コンパス，船体動揺測定装置，入出港支援装置などが実用化あるいは試作されている。これらの装置の基線長は短く，また基準点は船内にあるので常に移動するため，その位置は測位計算の都度DGPSまたは単独測位で求められている。この手法による精度はメーカごとに示され，また理論的にも論じられているが，数mのような短い基線長において，基準点から見た測位点の実測による定量的な精度は公に示されていない。そこで，基線長を6m以内に限定して，約1m間隔で実測したところ，測定精度の特性が解析でき，基準点から見た測位点の基線長別精度を一般式で定量的に示すことができた。