Experimental Results of Ship's Maneuvering Test Using GPS

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ABSTRACT

Kinematic GPS provides quite good accuracy of position in cm level. Though K-GPS assures high precision measurement in cm level on the basis of an appreciable distance between a station and an observational point, but it has measurable distance restriction within 20 km from a reference station on land. So it is necessary to make out a simple and low-cost method to obtain accurate positioning information without distance restriction. In this paper, the velocity integration method to get the precise velocity information of ship is explained. Next two experimental results (Zig-zag maneuvering test and Williamson turn) as the ship's maneuvering test and also the experimental results of leaving and entering port as slow speed ship's movement were shown. In these experimental results, ship's course, speed and position are compared with those obtained by kinematic-GPS, velocity integration method and dead reckoning position using Gyro-compass and Doppler-log.

1. INTRODUCTION

Kinematic GPS (K-GPS) as well known provides accurate positions. Though K-GPS assures high precision measurement in centimeter order on the basis of an appreciable distance between a station and an observational point. It has intrinsic disadvantage that a reference station on land is required, and the distance between the reference station point and the observation point is limited within 20km. So in case of using it at sea, it is necessary to make out a simple and low-cost method to obtain accurate positional information. In our research, the velocity is estimated using the carrier-phase-derived Doppler frequency. The velocity of a movable body can be easily determined using the GPS receiver generated Doppler measurement or the carrier-phase-derived Doppler measurement as long as the satellite velocity is precisely known. The Doppler measurement generated by GPS receiver is a measure of instantaneous velocity that is measured over a very short time interval, whereas the carrier-phase-derived Doppler measurement is a measure of mean velocity between observation epochs. The velocity integration with respect to time is the displacement during a period between the two epochs. In the previous ANC 05 Meeting at Dalian, on the basis of the experimental results of five buoys at sea, some comparative results between the vertical point positioning by the velocity integration method (VI-GPS) and the position by K-GPS were shown respectively. From the experimental results, the 3D displacements of movable body by the velocity integration method could be obtained in high frequency components over 0.07 Hz accurately (Hou, 2005).

In this research, two kinds of experiment were carried out to evaluate the accuracy of K-GPS and VI-GPS, and experimental results from K-GPS and VI-GPS are compared with the result from the Dead Reckoning Position (DRP) by means of Gyro-compass and ship's Doppler-log. At both experiments, four GPS receivers were set up on the training ship FUKAEMARU and the reference station was placed within distance of few km apart from ship's position. In the first experiment, two ship's maneuvering tests (Williamson turn and Zig-zag maneuvering test) were conducted and the experimental results are used to compare three positions by VI-GPS, K-GPS and DRP. In the second experiment, at the entering and leaving port conditions, the data from each GPS receiver were used to calculate the slow speed ship's 3D-movements, and the data of four GPS receivers on the training ship were sent to the reference station by wireless LAN.

In this paper, the outline of the experiments above is first described. Secondly, these experimental results are shown. From the results of Williamson turn, the ship's velocity by Doppler-log showed few seconds of time delay compared to the velocity by K-GPS and VI-GPS, and the ship's course by Gyro-compass also showed one second of time delay compared to the velocity by K-GPS and VI-GPS. From the results of Zig-zag maneuvering test, two results by K-GPS and VI-GPS were nearly similar, but results by DRP showed time delay compared with the trails from two GPS results. Finally, from the results of entering and leaving port experiments, the trail by K-GPS was quite good, but the VI-GPS and DRP results were not so good. VI-GPS had the integral error and the DRP had the time delay of course and speed measurements compared to the K-GPS results. As long as the measurement time is comparatively short, two results by K-GPS and VI-GPS were nearly similar. However, the more increasing the measurement time is, the larger the integral error occurs by VI-GPS and the time delay by the traditional method become large progressively. Consequently, as VI-GPS that has no use of a reference station data is one of the useful measurement methods of a movable body at sea, and we try to find the mitigation method for the integral error by VI-GPS immediately.

2. VELOCITY INTEGRATION METHOD

The observation equation for the GPS carrier phase measurements (Hou, 2006) is as the following:

$$\Phi = \rho + c \cdot (dt - dT) + \lambda N - d_{ion} + d_{trop} + \varepsilon_{\Phi} \tag{1}$$

Time differential observations are obtained by subtracting the observations at the previous epoch *k*-1 from those at the present epoch *k*. When the interval of observations is short, it is assumed that variations of propagation errors in the ionosphere and troposphere are small and negligible. The time differential observation is expressed in the following equation and temporal differences remove the phase ambiguities.

$$\delta\Phi = \delta\rho + c \cdot (\delta dt - \delta dT) + \varepsilon_{\delta\Phi} \tag{2}$$

where ρ is the distance between satellite and receiver (m); *c* is the light velocity in vacuum (m/s); Φ is the carrier phase measurement (m); λ is the carrier wavelength (m); *N* is the integer carrier phase ambiguity; d_{ion} is the bias of the ionospheric delay (m); d_{trop} is the bias of the tropospheric delay (m); *dt* is the bias of the satellite clock (s); *dT* is the bias of the receiver clock (s); $\delta\Phi$ is the phase observation in temporal difference between two epochs (m); δdt is the variation of the satellite clock errors (s); δdT is the variation of the receiver clock errors (s); $\varepsilon_{(*)}$ is the measurement noise and the errors which cannot be modeled and the symbol δ is the time differential operator. Observations at a 1 sec interval give a solution for unit displacement, *i.e.* velocity.

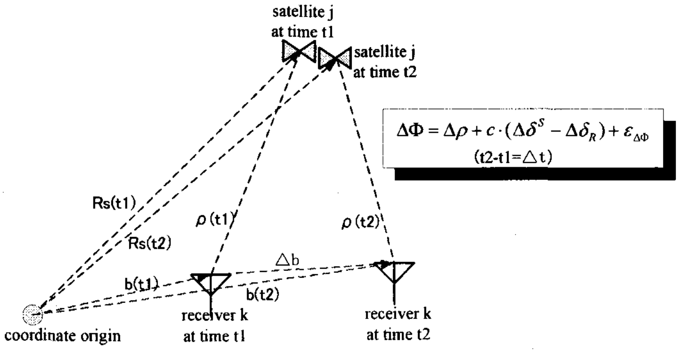

Fig. 1 Time differential carrier phase measurement

3. EXPERIMENT

3.1 Outline of Experiment

The experiment was carried out on April 8, 2005 in the coastal area of Kobe. Four antennas equipped with K-GPS were installed on bow, stern and both side of starboard and port of FUKAEMARU, as shown in Fig. 2. The reference station for K-GPS was installed on the breakwater of Faculty of Maritime Sciences pond (seen in Fig. 3) at a Kobe university. Three observations were done during navigation, leaving and entering the port. The data of ship motion by GPS system was analyzed and compared with the traditional measurement results. During navigation, Zig-zag maneuvering test and Williamson turn were conducted, and we compared the ship handling maneuverability indices T (yaw quick responsibility and course stability index), K (steady turning ability index) obtained by Gyro-compass and Doppler-log, K-GPS, velocity integration method, and the trail, speed were compared. Here, T, K are generally used in the first order approximation formula of turning movement, and are expressed as following equation;

$$T\frac{d\dot{\psi}(t)}{dt}+\dot{\psi}(t)=K\cdot\delta(t) \tag{3}$$

where $\psi(t)$ is turning angle (deg.), $\dot{\psi}(t)$ is turning angular velocity (deg./s), $d\dot{\psi}(t)/_{dt}$ is turning angular acceleration (deg./s^2), δ is rudder angle (deg.).

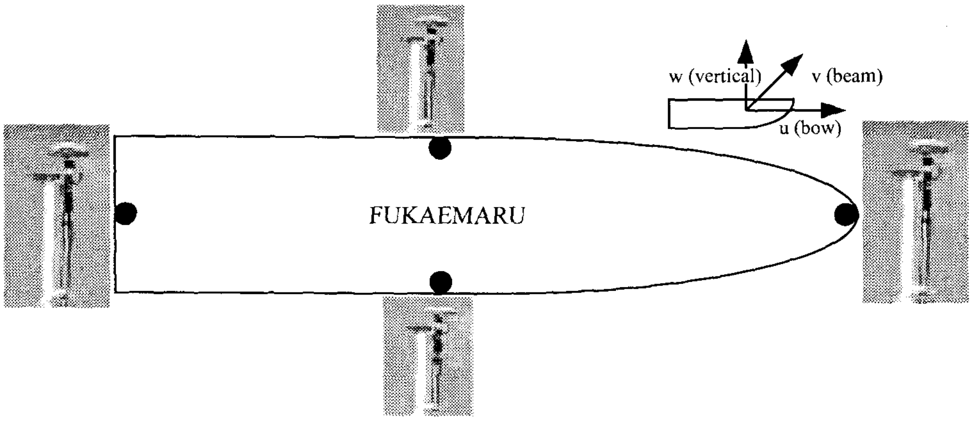

Fig. 2 GPS antenna position on FUKAEMARU

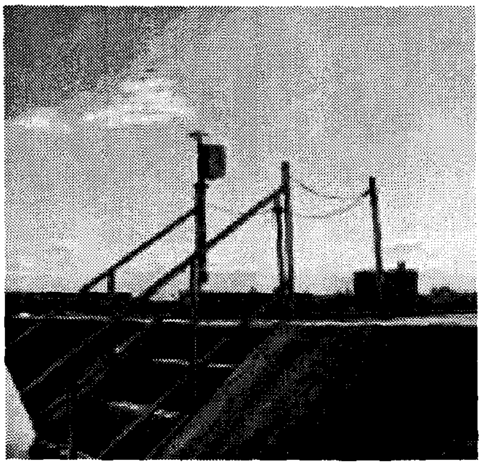

Fig. 3 Reference station

During leaving and entering the port, course and speed were compared with the data obtained by Gyro-compass course, speed of Doppler-log, K-GPS and VI-GPS. The GPS receivers measured the 3-dimensional movements (latitude, longitude and vertical direction) of the ship relative to the reference station by the K-GPS with 5 Hz of sampling frequency. The data was recorded in the PDA during navigation, leaving and entering the port, and compared with the results of K-GPS and velocity integration method, respectively.

3.2 Experimental Results

3.2.1 Ship's Maneuvering Test

During navigation, Zig-zag maneuvering test and Williamson turn were performed to measure the ship's maneuvering test and compared their ship handling maneuverability indices. The comparison of trail and speed of K-GPS, VI-GPS and DRP during Zig-zag maneuvering test and Williamson turn were shown.

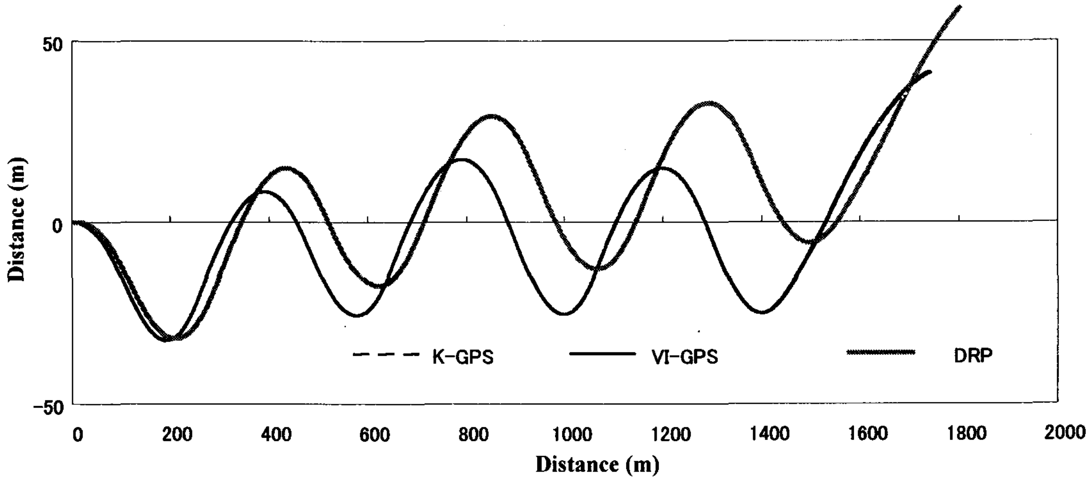

Fig. 4 Three trails of Zig-zag maneuvering test

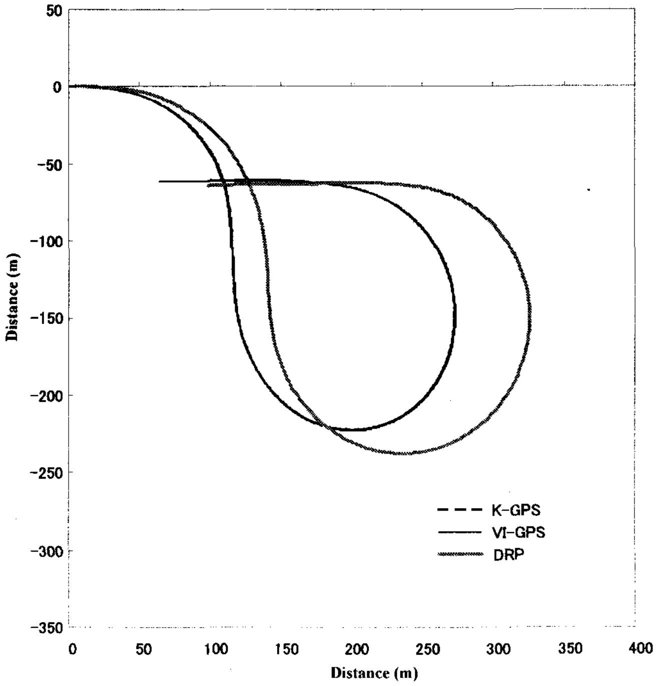

Fig. 5 Three trails of Williamson turn

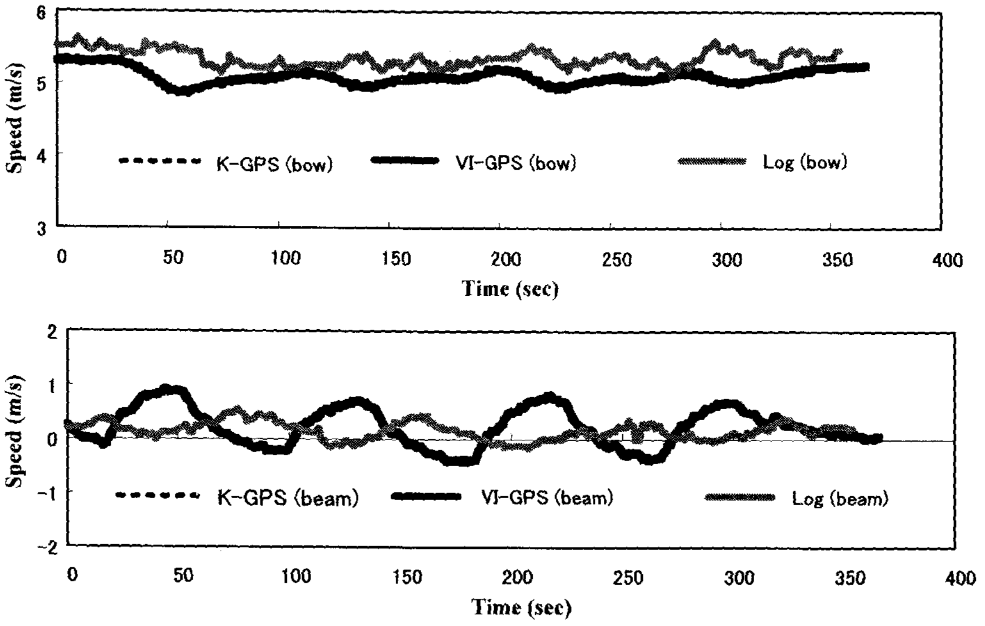

Fig. 6 Speed comparison of Zig-zag maneuvering (top is bow direction, bottom is beam direction.)

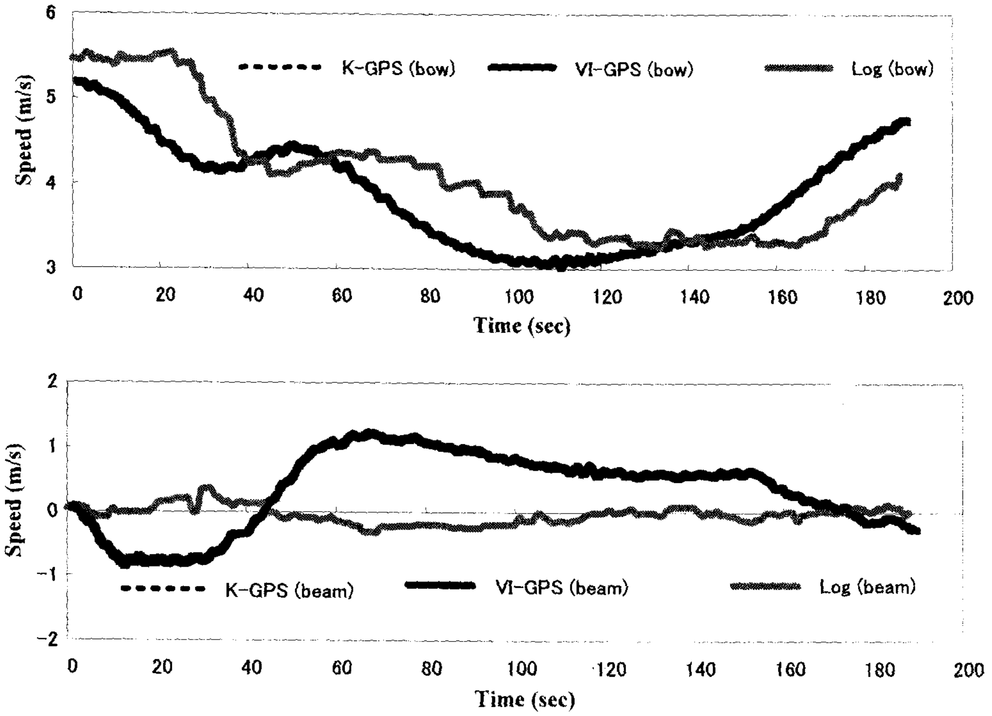

Fig. 7 Speed comparison of Willamson turn (top is bow direction, bottom is beam direction.)

Table 1 Ship handling Maneuverability index T, K

	T (sec)	K (1/sec)	T'	K'
K-GPS	19.25	0.17	2.27	1.45
VI-GPS	19.33	0.17	2.28	1.45
DRP	19.69	0.15	2.42	1.18

(T', K' is the dimensionless index of T, K)

Fig. 4 and 5 show trail results of Zig-zag maneuvering test and Williamson turn. As shown in Fig. 4 and 5, there is no difference between K-GPS and VI-GPS in trail, but the DRP shows some time delay compared with the results of K-GPS and VI-GPS. To find out the reason of time delay, the speed results compared between K-GPS, VI-GPS and Doppler-log were shown in Fig. 6 and 7. From the speed measurement, speed results of Doppler-log showed time delay compared to K-GPS and VI-GPS clearly. Also from the course measurement, the Gyro-compass course result showed about 1 second time delay compared to K-GPS and VI-GPS.

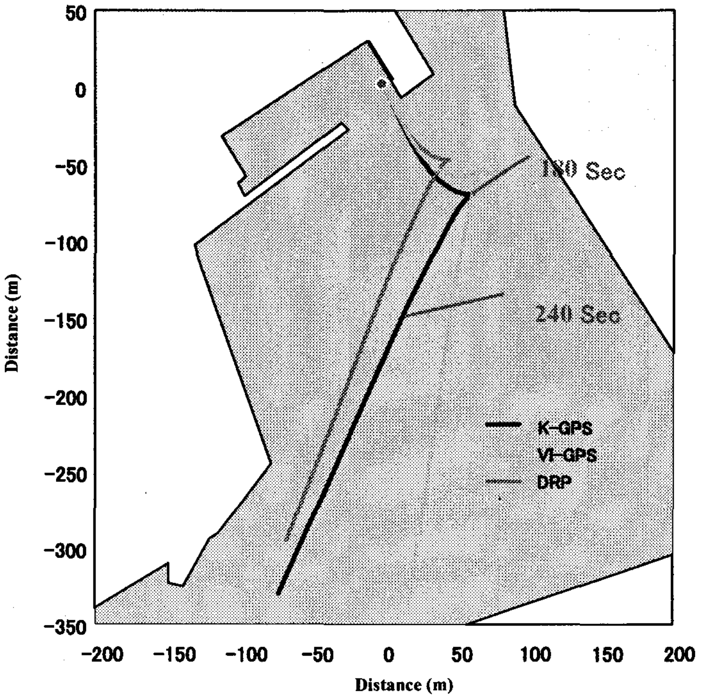

Fig. 8 Three trails of leaving port

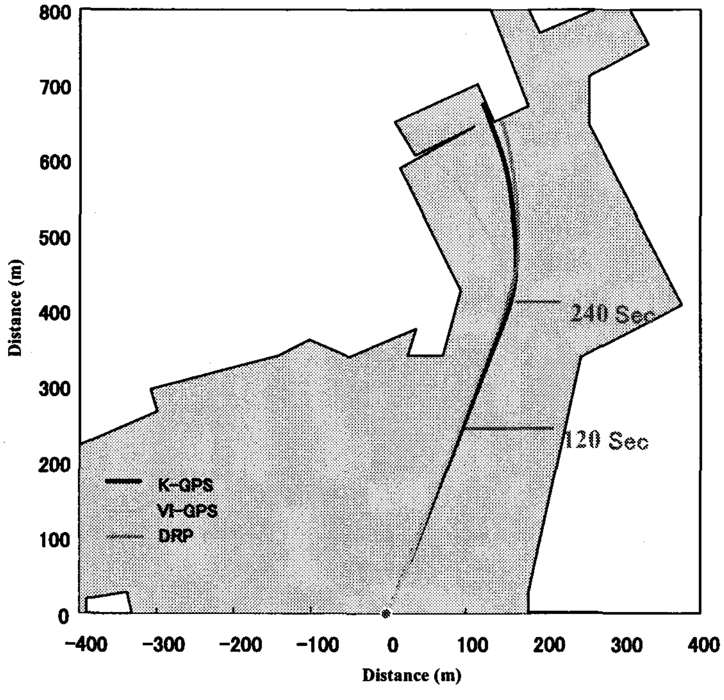

Fig. 9 Three trails of entering port

Table 1 shows the ship handling maneuverability index T (sec), K (1/sec) obtained from Zig-zag maneuvering test results. The results of K-GPS and VI-GPS show almost same value in maneuverability indices, but the maneuverability indices of DRP were slightly different from K-GPS and VI-GPS. Here, the index T', K' shows the dimensionless index of T, K which is T'=T*(V/L), and K'=K/(V/L), where V (m/s) is the ship speed, L (m) is the length of ship (Honda, 2001). Particularly, it is considered that the index T depends mainly on the time delay of Gyro-compass, and the K depends on the time delay of Gyro-compass and Doppler-log intricately (Nakama, 2005).

3.2.2 Leaving and Entering Port

When leaving and entering the port, Fig. 8 and 9 show three trails of K-GPS, VI-GPS and DRP, respectively. As well known, K-GPS has the measurement accuracy of cm level. The trails of DRP during leaving the port shorten due to the time delay of stern speed increasing. On the other hand, VI-GPS shows good accuracy of speed, but the course error increase due to the integral error along with time proceeding.

4 CONCLUSION

In this study, we carried out three different experiments of during navigation, leaving and entering port. The Zig-zag maneuvering test and Williamson turn were done during navigation, and the ship trail and speed of K-GPS, VI-GPS and DRP were compared to each other. There is no difference in ship trail and speed results between K-GPS and VI-GPS, but the DRP showed time delay compared to K-GPS and VI-GPS results. From the ship handling maneuverability index T, K, DRP had different values with the maneuverability indices of K-GPS and VI-GPS. When leaving and entering the port, the trail of VI-GPS showed different results compared to the K-GPS due to the integral error. During entering the port, DRP showed short trail due to the time delay of stern speed increasing.

From these experimental results, we assessed VI-GPS as bellow.

- There is no time delay from speed measurement.
- The position error increased with time proceeding due to the integral error.
- Speed information is obtained with quite good accuracy compared to K-GPS.

For the future study, VI-GPS is necessary to improve the integral error using more accurate corrections.

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