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The Study on the Development of a Ship's GPS-COMPASS Using GPS Position Information

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GPS 위치정보를 이용한 선박용 GPS-Compass 개발에 관한 연구

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요 약 문

선진국에서의 GPS 위성정보를 활용한 자세결정 센서개발은 새로운 GPS 관련연구 분야로 떠오르고 있는 실정이다. 지금까지 국제학회에 보고된 대부분의 연구는 GPS 위성신호의 Carrier phase 측정을 통해 고중차 등을 이용한 방법으로 주로 3-D 자세결정방식에 치중하고 있으나, 아직 실무에서의 활용은 이른 것으로 알려지고 있다.

본 논문은 GPS 위성신호의 범용의 C/A 코드 프로세싱 GPS 수신기 정보를 활용하여 선박의 방위센서 개발에 관한 연구이다.

본 연구에서는 1차적으로 GPS 위성신호의 오차벡터를 진시간으로 측정 및 분석을 통해 GPS 위성오차중 가장 심각한 S/A 오차 발생기간에도 방위센서 구축을 위한 정보획득에는 문제가 되지 않음을 확인하였고, 수신된 Two-Point 위성정보를 이용 새로운 선박의 방위센서 "GPS-Compass" 를 구축 비선형 모델하에서의 해상실험을 통해 본 연구에서 제시한 "GPS-Compass" 의 새로운 선박 방위센서로의 활용가능성을 보였다.

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INTRODUCTION

Derternining of a ship's direction is important in a marine navigation. There are three navigation instruments for determining ship's derection such as a magnetic compass, a gyrocompass and an electronic navigation system. Measuring the ship's bearing by magnetic copmass is not reliable due to several limitations of measuring the earth's magnetic field[1,2]. In the marine application, the typical direction may be still one by measuring the earth's orbitional axis using a north seeking gyrocompass.

Over the past decades, determining direction using radio navigation system has been available. The scheme may be classified into two categories. One is the way to find the relative direction with RDF, RADAR and etc. The other is the way to obtain the absolute direction by evaluating arrival times of radio waves transmitted from stations of known position. The passive navigation aids such as Loran, Decca and GPS may give the absolute direction. The direction using the systems are obtained between the present position and past one. Changes in direction cannot be calculated until the distance between measurements is sufficient to make the calculation between two points. In addition, while a ship is rapidly turning, variously meanuvering, the right bearing can not be obtained[3,4,5]. Furthermore, if the ship is in static condition or anchored, it is impossible to obtain any direction of the ship. As we have mentioned, determining ship's bearing with single radio navigation system exists in serveral limitations. The obvious limitation occurs due to historic position data to determine the bearing. It also depends on the accuracy of position to be obtained by radio navigation system. Fortunately, the accuracy positioning by active navigation sensor has revolutionly been improved since GPS released. It means that ship's bearing determined by the system has been improved. However, the bearing based on the system even GPS may not be prefable to the bearing information by gyrocompass in marine application. Even if the GPS receiver provides the ship's bearing more precise than other electronic navigation systems, it may not sufficent for the real time information. More recently, attitude determination systems based on the L-band carrier phase of Global Positioning System have been developed. The key of the system is the difference in the received phase by two antennas to a single satellite or two satellites[6,7,8,9].

The purpose of the research is to develop the alternative bearing sensor named GPS-COMPASS using two C/A code GPS receivers for overcoming the limitations. We have designed the GPS-COMPASS with two receivers installed on a ship. Then we examined and analyzed the sensitivity of the system through the real maneuvering pattern on the sea.

PLANE SAILING AND THE PRINCIPLE OF GPS- COMPASS

In considering the ship's position at sea with reference to any other place, either one that has been left or one toward which ship is bound, five terms involved the course,the distance,the difference of latitude, the difference of longitude and the departure.

The solution of various problems that arise from the mutual relation of these quanties are called sailings. When the only quantities involved are the course, distance, difference of latitude, and departure, the process is denominated plane sailing[10]. In this method, the earth is regarded as a plane, and the operation process as if the ship sailed. In plane sailing, the curvature of the earth being neglected, the relation between the elements of the rhumb track joining any two points may be considered on the plane right triangle formed by meridian of the place left, the parallel of the place arrived at, and the rhumb line. Here the ship's bearing can be obtained using plane sailing based on two-points measured by GPS receivers on a ship's center line.

APPLICATION OF PLANE SAILING TO DETERMINING OF SHIP'S BEARING

The basic concept of the plane sailing is applied into the ship for measuring its bearing. In Fig.1, let us assume points, A and B, are local positions in the earth. A is the point of departure; B, the point of destination; AC, the meridan of departure; BC, the parallel of destination; and AB, the rhumb line between the points. Let BAC represent the course Co; AB the distance D; AC the difference of latitude dL and BC the departure dP. Then from the triangle ABC, we have the following;

$$\sin Co = \frac{dp}{D} \quad (1)$$

$$\cos Co = \frac{dl}{D} \quad (2)$$

$$\tan Co = \frac{dp}{dl} \quad (3)$$

Now suppose A and B are the positions of GPS antennas located in the stem and the stern on the center line of the ship, respectively. Then D is the ship's length and Co is the ship's heading based on two points, A, B.

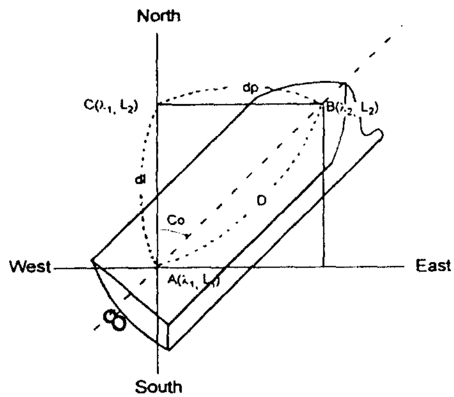

Fig 1. Plane Sailing and Concept Of GPS-COMPASS

Using above equations, a course of the ship is simply computed. If two points A,B are simultaneously measured by GPS receivers installed on the ship, the bearing Co can be simply computed in real time. Co is the angle which the center line of a vessel makes with meridan. It measured from 000° at north clockwise 360°. Sometimes it is desirable to measure the heading from the North or South points to either East or West.

THE SHIP'S HEADING IN ERROR VECTOR

Accuracy of the heading by GPS-COMPASS proposed here may depend on the pattern of the error vectors of two receivers and the magnitude of position error of each receiver. In view point of the bearing accuracy, the error pattern of two receivers is more important than the magnitude itself. For example, even if the magnitudes of the position errors are big in two receivers, the good heading accuracy can be resulted from the same direction. Also two points measured simultaneously may have mostly same patterns under general error sources if the conditions satisfy followings:

- Identical receivers in process algorithms and hardware possibly
- Combination of identical satelllites used to determine positions
- Acquisition time and etc

Therefore it is necessary to investigate the fundamental interpretation of the bearing error on GPS COMPASS. The coordinate based on East-West and South-North is represented by the X-Y coordinate in a horizontal plane. Where the directions of East-West and South-North are changed to axis of X and Y, respectively.

Then positions shown in Fig.1, A(λ_1, L_1), B (λ_2, L_2) and C(λ_1, L_2) are transformed to A(0,0), B(dp,dl) and (0,dl) in Fig.2.

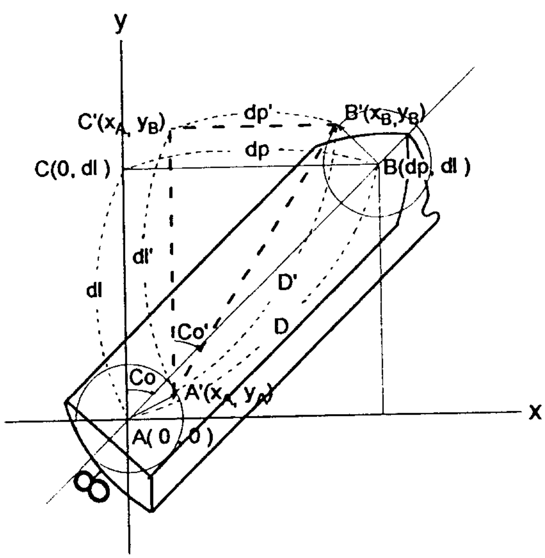

Fig 2. Description of Ship's Bearing in Error Vector

In order to discuss the ship's bearing involving the measured error of the position by receivers, the error vector defined in polar coordinate is considered. Suppose the measured positions are A'and B' with some error. And then they can be represented by A'(x_A, y_A) and B'(x_B, y_B) respectively.

Also the coordinate for difference of latitude becomes C'(x_A, y_B). A' and B' are measured values which deviated from real positions, A and B. And then ship's bearng Co, and distance D are changed to Co' and D' with respect to measured values with some error, A' and B'.

Let position error vector be **R**(r, θ) in the polar coordinate. Then

$$x_A' = r_A \cos\theta_A \tag{4}$$

$$y_A' = r_A \sin\theta_A \tag{5}$$

$$x_B' = r_B \cos\theta_B \tag{6}$$

$$y_B' = r_B \sin\theta_B \tag{7}$$

Where the r and θ describe magnitude of error and angle from origins of real positions. Therefore the coordinates due to position error can be obtained as follows.

$$x_A = x_A' \tag{8}$$

$$y_A = y_A' \tag{9}$$

$$x_B = |\, dp \sim x_B' \,| \tag{10}$$

$$y_B = |\, dl \sim y_B' \,| \tag{11}$$

Accordingly,

$$dp' = |\, x_A \sim x_B \,| \tag{12}$$

$$dl' = |\, y_A \sim y_B \,| \tag{13}$$

where dl' is the differance of latitude and dp' is the departure based on A' and B'.

Therefore the ship's computed bearing by positions involving error vector **R**(r, θ)

$$Co' = \tan^{-1}\frac{dp'}{dl'} \tag{14}$$

ERROR MODEL OF GPS-COMPASS

The accuracy of computed bearing mainly depends on the receiver's positions on the center line of the ship. In order to achieve high accuracy bearing, it is necessary to have the precise positions. Even though we would consider the previous assumptions, violation of the assumptions may exist in real circumstance. It means that error vectors of receivers are not same for the real time condition. Therefore, we would better evaluate the bearing error model of GPS COMPASS as followings.

CASE 1 ;

$$R_A(r_A, \theta_A) = R_B(R_B, \theta_B)$$

CASE 2 ;

$$R_A(r_A, \theta_A) \neq R_B(R_B, \theta_B)$$

Case 1 is for ideal assumption which error vectors for two points are simultaneously same. In order to have same error vectors in two receivers, it is necessary to satisfy the previous assumtions. It is also important to maintain the standard receivers to reduce the deviation in error pattern. In this case, the magnitude of error is not important if the ship's length is long. Case 2 is a practical aspect in the dynamic manuver of ship. The geomatric realization of the bearing error model is shown in Fig. 3.

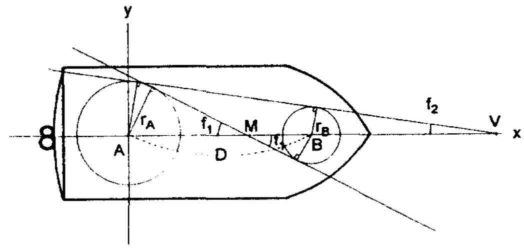

Fig 3. The Bearing Error for Error Vector

In this Fig., two receivers are located on A and B, respectively. ra and rb are radii of errors for receivers. And then arguments, f_1 and f_2 about the ship's center line are represented as follows;

$$\sin f_1 = \frac{r_A}{MA} \tag{15}$$

$$\sin f_2 = \frac{r_A}{VA} \tag{16}$$

After some manipulations[5,13], we have

$$(1 + \frac{r_A}{r_B})MA = \frac{r_A}{r_B}D \tag{17}$$

$$(\frac{r_A}{r_B} - 1)VA = \frac{r_A}{r_B}D \tag{18}$$

Then the above equations give the following.

$$\sin f_1 = \frac{r_A + r_B}{D} \tag{19}$$

$$\sin f_2 = \frac{r_A - r_B}{D} \tag{20}$$

Here f_1 and f_2 are maximum bearing error and minimum bearing error, respectively. The maximum bearing error can appear in opposite direction of error vectors each other. The value of maximum and minium bearing error depends on varying of error vectors. In addition, if the error vectors are same, no argument exists in error model. The more circumstances should be inspected to evaluate the bearing accuracy. From the previous mention, the longer length of the ship can produce the less error of bearing in any case. Further if the receivers are processed under the identical conditions mentioned previously. Theoretically, the errors due to SA, ionospheric delays, troposheric delay, empheris errors and satellite clock may not be critical to the ship's bearing error.

PRELIMINARY TEST AND ANALYSIS OF THE ERROR VECTOR

In order to investigate the error pattern of receivers and evaluate accuracy of bearing of GPS- COMPASS, the static and dynamic field tests have been carried out. First, the static test was carried out with varying ship's length. It is important to recognize the characteristics of error pattern and bearing error based on C/A code. Second, the dynamic test was conducted in manuvering ship at sea. The various ship's motions including nonlinear dynamic manuvering were involved in the test.

The preliminary test was done with the Motolora 6-channel core kits. The antennas were mounted on the poles of the center line and various baseline lengths were selected to to collect data. During the test, the information of the data was internally logged and recorded on computers. The analysis of the data is important to compare the error pattern of receivers to affect the bearing error. And then the bearing error can be investigated due to error vector. Once the positions are measured for two points, the bearing is computed every second. The reference bearing between two receivers first computed by the mean value of position collected during the test.

As outlined previously, the first step for determining bearing of the ship is to investigate the error pattern of two receivers. The data was collected from two receivers in real time. The distance between two receivers was varied. A selection of the short distance compared to the length of the typical vessel is to consider the worst case for C/A code.

It can give also the valuable information to furure work with the more advanced receivers. The steps that leads to the error pattern are as follows:

1) obtain relative error in latitude and longitude through data collection.
2) compute radius and angle of two positions from the orign of each receivers
3) compare the error pattern for two points.
4) evaluate accuracy of bearing of baseline about north.

These process was accomplished to compare the result of error pattern in receivers. It is necessary to realize the accuracy of GPS-COMPASS. Fig. 4 and 5 show plots of range error of latitude and longitude about antenna's location. The residuals were obtained from raw values of position by substracting the known position of receivers. For the purpose of identifying position errors in real time. It is acceptable to compare the residuals by two positions.

Although the range error is a fairly crude way for analyzing the error pattern, it does provide some basic information about error vector. Therefore, the trajectories of position and its error are shown in Fig.6 and 7. in order to realize the outline of the error pattern. Even if

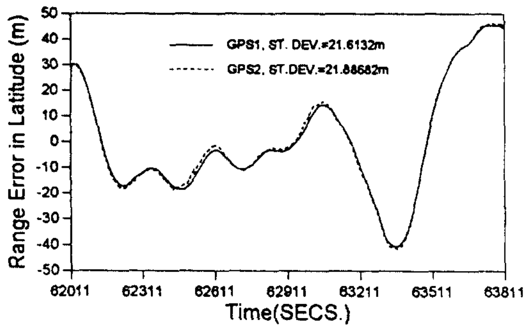

Fig 4. Range Error of Latitude

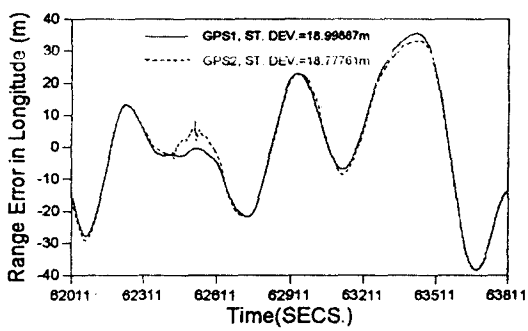

Fig 5. Range Error of Longtidue

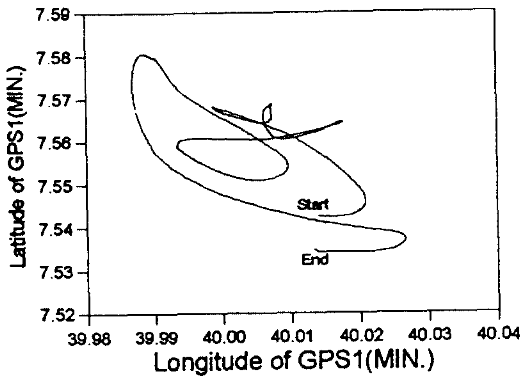

Fig 6-1. The Trajectory of Measured Position by GPS 1

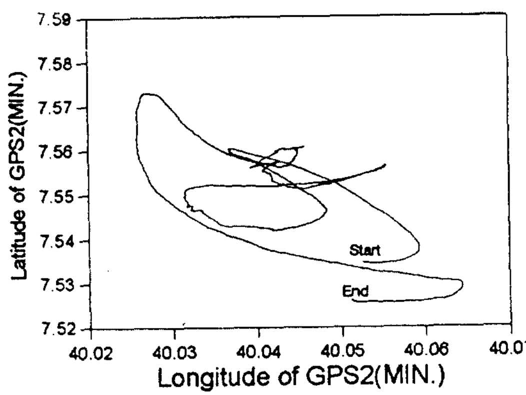

Fig 6-2. The Trajectory of Measured Position by GPS 2

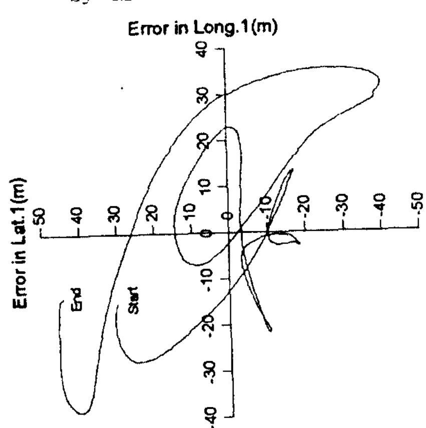

Fig 7-1. The Trajectory of Position Error in GPS 1

we would say that the error pattern of two receivers are similar to each other, some pertubations may occur in results.

To check the pattern more carefully, the error vector should be simultaneously compared. The error vector represented by radius and angle from the origin can be computed using dx and dy. Where the angle is represented between 000° and 360°.

In order to investigate the pertubation of the error pattern, the computed values are shown in Fig.8 and 9 for the comparison of the error between two receivers. And then their relative differences are plotted in Fig.10 and 11. In addition, the result of bearing using two points is shown in Fig.12.

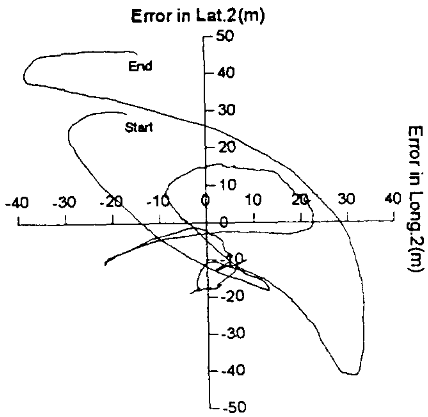

Fig 7-2. The Trajectory of Position Error in GPS 2

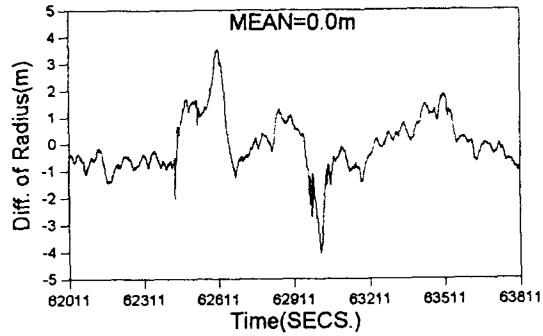

Fig 10. Difference of Radius Between Two Receivers

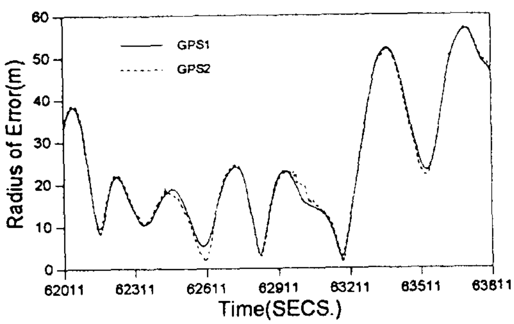

Fig 8. Comparison of Radius Error Between Two Receivers

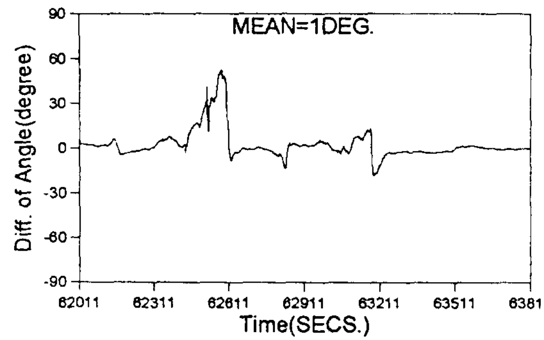

Fig 11. Difference of Angle Between Two Receivers

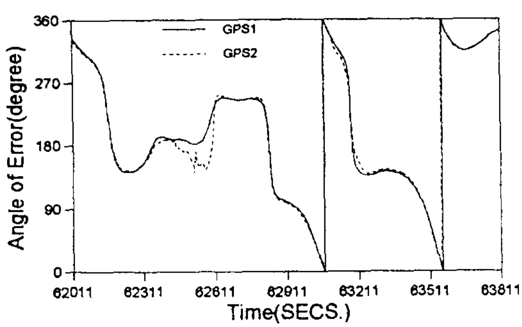

Fig 9. Comparison of Angle Error Between Two Receivers

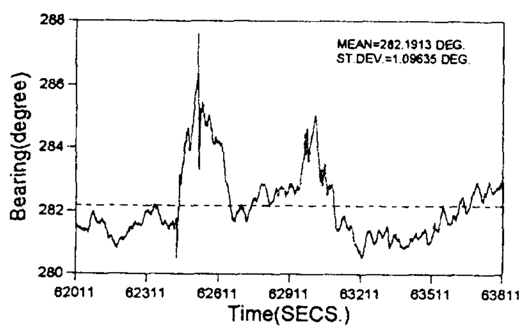

Fig 12. The Result Of Bearing Using Two Points in Real Time

As we have presented in results, it was verified that the error vector was closely similar to each other. However, note that some pertubations also exist in the comparison. The reason for this may stem from the fact that receivers and clock noise are the part of signal. Therefore, the more precise investigation should be carried out to realize the characteristics of the error pattern in various situations.

THE SUMMARY OF THE STATIONARY TEST

During the stationary test, we have verified that the error pattern of two receivers mainly maintained the similar trend with some pertubations. From the plots, the variation of the bearing occured frequently. Such phenomenon occured associated with unconsistancey of error pattern for two receivers as we mentioned previously.

Substituting the above result of error into equations (19) and (20), the maximum and minium of bearing error can be computed for the ship's length. Accuracy of bearing may vary in range of Max and Min based on the error pattern in the test. It was figured out that the standard deviation was approximately 1° in Fig.12. It also should be noted that the results of this was for C/A signal processed by specfic receivers used here.

THE RESULT OF NONLINEAR DYNAMIC TEST

GPS-COMPASS takes extremely a short time to get the bearing information because the computation of the ship's bearing is obtained by a pair of real time data measured simultaneously. It should be also noted that if the ship is manuvering in the nonlinear patterns, the single reciver has the difficulty to obtain the right bearing unlike a linear track.

The several scenarios were chosen to evaluate GPS-COMPASS mounted on a vessel for practical experiment. The GPS antennas mounted on flag's poles located at the stem and the stern in the center line of the vessel. And then the informations obtained by receivers was simultaneously sent to MCU(Main Control Unit) through the transmission line for logging and computing the ship's bearing at the bridge.

The turning circle of a vessel was taken as the nonlinear manuvering. The turning circle is to path followed by piloting of a ship in making a turn of 360° or more at a constant rudder angle and speed. The diameter of a turning circle vary with rudder angle and speed through water[10,12].

When approaching an anchorage, turning onto a range, piloting in restricted channel, maintaining an intended track, or at any time when precise piloting is necessary, the navigator must allow for turning characteristics of the ship. In view point of manuvering itself, it is a suitable model of nonlinear movement pattern. During the test, the vessel was pilotted with speed, 10 kts and rudder angle, 10°. We also tested with varying speed and rudder angle for the additional tests. The stem turns on the inside of the turning circle and the stern outside this circle. While the vessel was turning, the heading by gyrocompass was recorded by a compass recorder. Then result of bearing by GPS-COMPASS was compared to one measured by the gyrocompass.

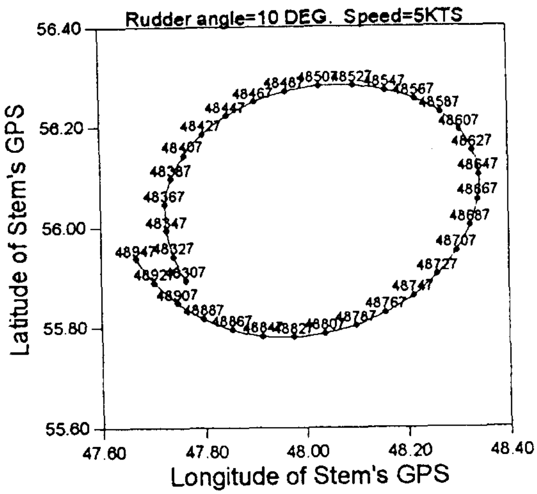

Fig 13. The Turning Circle of The Stem

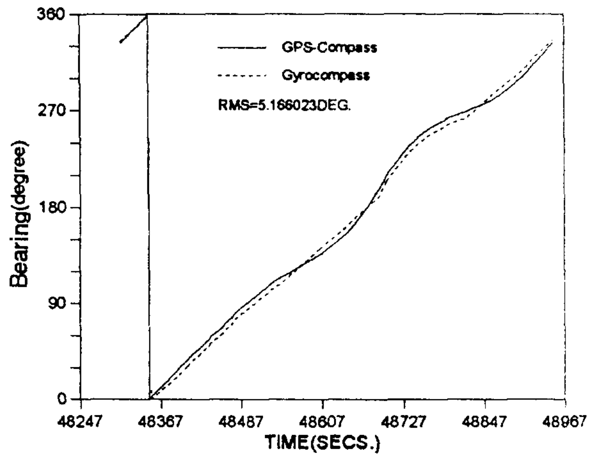

Fig 15. The Comparison of Ship's Bearing Between GPS-COMPASS and GYRO COMPASS in Nonlinear Dynamic Test

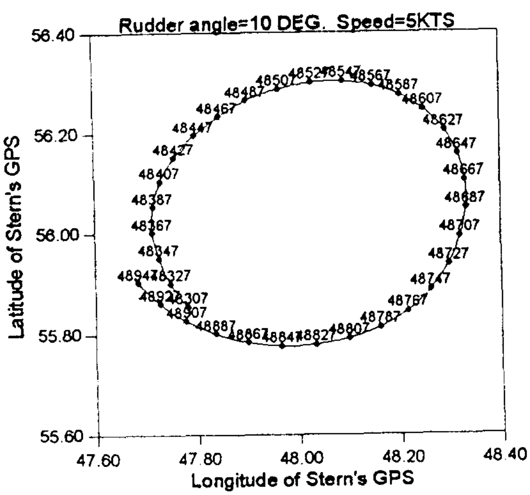

Fig 14. The Turning Circle of The Stern

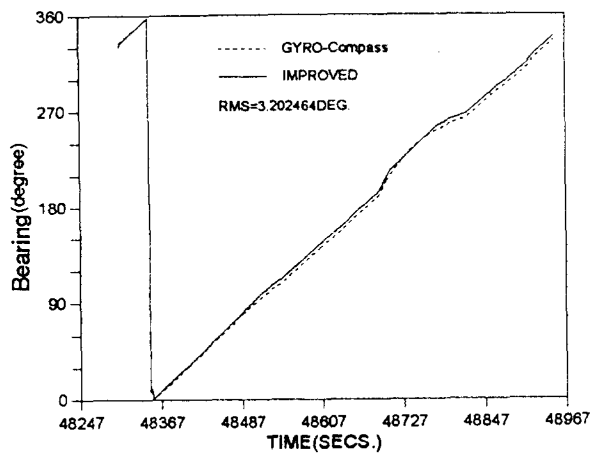

Fig 16. The Improved Bearing by Filtering Using Angular Velocity of Ship's Turning

Here the tracks of the vessel are shown in Fig.13 and 14. The complete circles for the stem and the stern are seperately drawn. The direction from the stern to stem in the figures is the vessel's bearing. Thus the bearing data for turning is presented in Fig.15. Note that the computed bearing data do not look exactly like the ones by gyrocompass. Rms value is approximately 5 degree. It may result from the difference of error pattern of two receivers due to the receiver's measurement noises involving ship's dynamic behabiour. A filtering based on an angular velocity of turning was used to improve the accuracy of bearing compared to gyrocompass[13]. The improved result is shown in Fig.16.

CONCLUSIONS

The approach described here carried out to overcome the limitation of a single GPS receiver for determining the ship's bearing in the nonlinear ship's dynamic pattern. In this study, a simple technique has been described and demonstrated. As we demonstrated in the stationary test, the bearing accuracy significantly depended on the error pattern of the receivers. In the sea test, the additional bearing error produce corresponding the ship's dynamic behabiour in contrast to the static condition. The filtering method based on the angular velocity for the ship's turning was used to improve the bearing accuracy.

The test conditions, the kind of receiver and ship's type, are limited for the inteded mission. However, in near future the research will be continued to enhance the system capability. It may involve followings:

- Usage of upgraded s/w and receivers
- Application of filtering techniques based on ship's dynamics and sea conditions
- Correlation factor between following-up characeristics of gyrocompass and rapid turn motion

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