Analysis of Pseudolite Augmentation for Vessel Berthing

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Abstract

GPS has been increasingly exploited to provide positioning and navigation solutions for a variety of applications. In vessel berthing application, however, there are stringent requirements in terms of positioning accuracy, availability and integrity that cannot be satisfied by GPS alone. This is because the performance of satellite-based positioning and navigation systems are heavily dependent on both the number and the geometric distribution of satellite tracked by receivers. Due to the limited number of GPS satellites, a sufficient number of 'visible' satellites cannot be sometimes guaranteed. This paper discusses some issues associated with the implementation of ground-based pseudolite augmentation for vessel berthing. Pseudolite means small transmitter that transmits GPS-like signals in local area. Actually, pseudolite can play three different roles in GPS augmentation scheme, depending on the operational conditions. Firstly, in the case of kinematic GPS operation where there are no signal blockages, and more than five satellites are available, additional pseudolites strengthen the GPS satellite-pseudolite geometry, and more accurate and reliable positioning solution can be achieved. Secondly, in the case when there are adverse GPS operational environments in which the number of tracked satellites is less than four, pseudolites can complement the GPS signals. In the third case, GPS signals are completely unavailable, such as when operated indoor. In such cases the pseudolites can replace the satellite constellation. However, the first role will be considered in this paper, since more than four satellite signals can usually be tracked in most marine applications. This paper presents that the pseudolite-augmented precise positioning system can provides continuous centimeter-level positioning accuracy through comparison analysis of RDOP simulation result of the GPS satellite constellation and the pseudolite-augmented GPS satellite constellation.

Keywords: GPS, Pseudolite, Augmentation, Positioning Accuracy, RDOP

1. Introduction

GPS (Global Positioning System) has been increasingly exploited to provide positioning and navigation solutions for a variety of applications. The current representative maritime voyage equipment is AIS (Automatic Identification System), which broadcasts the vessel's identification, GPS position, heading, course, speed, and a few other data relevant for collision avoidance and traffic management. But unfortunately, most of the maritime navigation equipment, including AIS and ECDIS (Electronic Chart Display and Information System), do not provide a precise position. This is due to the fact that the standalone GPS or DGPS (Differential GPS) is used to get a vessel position and the CDGPS (Carrier phase DGPS) does not satisfy the stringent performance requirement of maritime application requiring precise positioning accuracy such as automatic docking, dredging, and construction work. These applications need centimeter-level accuracy for precise positioning. Particularly for vessel berthing, a horizontal accuracy of less than 10 centimeters is necessary. Furthermore, the availability of more than 99.8% and continuity of more than 99.97% of the time is required.

A conventional laser docking system (LDS) provides a centimeter-level accuracy from jetty mounted laser sensors in order to help a vessel to approach to a pier. LDS is very accurate and useful for vessel berthing, whereas there are too many considerable problems at the design stage. Laser sensors of LDS need to be correctly positioned and installed on a jetty to allow for the full range of vessels to be berthed, taking into consideration their size, loading condition, and tidal variations possible at the facility. Jetties with large tidal variations may require an elevation sensor, which may be manually or remotely controlled. Laser sensors set too far apart may not target a vessel's flat hull area and will provide inaccurate distance measurement. Above all, LDS is expensive and its service coverage is limited to about a 200-meter radius.

In order to solve these problems of the conventional vessel berthing aid equipment, this paper proposes a pseudolite-augmented precise positioning system. Pseudolite means ground-based small transmitter that transmits GPS-like signals in local area. Actually, pseudolite can play three roles in GPS augmentation scheme, depending on the operational conditions. Firstly, in the case of kinematic GPS operation where there are no signal blockages, and more than five satellites are available, additional pseudolites strengthen the GPS satellite-pseudolite geometry, and more accurate and reliable positioning solution can be achieved. Secondly, in the case when there are adverse GPS operational environments in which the number of tracked satellites is less than four, pseudolites can complement the GPS signals. In the third case, GPS signals are completely unavailable, such as when operated indoor. In such case the pseudolites can replace the satellite constellation. However, the first role will be considered in this paper, since more than four satellite signals can usually be tracked in most marine applications. They can improve geometry for accurate positioning by providing additional ranging signals to augment the GPS satellite constellation when the geometric distribution of GPS satellite is inadequate. In this paper, pseudolite is used to aid in CDGPS positioning. This paper presents that the proposed system can provides the continuous service with centimeter-level positioning accuracy through comparison analysis of RDOP (Relative Dilution of Precision) simulation results between the GPS satellite constellation and the pseudolite augmented GPS satellite constellation. And it is shown that the proposed system satisfies the positioning performance required for vessel berthing at the test bed.

2. Maritime User Requirements for Precise Positioning

The minimum maritime user requirements for precise positioning were provided by the International Maritime Organization (IMO). The IMO classified the maritime precise positioning application into 5 fields and showed the system and service requirements applicable for each field. And the requirement criteria of each field was characterized as accuracy, integrity, availability, continuity, coverage, and fix interval; where accuracy means the accuracy of a position estimate with respect to the geographic or geodetic coordinates of the earth; availability means seen as the percentage of time that an aid, or system of aids, is performing a required function under stated conditions at any randomly chosen point in time; continuity means the probability that, assuming a fail-free receiver, a user will be able to determine position with specified accuracy and is able to monitor the integrity of the determined position over the time interval. Table 1 briefly summarizes the minimum maritime user requirements for precise positioning. From Table 1, it shows that the automatic docking is distinguished from other maritime precise positioning application fields by the point of view that the automatic docking requires not the vertical position accuracy but the continuity.

Table 1. The minimum maritime user requirements for precise positioning.

	Accuracy		Availability (% per 30 days)	Continuity (% over 3 hours)
	Horizontal (meters)	Vertical (meters)		
Automatic Docking	0.1	-	99.8	99.97
Hydrography	1 – 2	0.1	99.8	N/A
Dredging	0.1	0.1	99.8	N/A
Construction Works	0.1	0.1	99.8	N/A
Cargo Handling	0.1	0.1	99.8	N/A

3. Problem of Conventional CDGPS System

In this section, it is discussed whether conventional CDGPS system using only GPS satellite signals meets the requirements for automatic docking. It is widely known that conventional CDGPS technology provides the centimetre-level accuracy and basic positioning accuracy of CDGPS can be expressed as the product of the relative horizontal DOP (RHDOP) and the errors in ranging to the satellites as given by

$$\text{Horizontal Positioning Error} = \text{RHDOP} \times \text{Ranging Error} \qquad (1)$$

This paper assumes that the ranging error (1sigma) for CDGPS is 2.5cm from the zero-baseline experiment. From Equation 1 and the assumption, in order to achieve the positioning accuracy for automatic docking, the upper bound of RHDOP is set to be 2.0.

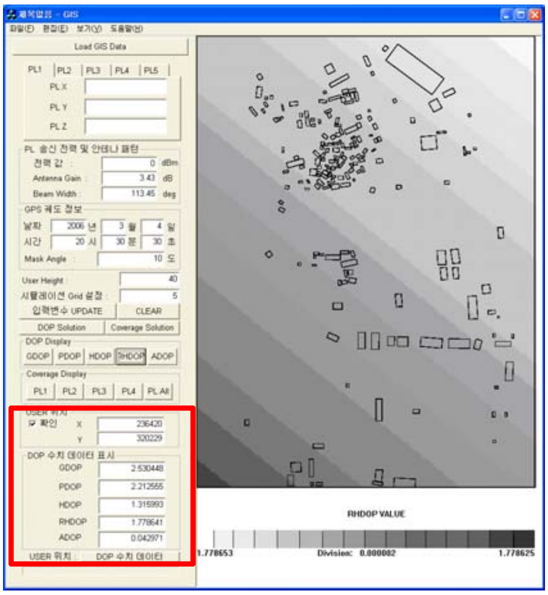


Figure 1. RHDOP simulation using only GPS satellites by simulation software.

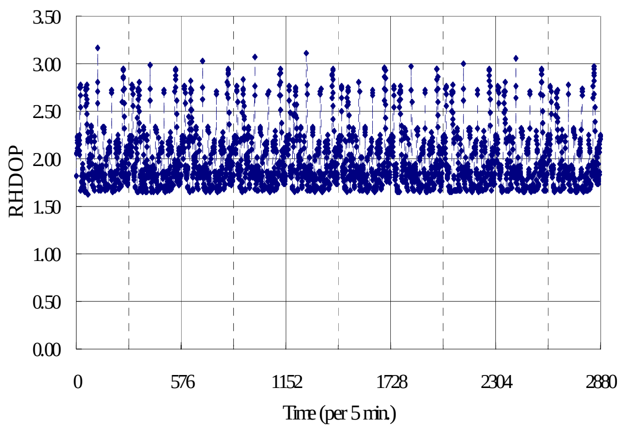


Figure 2. RHDOP changes over 10 days (4th ~ 13th March, 2006; using only GPS satellites).

To analyse the positioning performance of conventional CDGPS system, DOP simulation software is used as shown in Figure 1. For this simulation, the following parameters are applied to DOP simulation software: GPS ephemeris on 4th~13th March 2006, user location Daejeon Korea, sample time interval 5 minutes, and cut-off elevation angle 10.0 degrees. The RHDOP simulation results over 10 days are plotted in Figure 2.

Figure 2 shows that the RHDOP values change from 1.65 to 3.17 depending on GPS geometry, that the RHDOP values less than 2.0 can be achieved only for 64% per day, and that the estimated minimum, average, and maximum horizontal positioning errors are 8.25cm, 9.9cm, 15.85cm, respectively. In other words, it is shown that the geometric distribution using only GPS satellites is not always adequate to achieve the horizontal accuracy of less than 10 centimeters. From this simulation, it is clearly shown that conventional CDGPS system using only GPS satellites is not able to meet the continuity performance among the requirements for automatic docking since insufficient GPS geometric distribution causes the RHDOP peak as shown in Figure 2.

4. Pseudolite Augmented Precise Positioning System

Conventional CDGPS can offer centimeter-level horizontal positioning accuracy as LDS, whereas conventional CDGPS, unlike LDS, can provide broad coverage service for an unlimited number of users. However, as mentioned in Section 3, conventional CDGPS does not meet the required continuity for automatic docking. In order to solve the problem of conventional CDGPS, this paper proposes a pseudolite augmented precise positioning system as shown in Figure 3, where pseudolites are used to reduce the RHDOP values, to improve the horizontal positioning accuracy, and to enhance the continuity of CDGPS by providing the additional ranging signal.

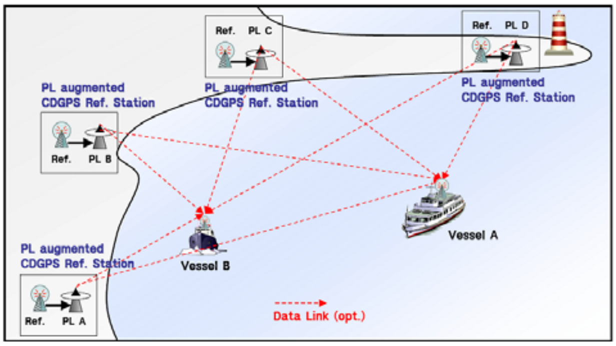


Figure 3. The concept of the pseudolite augmented precise positioning system.

To verify whether the proposed system is able to meet the required performance for automatic docking of vessels, the RHDOP values are collected in the same method as described in Section 3 using the DOP simulation software. Figure 4 shows DOP simulation results at a point in time in the 4-pseudolites augmented case. Here the same input parameters as Section 3 are applied to DOP simulation software with the exception of pseudolite information such as pseudolite positions. Figure 5 shows the RHDOP simulation results over 10 days in the 4-pseudolites augmented case.

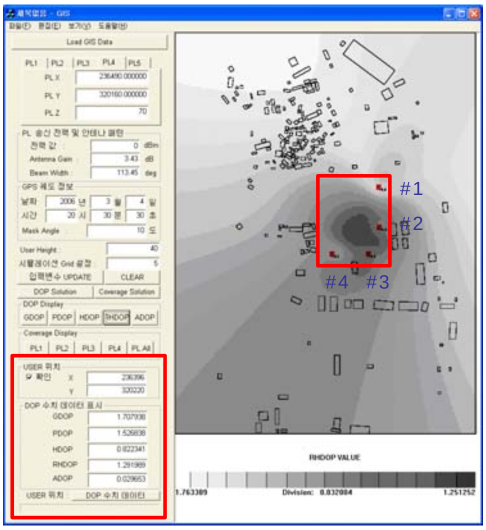


Figure 4. RHDOP simulation with 4-pseudolites by simulation software.

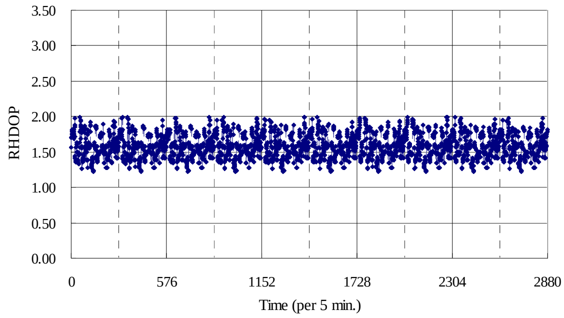


Figure 5. RHDOP changes over 10 days (4th ~ 13th March, 2006; with 4-pseudolites).

Table 2. RHDOP value depending on the number of pseudolites.

The # of Pseudolites / Pseudolite No.	RHDOP		
	Maximum	Minimum	Average
0	3.71	1.65	1.98
1 / #1	2.61	1.61	1.92
2 / #1, #2	2.40	1.48	1.89
3 / #1, #2, #3	2.21	1.36	1.73
4 / #1, #2, #3, #4	1.99	1.23	1.57

From Figure 5, the RHDOP values change from 1.23 to 1.99 and the RHDOP values less than 2.0 can be achieved all day. Hence it is shown that the horizontal accuracy of less than 10 centimeters can be achieved by the proposed pseudolite augmented precise positioning system. Particularly Table 2 illustrates that the RHDOP values are decreased by increasing the number of pseudolites.

To sum up, the proposed pseudolite augmented precise positioning system achieves the required continuity for automatic docking of vessels. This is due to the fact that the pseudolites ensure good geometry by providing additional ranging signals.

5. Performance Evaluation

This paper builds a test bed designed for performance evaluation of the proposed positioning system. The test bed consists of synchronized pseudolites and pseudolite/GPS receiver, where a synchronized pseudolite is used to minimize the effect of interference not only between GPS signal and pseudolite signal but also between pseudolites. Figure 6 shows the synchronized pseudolite, which is applied to this test bed. The transmitted power and angle of each pseudolite is determined to minimize the interference.

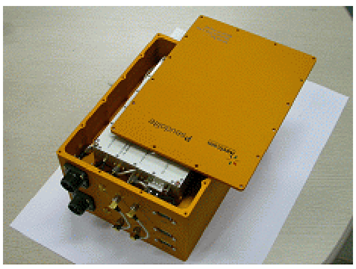
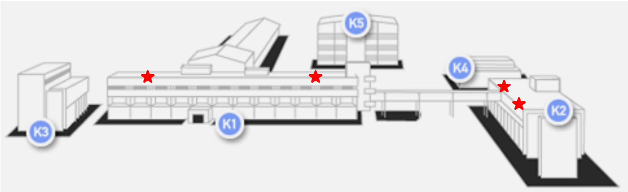
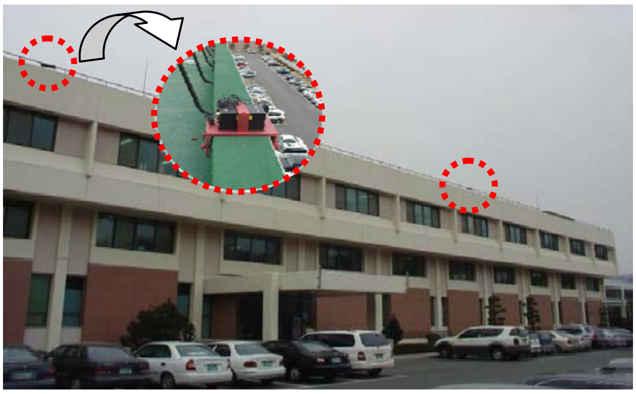


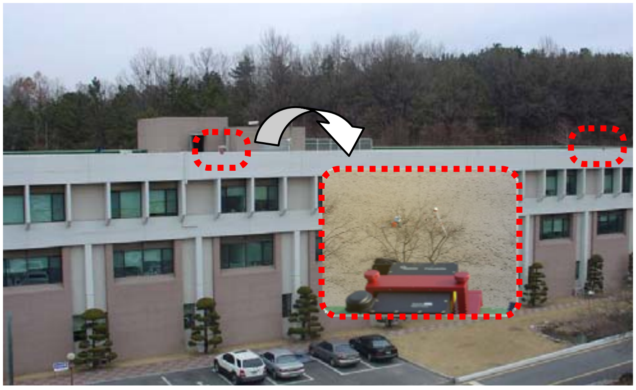
Figure 6. Photo of the synchronized pseudolite.



(a) The installed locations of the pseudolites (★).



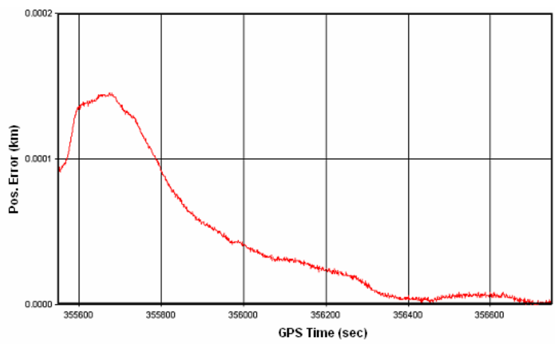
(b) The K1 building chosen for the test bed.



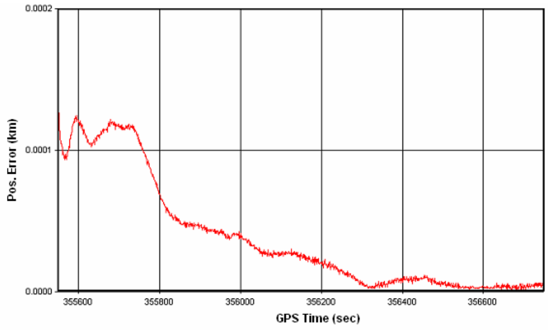
(c) The K2 building chosen for the test bed.

Figure 7. The test bed for the performance evaluation of the proposed positioning system.

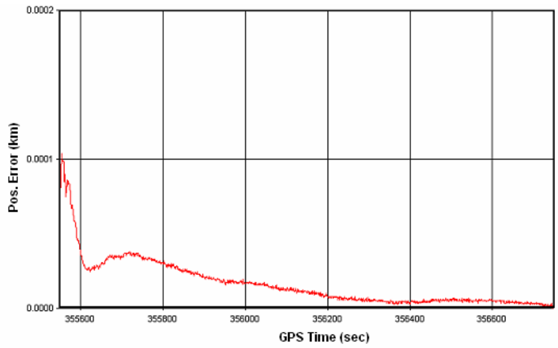
Figure 7 shows the installed locations of the pseudolites and photos of the building chosen for the test bed.



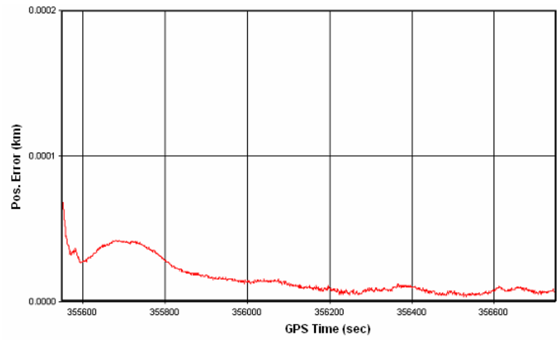
(a) Horizontal position error (GPS only).



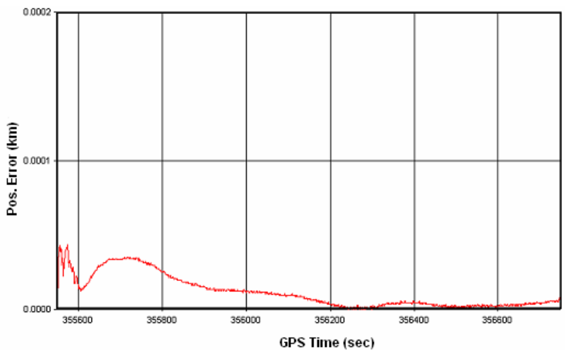
(b) Horizontal position error (GPS & 1-pseudolite).



(c) Horizontal position error (GPS & 2-pseudolites).



(d) Horizontal position error (GPS & 3-pseudolites).



(e) Horizontal position error (GPS & 4-pseudolites).

Figure 8. The results of positioning accuracy.

Table 3. Comparison of positioning accuracy.

The # of Pseudolites	0	1	2	3	4
RHDOP	2.97	2.61	2.08	1.36	1.29
Horizontal Position Error (Max.; cm)	14.85	12.76	10.05	7.45	4.45
Reference Figure	Fig. 8(a)	Fig. 8(b)	Fig. 8(c)	Fig. 8(d)	Fig. 8(e)

Figure 8 and Table 3 show the test results for the positioning performance evaluation carried out at the test bed. Figure 8(a) presents the positioning error of conventional CDGPS system. From Figure 8(a), conventional CDGPS meets the positioning accuracy for automatic docking if cycle slips do not occur in GPS signal processing and initial positioning errors are considered negligible in vessel berthing.

However these assumptions are impractical. Table 3 explains that additional pseudolites can significantly enhance the positioning performance for vessel berthing including reducing the DOP and improving the accuracy, continuity and reliability of the positioning solution. The performance evaluation results illustrate that the proposed precise positioning system meets required performance for automatic docking by pseudolite augmentation.

6. Conclusion

This paper shows that conventional CDGPS system using only GPS satellites is not able to meet the continuity performance among the requirements for automatic docking from DOP simulation. And this paper proposes the pseudolite augmented precise positioning system in order to solve continuity problem. In this paper, it is presented that the proposed positioning system can provide the continuous service with centimeter-level positioning accuracy through comparison analysis of RHDOP simulation results between the GPS satellite constellation and the pseudolite augmented GPS satellite constellation. It is also proved that the proposed precise positioning system meets the required performance for automatic docking of vessels from the performance evaluation carried out at the test bed.

For further work, it is necessary to study an interference mitigation algorithm and a solution to the near/far problem.

Acknowledgement

This work was supported by the Korea Research Council of Public Science and Technology (KORP) of Korea. We would like to express our thanks to Prof. Sang Jeong Lee at Chungnam National University for technical cooperation in the simulation for performance analysis.

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