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Prediction of eLoran Positioning Accuracy with Locating New Transmitter

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ABSTRACT

eLoran refers to a terrestrial navigation system using high-power low-frequency signals. Thus, it can be regarded as a positioning, navigation and timing (PNT) system to back up a global navigation satellite system (GNSS) or an alternative to GNSS. South Korea is vulnerable to interference such as GNSS jamming in particular. Therefore, South Korea has made an effort to develop an independent navigation system through eLoran system. More particularly, an eLoran testbed has been developed to be used in the northwest sea area and research on applicability of eLoran in South Korea has been underway. The present study analyzes expected performance of eLoran according to locations of newly built eLoran transmitting stations as part of the eLoran testbed research. The performance of eLoran is analyzed in terms of horizontal position accuracy, and horizontal dilution of precision (HDOP) information was used since it affects accuracy significantly. The target service areas of the eLoran testbed are Incheon and Pyeongtaek Ports, and the required target performance is positioning accuracy of 20 m position within 30 km coverage of the target service area.

Keywords: eLoran, GNSS back-up system, PNT, accuracy, HDOP

1. INTRODUCTION

Positioning, Navigation, Timing (PNT) information has been widely employed in various areas including communication, stocks, autonomous driving, and geodetic surveying. South Korea also provides Differential Global Navigation Satellite System and Real-Time Kinematic services for citizens to employ such information easily and conveniently through national infrastructure services. However, South Korea is dependent on foreign systems developed by the USA, Europe, China, and Russia to employ a satellite navigation system, which is a core of PNT service. Moreover, South Korea is vulnerable to interference due to global navigation satellite system (GNSS) jamming from neighboring countries. For example, fishing operation was stopped in the northwest sea area as well as mobile communication outage due to GNSS jamming in early 2016 (Fernandez et al. 2016, Grebler & Nichols 2016).

To solve the problem, much attention has been paid to the need of GNSS back-up or alternative navigation systems, and the enhanced Loran (eLoran) system has been regarded as the alternative system. eLoran is a terrestrial navigation system using high-power low frequency signals, whose distance range is long and it is robust to interference. Thus, South Korea has made an effort to develop an independent navigation system for the first time in order to cope with GNSS jamming through the development of eLoran system. More specifically, research has started to develop an eLoran testbed that satisfies positioning accuracy of 20 m within 30 km in Incheon and Pyeongtaek ports, which are located in the northwest sea in Korea. In this study, a new eLoran transmitting station was added and Loran-C signals at existing two locations were utilized to check whether the required performance was met in the target service area.

In the present paper, a candidate of new transmitting station for eLoran is selected, which is a critical factor that determines performance of the eLoran testbed, and accuracy

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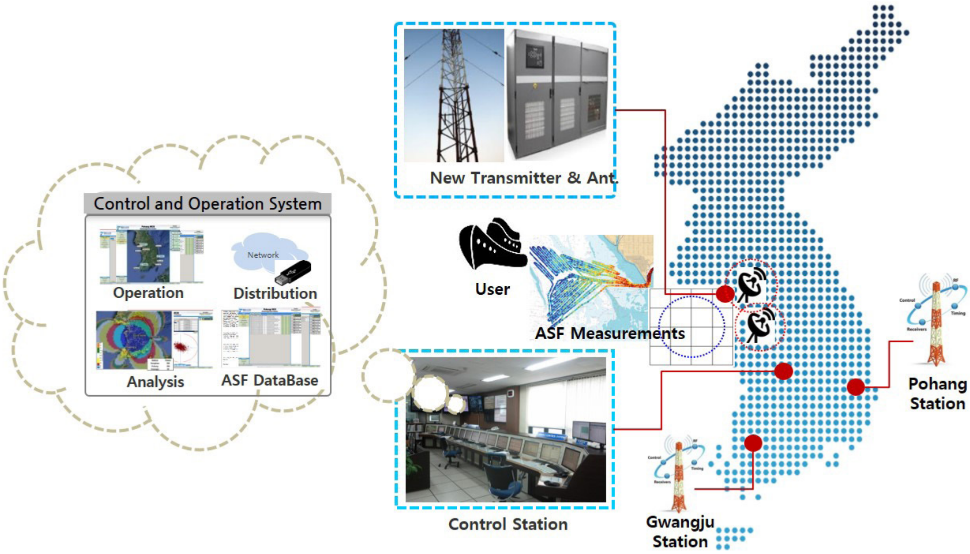

Fig. 1. eLoran testbed.

performance according to locations of candidate is predicted. From this on, the present paper verifies whether the required target performance of eLoran testbed is satisfied and analyzes the validity of the candidate as a transmitting station. The prediction of positioning accuracy is analyzed based on Horizontal Dilution of Precision (HDOP), which is a major factor of accuracy performance (Lee et al. 2013).

In Section 2, an eLoran testbed in South Korea is described, and a target performance of the testbed as well as candidate of new transmitting stations are discussed. In Section 3, prediction results of positioning accuracy performance are presented according to candidates of new transmitting stations. Finally, conclusions are presented.

2. ELORAN TESTBED

eLoran is an all-in-view system. It determines positioning using a time of arrival in signals of transmitting stations, which are synchronized with coordinated universal time (UTC). An eLoran system consists of three subsystems: transmitting station, differential Loran station (dLoran station), and integrated operating control station. The integrated operating control station is responsible for overall operation and management of eLoran system. The dLoran station generates correction information to improve positioning accuracy and transfers the correction data to transmitting station. The transmitting station transmits UTC-synchronized Loran signals and broadcast to users using the Loran data channel (LDC) message, that includes the correction information from dLoran station, so that users can acquire 20 m (95%) level of accuracy (USCG 2006, ILA 2007).

Table 1. eLoran testbed performance requirements.

Requirement	Performance
Positioning accuracy	< 20 m (95%)
Timing accuracy	< 50 ns (rms)
Coverage	< 30 km (from dLoran station)
Integrity	Provide integrity information
Data capability	Provide eLoran data using LDC

At least three or more signals are needed to estimate positioning using the eLoran system. The eLoran testbed is planned to use existing two Loran-C signals from Pohang and Gwangju and install the one new eLoran transmitting station and two dLoran stations additionally as shown in Fig.1 which are running in South Korea. Thus, three signals and LDC message that is broadcast from new transmitting station are used to provide pilot operation of eLoran services over Incheon and Pyeongtaek ports. The two dLoran stations are installed at Incheon and Pyeongtaek ports, respectively.

2.1 eLoran Performance Requirements

The performance requirements targeted by the eLoran testbed are presented in Table 1. The performance requirements of the eLoran testbed are divided into positioning accuracy, time synchronization accuracy, service area, integrity, and data channel capability. Here, the service area refers to a 30 km radius from the dLoran station that satisfies positioning accuracy of 20 m (95%) (Seo 2016).

Table 2. Loran-C chain in South Korea.

Role	Transmitter site	Position	Equipment (output: KW)	Antenna height (m)	C-Delay / Baseline
Control station	Daejeon	36°21'45.01386"N 127°17'30.68256"E			
Master	Pohang	36°11'05.450"N 129°20'27.440"E	ACCUFIX6500 (150 kW)	137	
Slave	Gwangju	35°02'23.996"N 126°32'27.295"E	ACCUFIX6500 (50 kW)	122	11000/945.97

2.2 Domestic Loran-C Operation

In South Korea, Loran-C signals are transmitted in Pohang and Gwangju currently and the current status is presented in Table 2 (NMPO 2016). South Korea belongs to the GRI 9930 Chain and has Pohang transmitting station as a primary station. Integrated operation and monitoring is done by the National Maritime PNT Office in Daejeon, which will be upgraded to the integrated operation and control station of eLoran in the future.

2.3 New eLoran Transmitter

A location of new eLoran transmitting station is a highly important factor that determines the performance of eLoran. The considerations of selection of eLoran transmitting station can be divided into three: First, it is a selection of candidate location based on simulations. The simulation analysis checks whether target positioning accuracy can be provided in the service target area. To do this, the following analysis factors are used: HDOP, User Equivalent Range Error (UERE), and signal power. Second, it is an analysis on radio environment. The analysis on radio environment analyzes the effect of radio interference source at a real transmitting station. Third, it is site survey. In the site survey, site area, ground resistance, possibility of lightening, and current status are analyzed, and infrastructure conditions, such as power, communication, roads, water supply, and drain facility, are verified. The most important part in the site survey is about site area, which ensures sufficient site area to install antennas which is more than 100 m height in eLoran transmitting stations. Moreover, ground resistance should be considered, and possibility of lightening and its frequency as well as preventive measures are also important considerations.

In the this paper, Incheon and Pyeongtaek ports, which were test ports in the testbed, were selected as a service area, and site area where antenna can be installed was considered, thereby selecting four candidates of eLoran transmitting station as presented in Table 3. Here, the northwest region in South Korea was assumed as installation area of new transmitting stations.

Table 3. The candidate of new eLoran transmitter sites.

	Candidate	Position
1	Gangwha-gun, Choji	37°36'54.6"N 126°31'41.6"E
2	Gangwha-gun, Sagi	37°35'57.3"N 126°25'28.0"E
3	Baengnyeong, Nampo	37°56'10.8"N 124°39'50.4"E
4	Gimpo, Todang	37°37'19.4"N 126°47'58.9"E

3. PERFORMANCE ANALYSIS RESULTS

The present paper predicted positioning accuracy performance of eLoran testbed according to locations of candidates of new transmitting stations from geographical viewpoints. The horizontal positioning accuracy (drms) is determined by HDOP and UERE as shown in Eq. (1) (Kaplan & Hegarty 2006). Here, σ_{UERE} refers to an error included in distance measurement measured at a receiver. Furthermore, HDOP refers to a value according to geographical position relationship between existing Loran-C reference station and new eLoran transmitting station. It becomes lower as the geographical position distribution becomes better. Therefore, higher positioning accuracy can be acquired as a value of HDOP becomes smaller.

$$\mathrm{drms} = \mathrm{HDOP} \cdot \sigma_{\mathrm{UERE}} \quad (1)$$

σ_{UERE} is affected by changes in a travel path of radio wave, jitter in transmitting stations, signal to noise ratio (SNR), receiver error, weather, and seasons (Hargreaves et al. 2012). Particularly, it is limited in predicting an error that can occur during the travel path of radio wave in South Korea where mountainous terrain and high-rise buildings are found in the way of radio wave travel path. Accordingly, it is highly important to have a process that measures an error that occurs in the radio wave travel path and correct the error, and through this, σ_{UERE} should be minimized.

On the other hand, HDOP is represented as a fixed constant according to user's location once a new transmitting station is determined. HDOP cannot be improved if a location of transmitting station is not changed or additional transmitting stations are not constructed. As a result, analysis on HDOP must be done when new transmitting stations are constructed. The horizontal positioning accuracy can become better as HDOP becomes lower in the target service area.

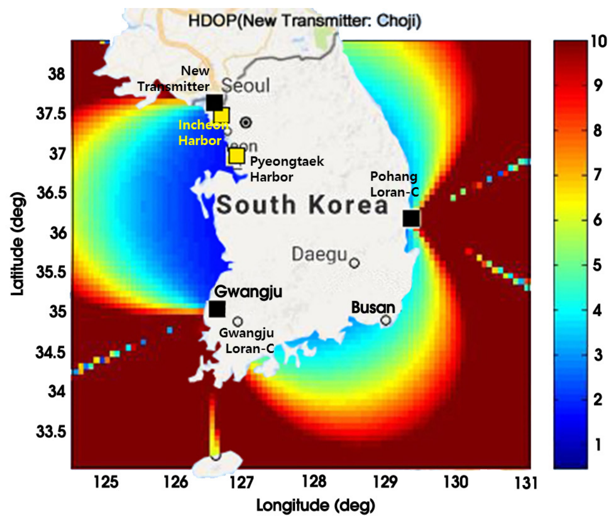

Fig. 2. HDOP result in Gangwha-gun, Choji.

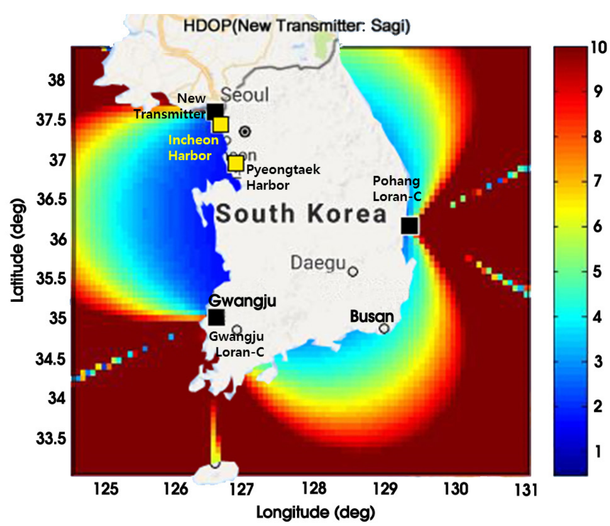

Fig. 3. HDOP result in Gangwha-gun, Sagi.

The HDOP results according to four candidates of new transmitting station are shown in Figs. 2-5. The lower HDOP is marked with blue color whereas the higher HDOP is marked with red color. Here, changes in SNR value according to propagation distance of signal at the transmitting station were not considered. The black-color square refers to Loran transmitting station and the yellow-color squares refer to Incheon and Pyeongtaek ports, respectively. Figs. 2 and 3 show Choji-ri and Sagi-ri in Gangwha-gun, which exhibit the results of two candidates are similar. Both of two candidates showed that HDOP was 2 in Pyeongtaek port and 2 to 3 in Incheon port.

The result of Nampo-ri in Baengnyeong-do is shown in Fig. 4, which has the best HDOP performance. Both of Incheon and Pyeongtaek ports showed two or lower HDOP. If a new transmitting station is established in Nampo-ri in

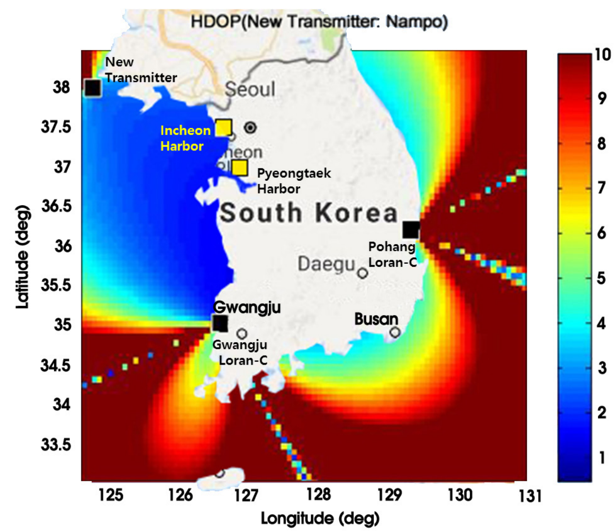

Fig. 4. HDOP result in Nampo in Baengnyeong.

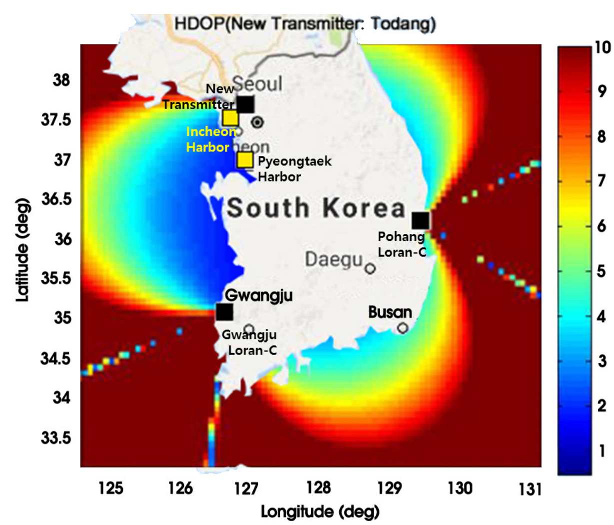

Fig. 5. HDOP result in Gimpo, Todang.

Baengnyeong-do, it can provide higher accuracy of eLoran services in a wide area than any other candidates do.

The result of Todang in Kimpo-si is shown in Fig. 5. It showed the worst HDOP performance and for Incheon port, HDOP performance showed 3 or higher, which may not satisfy the required target accuracy.

4. CONCLUSIONS

The present paper verified the prediction results of accuracy performance at four candidates according to the addition of new transmitting station of the eLoran testbed from geographical analysis viewpoints. The results of HDOP, which was a main factor that determined positioning accuracy, exhibited that Nampo in Baengnyeong-do had the best result out of four candidates in terms of geographical viewpoint. However, the region was a military zone so it is necessary to consider a security and an interference problem due to military equipment. As an alternative, two areas in Gangwha-do can be considered. Todang in Kimpo-si was verified as inappropriate to satisfy the performance requirements.

The present study verified applicability of eLoran services for users in the north and central regions in the west coast. It is expected to have more reliable and sustainable PNT information services for maritime users if the eLoran testbed is successfully developed and implemented after pilot services are provided in the future. Moreover, it can bring a positive effect on achievement of e-Navigation.

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