Study of Alternative Navigation Systems for GNSS in South Korea

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***Abstract*— As the GPS(Global Positioning System) vulnerabilities were introduced, alternative systems to GPS backup have been studied for several years. Enhanced Loran(eLoran) as the worldwide ground-based supplementary radio navigation system was recommended as the cost effective alternative to GPS backup. Many efforts on adoption of eLoran as GPS backup have been presented. The US has been the leading role and announced that 70% enhancement for eLoran was established last year. However, the Obama administration cut off the eLoran budget on the fiscal year 2010 budget proposal while GAO's reports submitted that GPS service gap would be possible just some years later. Besides the US's condition, there are still many positive opinions on eLoran to GPS backup. This paper introduces the historical and technical aspects of eLoran and Korea's research topics.**

Index Terms*— Alternative Navigation System, eLoran, GNSS, Positioning System.

I. INTRODUCTION

Since South Korea has no independent satellite navigation system, there are many needs to prepare the alternative navigation systems. The government has conducted the studies for alternative navigation systems and got a feasibility study for DGPS beacon signal and utilization of legacy Loran signal and enhanced Loran. Besides of South Korea, worldwide researches, mainly the US and the UK, on alternatives to GPS backup system have been conducted and conclude that eLoran is the most cost effective and independent system. The US has been a leading role in the development of eLoran system[1-5]. The UK also has introduced many results of eLoran development[6,7]. South Korea has been conducting the feasibility study of eLoran system[8]. However, the US president Obama cut off the budget of eLoran in FY10 while GAO suggested the GPS service gap[9,10,11].

Now is the very complex and sensitive situation for eLoran. However, the importance of and need for eLoran for GPS backup seem to be still thriving.

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This paper introduces the historical aspects of eLoran from Loran-C, technical aspects to adopt the eLoran as a GPS backup, and Korea's related works.

II. HISTORY OF ELORAN

Loran(LOng RAnge Navigation) is a terrestrial hyperbolic radio navigation system, operating between 90kHz and 110kHz. Loran uses very tall antenna with high power and broadcasts primarily a groundwave. Loran provides both lateral position and a robust time and frequency standard. Loran is a supplemental system for navigation in the U.S. National Airspace System(NSA) and a system for maritime navigation in the Coastal Confluence Zone(CCZ). Loran has a stratum 1 frequency standard that also provides time within 100ns of UTC(USNO).

Loran-C is the representative system worldwide while there are several versions from Loran-A to Loran-D.

Loran-C provides a predicted 2drms accuracy of 0.25nm(460m) and a repeatable accuracy of 60 – 300ft(18~90m), an availability of 99.7%, a level of integrity based on exceeding certain operational parameters measured at the transmitters and continuity no greater than 99.7%, but becomes potentially worse depending on receiver characteristics and geometry of the triad being used.

A. The past Loran & eLoran

The development of Loran began in 1940s. In 1970s, Loran established for civilian use. In 1990s, as GPS appeared, DOT (Department of Transportation) announced the plan to shut Loran down in 2000s.

In 1997, the upgrading and modernizing of the Loran-C system was announced and Presidential Decision Directive(PDD-63) directed DOT to study GPS vulnerabilities in 1998.

In 2001, the Volpe NTSC (National Transportation Systems Center) completed an evaluation of GPS vulnerabilities and the potential impacts. Based on the results, they recognized Loran as the best theoretical multimodal GPS backup and confirmed the necessity of managing Loran as a national asset. The U.S. started cost benefit analysis and feasibility study[12].

In 2002, LORIPP(Loran Integrity Performance Panel) and LORAPP(Loran Accuracy Performance Pane) were formed. LORIPP analyzed whether a modernized Loran system could meet the stringent integrity requirements for NPA(Non-Precision Approach) in the U.S. National Airspace System which required the probability of the system providing hazardous or misleading information under 1 x 10^{-7} per hour. LORAPP analyzed whether a modernized Loran system could meet the stringent accuracy requirements for HEA(Harbor Entrance and Approach) which required the positioning accuracy of 8-20m.

The comparison of backup alternatives to GPS was shown in Table 1.

TABLE 1
COMPARISON OF BACKUP ALTERNATIVES TO GPS

	PNT	Multi-modal	Independent of GPS		
			System	Signal	User
Galileo	∨	∨	∨	×	×
eLoran	∨**(no 3D)**	∨	∨	∨	∨
DGPS	×	∨	×	∨	×
SBAS	×∨	∨	×∨	×	×
Radar	×	×	∨	∨	∨

In late 2006, DOT convened an IAT, in cooperation with DHS(Department of Homeland Security).

In 2007, the Spaced-Based PNT(Positioning, Navigation and Timing) Executive Committee, co-chaired by the deputy Secretaries of the DOD(Department of Defense) and the DOT, concurred with a joint DHS-DOT, announced “enhanced” Loran(eLoran) as a national PNT backup to the GPS for the U.S. homeland.

In this way, the Bush administration appeared to have finally made a long-delayed decision to complete implementation of enhanced Loran system to serve, in part, as a backup to GPS.

B. The recent status of eLoran

In early 2008, DHS decided to use an eLoran as a backup to GPS, and announced the migration of Loran-C from the USCG(U.S. Coast Guard) to the DHS’s NPPD(National Protection and Programs Directorate)[13].

USCG operates 24 Loran stations nationwide. 19 have been upgraded to eLoran, which broadcasts a data channel to improve accuracy, signal availability and integrity of information.

Before the President Obama’s Fiscal year 2010 budget proposal which called for termination of Loran in the coming year, the upgrade program of eLoran seemed to be conducted favorably. However, at a May 7 in 2009 press conference, the president described Loran as a system that’s been eclipsed by the rise of GPS.

The Senate version, passed July 9, provides $18 million to extend Loran-C operations through January 4, 2010.

Finally, Loran-C operations terminated the service at February 8.

However, the RTCM(Radio Technical Commission for Maritime Services) is developing performance standards for eLoran in the maritime environment.

eLoran also has strong support from the GLA(General Lighthouse Authorities) of the UK and Ireland.

The worldwide attention is focused to the US official ambivalence and its consequence.

III. TECHNICAL ELORAN

eLoran consists of the advanced receiver, transmitters and the additional dLoran (differential Loran) sites in order to increase the accuracy of current Loran-C. Table 2 shows the comparisons between Loran-C and eLoran.

TABLE 2
LORAN-C VS. ELORAN METRICS

	Accuracy	Availability	Integrity	Continuity
Loran-C Definition of Capability	0.25nm (463m)	0.997	10second alarm/ 25m error	0.997
FAA NPA (RNP 0.3) requirement	0.16nm (307m)	0.999 – 0.9999	0.9999999 (1x10-7)	0.999-0.9999 over 150sec
USCG HEA requirement	0.004-0.01nm(8-20m)	0.997 – 0.999	10second alarm/25m error(3x10-5)	0.9985-0.9997 over 3 hours

A. eLoran system

As eLoran uses high-powered transmitters and low-frequency signals, it is very unlikely to be interfered with or jammed by the same causes that would disrupt GNSS signals[14]. This means that small, low-cost eLoran receivers, even built into GNSS units, can mitigate the impact of disruptions to GNSS[15].

The principal difference between the eLoran transmitted signal and the traditional Loran-C signal is the addition of a data channel. The data channel conveys corrections, warnings, and signal integrity information to the user’s receiver via the Loran transmission.

eLoran transmission is synchronized to UTC by a method wholly independent of GNSS. This allows the eLoran service provider to operate on a time scale that is synchronized with, but operates independently of GNSS.

Control centers respond rapidly to failures and maintain the published very high levels of availability and continuity.

Monitor sites, located in the eLoran coverage area, are used to provide integrity for the user community.

eLoran users’ receivers operate in an all-in-view mode. That is, they acquire and track the signals of many Loran stations and employ them to make the most accurate and reliable position and timing measurements. An eLoran receiver is capable of receiving and decoding the data channel messages and applying this information based on the user specific applications.

A significant factor limiting the accuracy of the Loran system is the spatial and temporal variation in TOA (Time of Arrival) of the transmitted signal, which is called ASF (Additional Secondary Factor). ASF is due to the signals propagating over land paths of varying topography and conductivity.

B. ASF in eLoran : Key Error Sources

ASF corresponds to a slight retardation in the TOA of the transmitted signal, and can vary greatly due to the non-uniform nature of ground conductivity and topography as well as weather condition. This delay can be significant and can result in position errors of hundreds of meters or more. Hence, a key component in evaluating the utility of eLoran as a GPS backup is a better understanding of ASFs and a key goal is how to mitigate the effects of ASFs to achieve more accurate positioning. Accordingly, reasonable estimates of ASF are necessary for accurate positioning.

As mentioned earlier, the significant factors of ASF are the spatial and temporal variation. The spatial term, the constant part of the ASF, is related to changes in terrain features and changes in the non-uniform conductivity over the eLoran signal's propagation path. The temporal term is included to catch any remaining short term TOA variability. The spatial term is compensated using the published grid map which is long-term averaging data of ASFs. And the temporal term is generated as a differential Loran correction by local dLoran reference site. The differential Loran correction is broadcasted via transmitters on LDC (Loran Data Channel).

IV. KOREA'S APPROACHES

Korea has been studied alternatives for GPS backup for several years. The first research was the feasibility study of using DGPS beacon signal in 2005. DGPS beacon signal uses the medium frequency as same as eLoran signal. Therefore, Korea could move on to eLoran study rather easily. The Loran chain is 9930.Korea has been conducting three sub research topics.

Fig. 1. GRI 9930 chain and Target area

A. ASF estimation software

As mentioned before, ASF can be estimated by some ASF models. There are several ASF estimation models such as Monteath, Wait and Millington, etc. The dominant ASF estimation model is Monteath model which is applied to BALOR system in the UK. Monteath model uses the most accurate databases of ground conductivity, coastline and terrain elevation. Monteath model is known to successfully predict ASFs to the distance of 1,000km from the transmitter. However, the latest US results said that estimated ASF data didn't satisfy in some condition, so the measured ASF data could be used to generate the spatial map. However, since the terrain and weather conditions are different from each country, it is needed to validate the feasibility of estimated ASF data first. The estimation software of Monteath model using C-language was implemented. The input databases are DEM(Digital Elevation Model) from NASA SRTM(Shuttle Radar Topography Mission) with 30m resolution, the ground conductivity database from ITU-R P.832 and the coastline database in Korea.

The first feasibility analysis of estimation data is conducted with measurement of ASF delays, as another research topic [16].

B. ASF measurement

The skill of ASF measurement method under the condition of receiving legacy Loran-C signal without TOC(Time of Coincidence) has been conducted, since eLoran system is not yet established in Korea[17].

Pohang Loran station which is the master station of Korea chain 9930 makes signal by using Cesium atomic clock as a reference, but there is not a TOC function which synchronizes the reference time regularly. To solve this problem, the measurement systems as shown in figure 2 are proposed and developed.

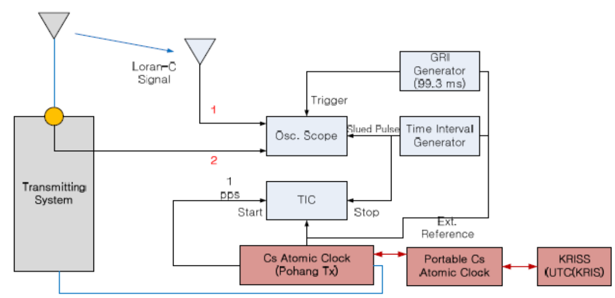

Fig. 2. Block diagram of propagation delay measurement system for Loran-C signal at a transmitter

To measure the ASFs in user equipment, the TOA measurement equipment was designed shown in Figure 3.

1) Test with estimations and measurements

The ASF measurements are gathered at some points from the Pohang transmitter. The results show the consistency between the predicted ASF and measured

ASF with about 0.8us offset. Until now, it seems that the validity of the measured ASF values and the ASF predictions are verified. More tests are planned on vary environments to get more rigid conclusions.

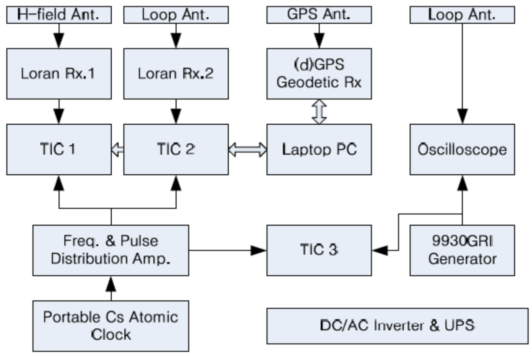

Fig. 3. Travelling test equipment

2) Multiple dLoran sites

For realizing the level of the position accuracy to meet the HEA specifications, the temporal ASF should be measured and compensated by LDC data. The temporal ASFs are related to the location of dLoran reference sites and affected by the travelling path between the transmitter and the dLoran reference sites. This research topic has the goal of the more accurate positioning method for multiple dLoran sites which have different topography condition and the correction methods[18].

V. CONCLUSIONS

This paper introduces the Korea's researches to backup GPS. As a dominant system for GPS, historical and technical views on eLoran are introduced. Although the mitigation from Loran to eLoran seemed to be conducted well, the US determined the close of loran service. However, since there are strong needs and circumstances for continuous eLoran program to GPS backup, we should pay attention to its process.

This paper introduces Korea's eLoran studies also. The methodologies for deploying the eLoran HEA positioning system are briefly presented.

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