Can eLoran Deliver Resilient PNT?

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BIOGRAPHIES

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Dr. Paul Williams is a Principal Development Engineer with the Research and Radionavigation Directorate of The General Lighthouse Authorities of the UK and Ireland, based at Trinity House in Harwich, England. He is currently the technical lead of the GLAs’ eLoran Work Programme, and is involved in planning the GLAs’ maritime eLoran trials and works on a wide range of eLoran related projects. He holds BSc and PhD degrees in Electronic Engineering from the University of Wales, is a Chartered Engineer, a Fellow of the Royal Institute of Navigation, a board member of the International Loran Association and is chairman of the Radio Technical Commission for Maritime Services Special Committee 127 on Standards for Enhanced Loran (eLoran) Systems.

Mr. Chris Hargreaves is a Development Engineer with the Research and Radionavigation Directorate of The General Lighthouse Authorities (GLA) of the UK and Ireland, based at Trinity House in Harwich, England. His main area of work for the GLAs is in project delivery of their eLoran Work Programme, wherein he takes part in trials, develops software and data analysis techniques. He holds an MSci in Maths and Physics from the University of Durham, and an MSc in Navigation Technology at the University of Nottingham. He is a member of the Royal Institute of Navigation.

Martin Bransby is Research & Radio-navigation Manager for the General Lighthouse Authorities of the UK & Ireland. He is responsible for the delivery of its project portfolio in research and development in such technical areas as AIS, resilient position navigation & timing, e-Navigation, GNSS and Lights. He is a Fellow of the Royal Institute of Navigation, and holds memberships of the Institute of Engineering & Technology and the US Institute of Navigation. He is also a member of the International Marine Aids to Navigation and Lighthouse Authorities’ (IALA) Aids to Navigation Requirements & Management Committee.

ABSTRACT

The implementation of e-Navigation is underway. This concept for the harmonization and integration of maritime information systems onboard and ashore is likely to become a reality over the next five years, leading to fewer accidents, safer more efficient navigation and protection of the environment. Almost every solution provided under the e-Navigation initiative depends on an electronic position input. At present that input comes almost exclusively from GPS. Given the vulnerability of GPS (and other Global Navigation Satellite Systems - GNSS) to disruption, that situation is not sustainable. Various options for GNSS backup are being explored. This paper looks at some of the alternatives that have been tested and demonstrated and assesses their potential for completing GNSS to provide resilient PNT. eLoran is the most advanced of the alternatives and the only one likely to be ready in time for the implementation of e-Navigation: eLoran has reached Initial Operational Capability in the UK. This paper reports the results of demonstrations carried out there, describes the equipment being evaluated and sets out the steps towards Full Operational Capability. The status of Loran in other parts of the World is reported and some initiatives proposed that could make it a realistic component of a World Wide Radio Navigation System, providing Resilient PNT for all applications.

INTRODUCTION

Maritime risk is increasing globally. The trends are for larger and faster ships, fewer and less experienced crew, more crowded coastal waters and a growing reliance on satellite navigation and electronic charts with resulting loss of traditional sea-going skills. Today, over 80% of accidents are caused by human error. The International Maritime Organization (IMO) response is e-Navigation: a
ALTERNATIVES TO GNSS
Inertial systems have long been used to complement GNSS, as they can provide short-term accuracy and stability and are independent of external signals. Inertial systems have been integrated with GNSS for many specialised applications, such as hydrographic survey. In recent years mass-market inertial technology (MEMS) has provided a low-cost option, but it is still necessary to use high-grade, expensive inertial units to provide a backup for a GNSS outage lasting for more than a few tens of seconds. As there is no certainty that this situation will change in the foreseeable future, it has been necessary to pursue the quest for a complementary radio-navigation system to ensure a continuous electronic position input.

The three main candidates for such a backup system to GNSS in the maritime sector have been ranging on existing radio signals (R mode), absolute positioning by radar and enhanced Loran (eLoran). R-mode has been evaluated using signals from maritime DGNSS beacons and indications are that the required accuracy levels can be achieved, within the coverage of these beacons (Johnson et al, 2014), taking into account the reduced range at night due to skywave. However, some enhancement work would be needed on the stations, receivers would need to be standardised and approved and regulatory measures put in place. Absolute positioning by radar has also been demonstrated to work, giving very accurate results within a limited range of the coast (about 10 M) (Ward et al, 2014). Considerable additional shore-side infrastructure would be needed, but the most significant obstacle would be the need to replace or modify radars on vessels throughout the world, requiring international consensus and a very long implementation period. Another method requires only modification of onboard radars and less expensive shore-side infrastructure, but is likely to be even more limited in terms of range.

eLoran, by contrast, is an internationally standardized positioning, navigation, and timing (PNT) service for use by many modes of transport and in other applications. It is the latest in the long-standing and proven series of low-frequency, LORAn-RAnge Navigation (LORAN) systems, one that takes full advantage of 21st century technology. eLoran meets the accuracy, availability, integrity, and continuity performance requirements for aviation non-precision instrument approaches, maritime port approach manoeuvres, land-mobile vehicle navigation, and location-based services, and is a precise source of time and frequency for applications such as telecommunications, energy distribution and financial networks. The now obsolete Loran-C system is enhanced by more precisely synchronized signal transmissions, better, smaller receivers, and a Loran Data Channel, using the Loran signal itself to broadcast vital data to support application services.

Since 2004, the General Lighthouse Authorities of the UK and Ireland (GLA) have been leading the introduction of eLoran in Europe: a new unmanned transmitter station has been deployed in NW England; successful GPS jamming and eLoran trials have been conducted, demonstrating that a fully operational, resilient PNT system can be provided. The additional, non-maritime benefits, of eLoran have been proven, including the use of the Loran Data Channel for secure data transmissions, resilient timing for telecommunications and robust land-vehicle tracking systems. The GLA aim is that, with their European partners, a Europe-wide eLoran service will be delivered to secure the broad benefits that are enjoyed from GNSS and enabling new applications and services. eLoran is the only credible and cost-effective option that, in the time available, can deliver e-Navigation’s urgently needed benefits of safety and security at sea and protection of the marine environment.
eLoran is therefore a proven system that could be introduced world-wide to ensure resilient PNT. However, this would still need consensus, at least at a regional level and resources to provide the necessary infrastructure.

**ELORAN IOC**

In order to demonstrate the viability of eLoran as a complementary backup to GNSS the GLA have established prototype eLoran Initial Operating Capability (IOC) in the UK (Williams et al, 2013). eLoran delivers similar quality PNT data to GPS from a network of high-power, low frequency, terrestrial transmitters.

The Loran-C system was used for many years, but suffered from significant positioning bias errors due to a number of radio frequency signal propagation delay Factors. The Primary Factor (PF) is due to the signal travelling slower in air than free-space, the Secondary Factor (SF) is due to the presence of the Earth’s surface and the electrical properties of the oceans. Additional Secondary Factor (ASF) is due to the additional electrical resistance encountered by non-seawater terrain, land, mountains, deserts etc. PF and SF can be modelled, but to get high accuracy from eLoran requires accurate calibration of ASF through measurement.

To do this, ASF surveying and mapping has been conducted along the port approach channels at Aberdeen; along the the Firth of Forth; Middlesbrough; Hull and the Humber Estuary Traffic Separation Scheme (TSS); Harwich and Felixstowe; The ports of London, Medway and the approaches past the London Array wind-farm and also through the Dover Straits.

To complement these services, seven differential-Loran (DLoran) Reference-Stations, one located close to each of these survey areas have been established. These stations monitor the time of arrival of the received eLoran signals, and generate differential-corrections that are broadcast via the Anthorn Loran Data Channel (LDC), to account for temporal variations in these ASF maps.

Making use of these ASF maps, combined with the locally-produced differential corrections, can allow a maritime user of eLoran IOC to obtain position accuracy of the order of 10m (95%), within a radius of 30 to 50 km of the DLoran reference station.

**RESILIENT PNT**

The GLA have developed the operational concept of Resilient PNT by creating a radio-receiver and software setup that can replace a conventional GPS receiver onboard a vessel and provide continuous position and navigation data even in the face of complete GPS denial. These R-PNT receivers provide the ASF and differentially-corrected eLoran positioning capability, and continuously monitor the quality of GPS triggering the automatic and seamless switch-over to eLoran (and back again) when necessary.

This service is limited however by the range of validity of the eLoran IOC service. Since ASF data is required, accurate eLoran positioning is only available while the receiver is located within one of the precisely surveyed ASF Maps and within the range of validity of a DLoran Reference-Station. These Stations have an associated cost, and require a certain amount of infrastructure (power, internet connectivity and a suitable antenna site), also the ASF surveying process is time-consuming and costly.

As a result it is economically impractical to expand IOC to cover every square kilometre of the UK’s waters. Instead a method of providing ASF for accurate eLoran positioning is required for the intervening sea-space between DLoran reference station sites, and so the GLAs have created the concept of Coastal Voyage-phase eLoran.

**COASTAL VOYAGE-PHASE ASF**

It has long been proposed that ASF can be provided for large areas at relatively low-cost by using mathematical modelling of eLoran signal propagation physics to calculate and map expected ASF. Modelling ASF is notoriously inaccurate, mainly due to the inadequacies of our ability to know precisely the electrical properties of the terrain over which the signals pass. Occasional measurements of ASF in the field can allow calibration of this modelling process.

The GLA have equipped all six of their fleet of buoy-tender vessels with combined eLoran / GPS receivers, these make continuous calibration measurements of the modelled ASF as the vessels go about their everyday business.

A map of ASF, covering the whole of the UK coastal waters, has been produced and calibrated with real-world measurements comparing eLoran to a GPS based ground-truth. This map contains only the spatial components of ASF, any temporal variations between the day of calibration and the day of use remain as unknown error-sources in eLoran positioning. As such, position-fixing using this map alone is accurate to about 30-50m (95%) depending on location and time of year.

Better performance can be obtained by calibrating these temporal variations using GPS when GPS is available and behaving reliably. Since differential-eLoran corrections typically vary quite slowly throughout the day, a single GPS-derived correction for the Coastal Map can stay accurate for many hours, and a user can typically expect to obtain 10-20m (95%) accuracy from eLoran used for Coastal Navigation, for an hour or more without a GPS reference. 
SEAMLESS R-PNT
There now exists a requirement for an eLoran receiver on board ship to be equipped with all the relevant ASF data and provide, as best as it can, continuous, accurate and seamless navigation from eLoran, UK-wide. A bespoke piece of software has been written which can:

- Read in and store ASF correction tables for all IOC Ports and a UK-wide Coastal ASF Map
- Interface with the eLoran and GPS receivers and read in the NMEA data messages
- Read the UTC-timing and DLoran correction data included in the Eurofix Loran Data Channel (LDC), and store these corrections for use with the particular ASF map.
- Select which eLoran transmitters to use in solution, determine which ASF map to look up corrections, and apply the relevant DLoran corrections
- Determine if DLoran corrections are unavailable for a particular map, if so calculate and use GPS-derived local corrections instead.
- Fix a position from the weighted least-squares solution of eLoran pseudoranges, corrected for ASF and differential.
- Determine the Horizontal Protection Level and Integrity of the fix.
- Communicate the fix, with a relevant ‘use/do-not-use’ flag to the vessels’ own equipment (ECS, ECDIS or similar chart-plotter)

Resilient-PNT Receivers equipped with this software are now in place on the vessels of early-adopters of this system. These have been interfaced to the ships’ electronic chart display so that, in the event of GPS disruption, the crew would be able to select R-PNT positioning source.

This work has highlighted a number of points that are important for providing a truly seamless navigation solution and these will be described in a follow-up paper.

PROGRESS IN OTHER AREAS
A compatible system (eDLoran) has been developed for operation by ships’ pilots on the Europort approach to the Port of Rotterdam. However, Loran is a regional system dependent on international collaboration. The 9 transmitters in northern Europe are operated by Denmark, France, Germany, Norway and the UK. Both Norway and France have declared an intention to cease Loran transmissions at the end of 2015. Moreover, France intends to dismantle its Loran infrastructure in 2016. Arrangements for the commercial operation of the infrastructure are being investigated, but this depends on some form of regional agreement. The European Union appears to have no policy for resilient PNT, the European Radio Navigation Plan having twice been drafted but never published. The view seems to be that the introduction of Galileo will achieve resilient PNT, which it will not.

Meanwhile South Korea is implementing a national eLoran service and it is understood that similar plans are being considered in Russia and China. eLoran can provide resilient PNT backup across all sectors, especially for Critical National Infrastructure, including intermodal transport, telecommunications, public media broadcasting, finance, energy, emergency services and security. eLoran can also provide a resilient broadcast communications channel for secure data.

The GLA are supporting UK industry to investigate cross-sector applications of eLoran, especially precise timing solutions and land mobile applications.

CONCLUSIONS
1. eLoran can deliver Resilient PNT and this has been demonstrated on several vessels.
2. Seamless handover from primary (GPS) to secondary (eLoran) positioning source has been successfully implemented.
3. Surveying and mapping of ASF has been carried out for several major ports and the required levels of performance demonstrated.
4. DLoran reference stations to correct for short-term, temporal variations have been installed and commissioned.
5. Good levels of performance have also been demonstrated for coastal voyage phase away from the ASF surveyed areas.

REFERENCES