GNSS & WGS 84 for Marine Navigation in UK Waters

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The following paper reports on the progress of a large collaborative project in the UK to investigate novel strategies for the implementation of GNSS within all phases of marine navigation. The project is funded by the UK Government (Engineering and Physical Sciences Research Council) under the leadership of the IESSG at the University of Nottingham. The project receives the support from a prestigious team of collaborators which include the UK Ministry of Defence Hydrographic Office, Trinity House Lighthouse Service, Northern Lighthouse Board, Commissioners for Irish Lights and the Port of London Authority. This consortium is of strategic importance, as their operations encompass the provision of aids to navigation for all phases of marine transport within the UK and elsewhere.

1. INTRODUCTION. GNSS technology has been available for well over a decade. Initially developed by the US and FSU military as force-enhancers, GPS and GLONASS are currently being used for applications in many diverse fields of civilian activity. Principal among these are air, marine, land and space navigation. The use of GNSS for civil navigation has gained widespread support from international organisations such as the International Civil Aviation Organisation (ICAO), the International Maritime Organisation (IMO), the International Hydrographic Organisation (IHO) and from national agencies responsible for maintaining maps, charts and navigation aids (e.g. civil aviation authorities, hydrographic departments, coast guards, lighthouse authorities, airport operators, port authorities and national survey organisations). Recognising the potential of GPS for multi-modal navigation, ICAO and IMO have recently discussed cooperation for the use of satellite navigation, in the form of a joint working group. This partnership will help to ensure that future satellite navigation services will meet the requirements of the maritime users as well as the aviation community.

GPS and GLONASS are best known as measurement systems. They have 24-hour all-weather global coverage. GNSS can provide the user with a variety of observables

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to satisfy different positioning requirements. GNSS point positioning and relative positioning accuracies range from tens of metres to millimetres, offering the potential of GNSS-based services for all phases of marine navigation. Furthermore, GNSS has an associated global coordinate reference system, WGS 84, which is set to become the universal standard for both marine and civil air navigation. Indeed, by 1 January 1998, at the request of ICAO, the locations of all civil air radio navigation aids, airport facilities and flight path obstacles were required to be published in WGS 84 coordinates. The IMO and IHO have suggested a similar policy for marine navigation coordinate information in the Performance Standards for Electronic Chart Display and Information Systems (ECDIS) [IHO, 1993 and IMO, 1995]. Despite the numerous advantages over ground-based systems, several significant challenges must be overcome before GNSS technology can be used to provide a seamless system for all phases of marine navigation. These challenges form the basis of the project.

2. PROJECT AIMS AND OBJECTIVES.

The project's overall aim is to harmonise the different positioning and display systems used in marine navigation, ashore and afloat. In doing so, the project will address the fundamental problems facing organisations such as IMO, IALA, IHO, port authorities and the vessel owners when attempting to integrate positional information from GNSS, aids to navigation and existing charting onto a common reference system. To achieve this aim, the project has the following objectives:

(i) To carry out fundamental research into methodologies and optimal strategies which are required for the implementation of the WGS 84 coordinate datum in marine navigation. This requires investigating and establishing appropriate strategies for the transformation of existing nautical chart data and other navaid information (e.g. radar sites and marine beacons) into WGS 84, or re-surveying when necessary.

(ii) To develop new concepts, specifications, algorithms and software for a new integrated system for Vessel Traffic Services (VTS), combining current radar positioning with modern Differential GNSS (DGNSS) telemetry technology for the navigation of vessels. Current VTS surveillance systems are radar-based and operate over a local area. The integration of GNSS position information into existing systems will enable port authorities to monitor vessels both inside and outside their areas of jurisdiction, thus improving safety at sea and in ports.

Furthermore, to achieve a truly seamless system for all phases of navigation, the project will investigate integrating GNSS observations with ground-based Loran-C for operational use in the medium term. The UK General Lighthouse Authorities are considering adopting Loran-C as a terrestrial navigation system to back-up and complement the use of GNSS and radiobeacon-based DGNSS systems.

(iii) To establish a methodology for assessing the integrity of GNSS for marine navigation in UK waters. This will require the development of algorithms and software tools that will help in assessing GPS integrity for all phases of navigation, but especially for safety-critical operations (port approaches, berthing and harbour navigation).

(iv) To investigate the combined use of Real Time Kinematic GPS, tide gauge records and hydrographic survey data to provide robust and reliable techniques for accurately monitoring the height of deep draught vessels in shallow clearance zones and restricted passages.

3. FROM CIVIL AVIATION TO MARINE NAVIGATION.

In 1989, ICAO issued a mandate which stated that all civil air navigation facilities must be registered to the WGS 84 coordinate datum in their national AIP (Aeronautical Information Publication) by 1 January 1998. In Europe, Eurocontrol was tasked with the implementation of WGS 84 for civil air navigation in the ECAC states. As part of the *WGS 84 Implementation Programme*, Eurocontrol commissioned a series of studies to address the technical issues involved in referencing national AIPs coordinate information onto the WGS 84 datum. Since 1989, the IESSG at the University of Nottingham has been instrumental in many of these activities [IESSG, 1992, 1993, 1995]. Building on our successful collaboration with Eurocontrol in civil air navigation, this new project is carrying out identical activities for the marine navigation community. This includes a pilot survey of a typical European port, the coordination of en-route (coastal) aids to navigation and the assessment of GNSS integrity for marine navigation. These tasks form part of the initial phase of our project and are detailed in the remainder of this paper.

4. PILOT SURVEY OF A TYPICAL EUROPEAN PORT. In anticipation of the future need to register port navigation facilities on to the WGS 84 datum, the IESSG has recently carried out a pilot survey of the Port of London. The survey has been used to assess the accuracy of the existing coordinate information, to identify potential problems and to estimate the effort required in 're-surveying' or 'transforming' a typical European port onto the WGS 84 datum. The first phase of the pilot survey focused on the re-surveying of the Port of London's nine VTS radar sites.

During the pilot survey exercise, the radar facility was switched off to ensure minimal interference with the GPS signals. At each radar site, one hour of GPS carrier phase observations was collected at a 30-second epoch interval. Each radar site was subsequently positioned independently, relative to two Continuously Operating GPS Receivers (part of the British National GPS Facility). This procedure resulted in two independent position solutions for each radar site. The difference between the two independent solutions (repeatability) gave an indication of the quality of the newly surveyed coordinates. The 3D-vector differences (repeatabilities) between the two position solutions are given in Figure 1. They demonstrate good agreement

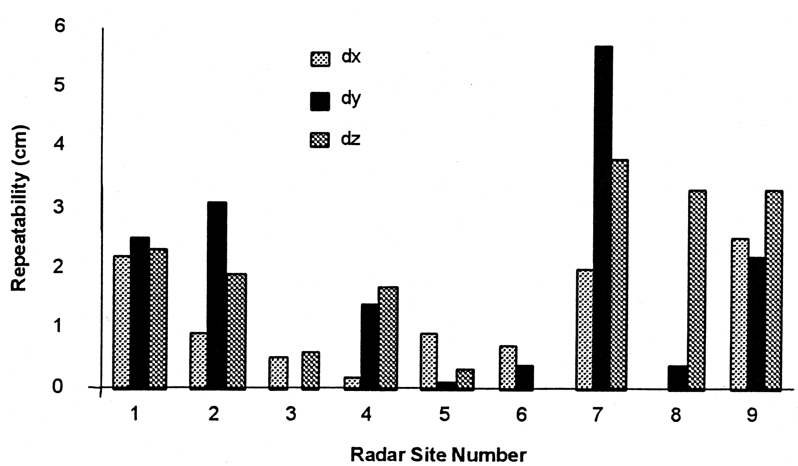

Figure 1. WGS 84 Coordinate Repeatabilities for the VTS Radar Sites.

between the two GPS position solutions at each facility. From the results presented in Figure 1, the accuracy of the new WGS 84 coordinates for the nine radar sites is estimated at better than 10 cm.

Having surveyed the nine radar sites onto the WGS 84 datum in a controlled procedure, the next task was to assess the quality of the existing published coordinate information for the same radar sites. In this experiment, the new WGS 84 coordinates for the sites were transformed to the UK national mapping datum (OSGB36) using publicly available transformation parameters. The parameters have a quoted accuracy of 2 metres [OSGB, 1995]. The transformed coordinates were then compared to the published coordinates for each site, in order to assess the quality of the existing information. The existing published coordinate information was supplied at a resolution of 0·01 minutes, equivalent to a resolution of 12 metres in Easting and 18 metres in Northing. The results of the coordinate comparison are given in Figure 2.

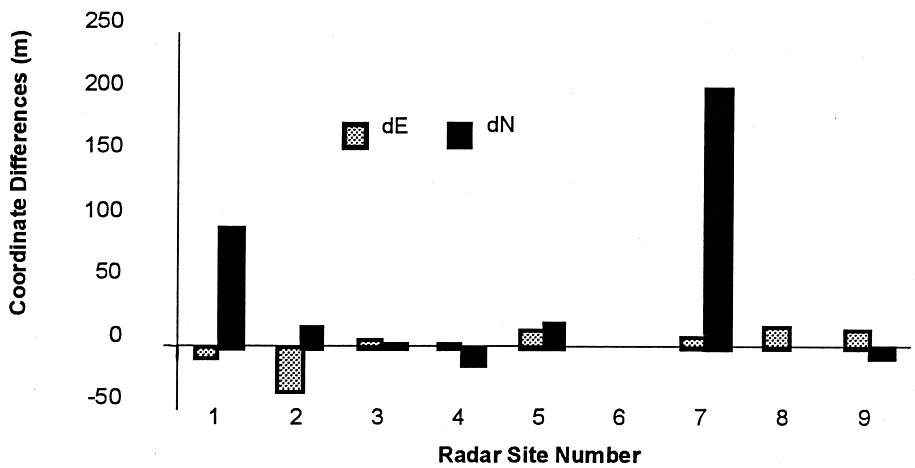

Figure 2. Comparison of 'Transformed' WGS 84 Coordinates and the Published Values.

It is clear from the results presented in Figure 2 that the published coordinates for the majority of the radar sites are in agreement with the new coordinates. However, there are sizeable differences for two radar sites (as indicated). The source of these errors has not been established. Furthermore, the errors have never previously been identified. This is because the primary function of the VTS radar is one of surveillance and not navigation. Radar, although poor in terms of absolute positioning (~ 100 metres accuracy), provides a precise relative picture of vessels and obstructions which is suitable for VTS surveillance operations. For surveillance and collision avoidance applications, precise relative positioning of vessels is more important than their absolute positions. Looking to the future and the introduction of Automatic Identification Systems (and DGNSS transponders), the integration of radar-derived and GNSS-derived coordinates by VTS centres will be a complex task unless sites and other traditional aids to navigation (including lights, buoys, charts) are also referenced to WGS 84.

The next phase of this work will include estimating the size and cost of the task in implementing WGS 84 within UK and European ports. As a guideline to the magnitude of the problem, there were around 60 major airports in the United

Kingdom which had to be registered onto WGS 84. In the marine community, there are 96 major ports in the UK. At each airport, around 50 facilities, obstructions and features had to be referenced to WGS 84. The Port of London alone has around 1000 aids to navigation that will need to be coordinated onto WGS 84 (to varying degrees of accuracy). The implementation of WGS 84 for marine navigation is expected to be a much greater task than that experienced by its aviation counterpart. After all, there is no equivalent of the ICAO mandate, no equivalent of Eurocontrol, and why should Port Authorities invest in re-surveying their navigation facilities when they have experienced no difficulties with their current VTS?

5. COORDINATION OF AIDS TO NAVIGATION. To complement newly coordinated port facilities, there is also a future requirement in UK marine navigation to reference all coastal (en-route) aids to navigation to the WGS 84 coordinate datum. However, unlike the radionavigation aids used in aviation, most of the aids to navigation used in marine navigation are visual references (e.g. buoys and lights). This complicates the task of coordination, since visual aids can only be observed remotely by optical methods (e.g. photogrammetry) or by a field visit. Since the UK General Lighthouse Authorities are responsible for the operation and maintenance of around 1200 aids, any technique involving field visits would prove costly. The majority of the 1200 aids are buoys (743) and lighthouses (343), of which 313 are unmanned! Furthermore, the accuracy requirement for UK GLA Aids to Navigation is based on the suggestion of the IMO level for restricted waters of 10 metres, and there may be cases where this is inadequate, and 1 metre could be required.

As a preparatory experiment, a field visit was carried out to assess the quality of the published coordinates of three aids to navigation (buoys) in the Thames estuary. It proved to be a simple demonstration to highlight the nature of the problem of coordinating aids to navigation. The survey craft, equipped with DGPS, traversed a track alongside the three buoys. At each buoy, the craft moved alongside and paused to collect a set of DGPS position fixes, from which it was possible to estimate the position of the buoy. The DGPS derived positions of the buoys were compared with the published (chart) coordinates. The coordinate discrepancies are given in Table 1, in terms of difference in Easting (dE) and Northing (dN).

Table 1. Differences between Surveyed and Published Values for Aids to Navigation.

Aid to Navigation	dE (m)	dN (m)
Buoy 1	2	69
Buoy 2	4	55
Buoy 3	4	37

The results presented in Table 1 demonstrate a definite relationship between the location of the buoy and the error in its published position. Buoy 1 has the greatest error and is situated the farthest up river, while Buoy 3 is located nearest the coast and has the smallest error. The coordinate differences may be related to the length of mooring on the buoy and to the strength of flow of the channel. This hypothesis may explain why the Easting differences are so small, due to the fact that at the survey location, the River Thames runs predominantly in a North–South direction, with little East–West flow.

These initial results have highlighted some of the issues concerning the precise location of Aids to Navigation that will require further investigation during the later phases of the project. It is also proposed to conduct similar field visits for more remote locations, using a helicopter.

6. ASSESSING THE INTEGRITY OF GNSS FOR MARINE NAVIGATION. In addition to investigating the coordinate infrastructure issues, the project is also examining the technical and operational performance of GNSS for marine navigation in UK waters. One of the most important performance requirements for the use of GNSS in UK marine navigation is the need to monitor the GNSS system and the position fix, and subsequently to inform the mariner when the accuracy of the fix does not meet his requirements. This is the so-called integrity problem. Integrity is defined by the IMO as '…*the ability to provide users with warnings within a specified time when the system should not be used for navigation*' [IMO, 1997]. A system is said to have 'integrity' if the system can provide timely warnings when the system is not safe to use.

The requirements of integrity differ for different applications and for different phases of navigation. The UK GLAs have yet to propose the integrity parameters for UK marine navigation, although they do appreciate the requirement for integrity during all phases of navigation [GLA, 1997]. To meet the users' requirements, there must be a method to detect and potentially isolate any GNSS measurements that will cause errors in the computed position fix. It is the purpose of this task to investigate, propose and assess different integrity parameters for the different phases of a voyage. This task will examine the use of different GNSS constellations/configurations to satisfy the need for RAIM (Receiver Autonomous Integrity Monitoring) in marine applications.

Work in this area has begun by using the integrity parameters from the aviation counterpart, namely the Non-Precision Approach phase of flight. These parameters have been modified to suit the Coastal phase of voyage. Initial tests have examined the use of GPS and GPS/EGNOS augmentation to perform RAIM.

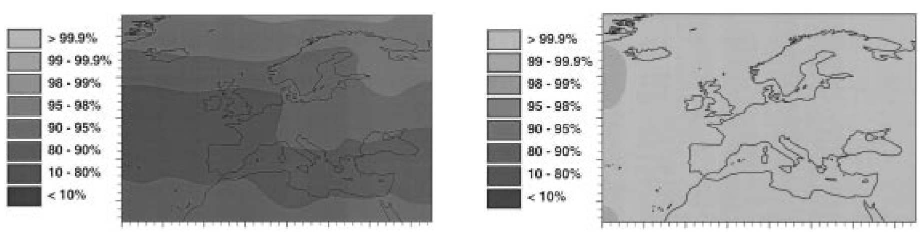

Figure 3. GPS RAIM and GPS/EGNOS RAIM for Coastal Phase of Navigation.

Figure 3 illustrates the preliminary results of RAIM availability over 24 hours, for GPS and GPS/EGNOS in the coastal phase of navigation. It can be seen that, although GPS alone can provide RAIM some of the time, the addition of the EGNOS overlay substantially increases the availability to greater than 99%. Similar experiments will be carried out for harbour approach and entry.

7. CONCLUSIONS AND FURTHER WORK. The main technical challenge facing the UK marine community in the implementation of GNSS is to ensure that all aids to navigation (visual, electronic, floating, ship-based and shore-based)

can be used in combination with GNSS to a high level of accuracy and integrity in order to satisfy the users' requirements. This includes two distinct stages:

Implementation of WGS 84 – First, it is necessary to provide a consistent coordinate information infrastructure to support the eventual introduction of GNSS. This does not relate to the provision of a new physical infrastructure. Rather, it concerns the provision of all coordinate information on a single coordinate system that is compatible with GNSS-derived information. The project has already uncovered some of the problems that will be encountered by the marine community in the implementation of WGS 84. Further tasks will address the requirements of the UK Hydrographic Office and the problems associated with transforming navigation charts onto the WGS 84 datum.

Implementation of GNSS – Secondly, it will be necessary to integrate the different 'mix' of Aids to Navigation to meet the requirements of the UK marine community. These requirements include not only technical and operational requirements but also political and institutional. The project has begun to assess some of the technical performance requirements of GNSS, most notably in terms of system accuracy and integrity. The algorithms and software tools, developed during our previous work with Eurocontrol, have been modified to cater for the requirements of the waterborne user. Preliminary assessments have been carried out to evaluate the use of different GNSS constellations for different phases of a voyage. Due to the lack of statistical information, the preliminary tests have been based on parameters 'adapted' from civil aviation. Future tests will focus on deriving new integrity parameters to meet the specific needs of the mariner.

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KEY WORDS

1. GNSS. 2. Marine. 3. Aids to Navigation.