INNOVATION in MARITIME NAVIGATION

By S E Gaskin FRIN FNI
Secretary General,
International Association of Institutes of Navigation

A conference at Trinity House, London hosted by the General Lighthouse
Authorities of the UK and Ireland, the Royal Institute of
Navigation and the Knowledge Transfer Network.

The conference was opened by welcome addresses from Captain Ian McNaught,
Chief Executive, GLAs and Deputy Master of Trinity House, Captain Peter Chapman-
Andrews, Director of RIN and Mr. Bob Cockshott on behalf of the KTN.

Before introducing the programmed sessions Rear-Admiral Nick Lambert invited the
delegates to hold 3 thoughts:

- That the day was not intended to be a ‘give GNSS a kicking’ event. Rather, it
  should aim to address how new technology might be used to make GNSS even
  better and more reliable.
- Given that the maritime environment is uniquely difficult and one where
  ‘backing up’ systems has been, and should be, a sine qua non, the marine user
  community is well placed to be a ‘bellwether’ for the management of wider
  societal need for the provision of resilient systems.
- At least part of the issue is the difference in outlook between the new
  generation of ‘digital natives’ and the present generation of practitioners and
  those involved in preparing requirements and standards, who might be termed
  the ‘transitional generation’.

The Mariner’s Perspective

The first speaker was Captain Robert McCabe, President of the Nautical Institute,
who offered a mariner’s perspective on the impact of modern systems on the conduct
of ships. He described the mariner’s requirement as being: a ‘cocked hat’; as small
as possible, always available and reliable – simple straightforward and uncomplicated.
He expressed a concern that ‘machine centred automation dulls situational
awareness’. In considering GNSS, invariably the primary PNT source for most ship’s
bridges today, Capt. McCabe remarked that the apparent requirement for ever greater
accuracy was driven, at least in part, by the fact that GNSS is capable of delivering it.
He went to suggest that there WILL be occasions when the user will lose the use of it
and that they should learn to recognise that loss. The management of that loss will
be achieved by the adoption of good procedures for utilising reversionary systems
together with innovation in developing solutions to ensure the resilience of the
navigation system. Those solutions might include some, or all, of these: S-Mode,
Astro (NavPac4), RACONS, ePelorus, and eLORAN (or an equivalent terrestrial
system). Furthermore, the loss of the ability to determine position might best be
mitigated by the use of multiple systems. He closed by remarking that whatever solutions are adopted Communications will be pivotal in their implementation.

**Future Navigation Technologies**

This session was presented by Nick Cutmore (Secretary General of the International Maritime Pilots’ Association). He argued that the Pilot’s armoury has always been, and will continue to be, the utilisation of a spectrum of technologies such as: AtoNs, varied displays, PNT resilience, Portable Pilotage Units (PPUs) and ‘own port terrestrial positioning systems. He also expressed Pilots’ general concern about divergence in the quality of global ENC coverage and an over-reliance on GNSS. He went on to give a number of examples of how the ship handling challenge has evolved in recent years particularly as, in many cases, ships are outgrowing the ports available to them whilst their crews, bridge visibility and ‘acceptable’ under keel clearances are reducing, necessitating expanding use of Dynamic Escort Towage and Dynamic Under Keel Clearances! These are having the effect of increasing the load on ships crews and (in some cases) increasing the contribution required of the Pilot. In summation he opined that development should be driven by the needs of people and ships.

**Trustworthiness of PNT and Chart information**

Capt. Roger Barker (Director of Navigational Requirements, Trinity House) used the third session to reveal a selection of examples of charting/ECDIS weaknesses, all of which represented the very real possibility of marine disaster to the unwary mariner, compounded in instances where lazy mariners made use of ‘second hand’ ‘routes’ or routes prepared for other vessels and often before recent changes to OEIs, separation schemes, buoyage, etc. In other words some mariners were clearly not keeping up to date with either physical changes in an area or changes to charts. He listed particular concerns as being: failures in the distribution of new information amongst ships’ officers, the ad hoc transfer of routes between ships of different types as individuals took results of their planning efforts with them on changing vessel (the curse of the USB), the lack of use of the source diagram because it is often not visible in an ECDIS presentation and the vulnerability of electronics in general. He finished by asking rhetorically how do we use technology to mitigate these risks?

Might there be a benefit in seeking to share the insight and experience of other sectors (such as the auto industry and aviation) in addressing these challenges?

**Is GNSS/Inertial Integration the Answer?**

Prof. Terry Moore (University of Nottingham) began by giving an overview of the range of primary GNSS now operational (Global: GPS, GLONASS, Galileo, BeiDou and Regional: QZSS, IRNSS) together with the main Space Based Augmentation Systems (EGNOS, WAAS, MSAS, GAGAN, SDCM) adding a note of caution regarding the validity of the solutions provided by the latter at the extremes of their coverage. He then summarised the development of GNSS before switching attention to Inertial navigation systems. We were reminded that, simplistically, all Inertial
Systems are based on a set of 3 gyros, 3 accelerometers and 3 axes contained within an Inertial Measurement Unit (IMU) and that, effectively, performance is related to the amount of money invested in a given system. He presented some examples of INS ranging from a RLG costing about £100K with a drift rate of 100 metres after 10 mins. to a MEMS costing < £1 with a drift rate of 100 metres after < 60 s. In conclusion Prof. Moore suggested that there is a synergy between GNSS and Inertial Navigation and that, especially in light of some recent significant outages of GNSS, there is a new paradigm being applied to the development of future positioning solutions whereby INS are the focus and GNSS becomes the principle method of ‘bounding the error growth’ in an INS. Integration certainly is AN answer.

Diversity in Integrated Navigation

Dr. Paul Groves (University College London) opened his presentation with two assertions: firstly that the user needs a better receiver standard than that defined in MSC.401 (95) and, second, that whilst most GNSS problems can be mitigated by utilising the multiple constellations now available, the challenges of jamming and multi-frequency can only be solved by other techniques. He continued by briefly describing a variety of the other techniques and the magnitude of their associated errors, most of which were significant. Dr. Groves went on to introduce the positioning methods that currently represent possible alternatives to GNSS and their weaknesses:

- Low Frequency Ranging (LORAN) – requires international co-operation, private funding is high risk and Government cannot lawfully mandate the use of a commercially delivered system.
- Communications satellites – poor reception in the polar regions and poor geometry at the equator, though LEO satellites might be more useful and Government cannot lawfully mandate the use of a commercially delivered system.
- 300 kHz Beacon RDF – poor geometry of a network will limit accuracy.
- AM Radio Broadcast – requires a reference station and datalinks and the current infrastructure is being dismantled in Europe.
- VHF/UHF – a network requires at least 3 transmitters and a synchronisation signal (such as from TV DAB).
- Radar – requires a robust method for identifying radar targets and azimuth resolution is not particularly good.
- Bathymetry – only really viable utilising multi-beam sonars and not really effective in deep water.

He proposed that the best positional solution would be achieved from the Integration of two or more techniques because:
Availability – of any one system can never be guaranteed to be 100%.

Reliability – the more information available the easier it is to detect a fault in any one system.

Accuracy – some system accuracies are better over a long term and some over a short.

In conclusion Dr. Groves suggested that the IDEAL solution to determining position would be an ‘engine’ which would: integrate DR, GNSS and one or more other systems through a Universal Integration Filter, continuously compare the systems in order to exclude error and update the calibration of each and continuously display the accuracy and integrity of the solution presented. But, he observed that such a solution was complex necessarily involving multiple organisations, proprietary ownership and presenting a challenge to the addition of new technology. His recommendation was to adopt ‘state of the art’ GNSS receivers together with receivers for a wide range of terrestrial signals and to utilise DR.

**Opportunistic radio positioning**

Dr. Ramsey Faragher (Focal Point Positioning) introduced the concept of making use of radio signals that are not intended to be used for positioning. He introduced the various methods (with remarks) that can be employed:

- Comparison of time of arrival of signals at different antennae – most common.
- Examination of the carrier wave phase – ambiguities to resolve.
- Comparison of the angle of arrival of signals at different antennae – very rare.
- Measuring signal strength – not viable outdoors.
- ‘Fingerprinting’ – limited to short ranges.

He continued by noting the principle error sources which include: clock stability, geometry, bandwidth limitations, frequency instability, signal identification, and multi-path interference. Dr. Faragher then summarised the potential signals of opportunity that might be utilised (ideally using Software defined radio receiver) and noted some key issues related to them:

- Augmented eLORAN – infrastructure being dismantled in some areas.
- MW Radio – close to LORAN frequency but also being switched off.
- LW Radio – timing related to atomic clocks but also being switched off.
- DAB – moderate range but locked to GNSS.
DVB-T – long range and independent(ish) of GNSS.

Cellular mobile communications – very short range and dynamic cell identity an issue.

ADS-B/AIS – only about 100 m accuracy but good for collision avoidance.

In conclusion he proposed: that the future might be the use of Software Defined Radio to utilise signals of opportunity (SOps) to ‘bridge’ GNSS outages offshore, employ DVB-T signals to provide ‘littoral pilots’ delivering high accuracy close inshore and that positioning systems should become cynical of GNSS over time.

R-Mode and Radar Positioning

Dr. Paul Williams (GLAs) opened his presentation by observing that in the US, China, Republic of Korea, Russia and (probably) Saudi Arabia eLORAN or its equivalents continue to be supported, but not in Europe – so what can we use instead? He went on to introduce the concepts of R-Mode and Radar Absolute Positioning. R-Mode can utilise the IALA MF DGPS Radio Beacons (at 300 kHz) and AIS VHF (160 MHz) (limited to LoS) in order to provide a Position, Timing, Navigation and Data service. Radar Absolute Positioning makes use of either active transponders or radar return feature/map matching to determine position to varying degrees of accuracy (diurnally dependent) but cannot provide Navigation, Timing and Data services. Dr. Williams then gave a brief overview of the current status of Radar Absolute positioning noting specifically that an IALA eNav concept is at the very early stages of a development ‘roadmap’ and that current equipment is generally not capable of supporting the technique despite the fact that a prototype system (RADARFIX) that delivered 2 m accuracy was trialled by the Canadians as long ago as 1988! In summing up he observed that it might take 20 years to work through international consensus, preparation of the necessary agreements and performance standards (including mandation) and the modification (or replacement) of the current generation of ship borne radars. His final remark was that even though the technique had good potential as a positioning and navigation system it cannot deliver Time.

Training of end-users in GNSS reliability

Mr. Mark Broster (ECDIS Ltd.) gave a presentation informed by the breadth of his company’s interaction with both manufacturers and users and enhanced by quite a lot of video. In it he demonstrated two of the challenges faced at sea – the multiplicity of ECDIS systems (38 brands) and radars (7 principal brands) and their vulnerability to deliberate (or inadvertent) cyber attack. The variety of systems available highlighted the challenge to seafarers of knowing how to fully utilise the equipment provided, noting that upon examination, in fact all the available ECDIS systems have the capability to operate without a GNSS positioning source and to execute DR navigation. He related his concern that a culture of total dependence upon GNSS delivered positioning appears to be taking hold, so much so that on a recent ship visit he proposed to the Master that they experiment by switching off the GNSS input to the ECDIS and that after a very short period the Master was desperate to restore it notwithstanding the fact that his equipment continued to function and generated and
displayed a position. Thereafter, Mark described the early findings of a trial his company is undertaking to identify the scope of the vulnerability issue that consisted of a litany of potentially catastrophic impacts on safe navigation!

Local positioning systems in support of Dynamic Positioning platforms

Mr. Dave Sanderson (Guidance Marine) introduced some of the positioning systems developed by his company primarily for use by vessels employing Dynamic Positioning and therefore short range. The systems make use of radar or laser principles that have suffered from the necessity to deploy reflectors onto the ‘target’ platform before they can be used. However, the company is now developing a short-range (approx. 300 m) system ‘SecureScan’ that makes use of a technique named Simultaneous Location and Mapping (SLAM). Able to operate without a pre-deployed ‘target’, it can be utilised immediately without the risks attending the deployment of a target to another vessel and will be particularly efficacious for automated piloting and ship-to-ship transfers.

MoD and Quantum Technology

Mr. Andrew Middleton gave an informative overview of the positioning challenges faced by the Ministry of Defence and its investigation into the potential of quantum technology to solve some of those challenges. He began by identifying that since knowing one’s position is a key part of being effective militarily and that positioning systems are, therefore, likely to be targets in any future conflict. So the ‘exam question’ is ‘what if there is a denial of service?’ The supplementary question might be ‘is quantum technology a route to positioning system resilience?’ perhaps by enabling a precision Inertial Navigation capability. He observed that at present an IN that could achieve an error of less than 1 km/day might be described as good but defence would prefer has a drift rate in the order of 1 m/month! However, the type of sensor that could deliver such accuracy is likely to be large, very expensive and will still be subject to the errors resulting from the fact that Earth is a non-homogenous, non-spherical body with infinitely variable local gravity effects which will require high resolution Gravity Maps and a sensitive differential gravimeter in order to be able to correct for drift in a quantum INS. Mr. Middleton went on to remark that the other key piece of data required is a time reference and that the MoD is also in the early stages of examining the performance of three different clock solutions: Fibre Quantum clocks, Ytterbium clocks and Strontium clocks. He concluded by indicating that the focus of MoD’s long-term research is on navigation and timing and expressed the expectation that that Fibre clocks might be a reality in the next two years while examination of quantum techniques might unblock progress in the development of inertial solutions.

Flexible Digital Navigation

Lt. Cdr. Adam Egeland-Jensen (RN Navigation Training Unit) began his summary of the Royal Navy’s approach to the transition from navigation on paper charts to navigation using ECDIS. He began by noting that the RN had done all its navigation
on paper until the mid 1980s by which time mechanical plotting tables had been introduced which enabled the user to update his position (derived from multiple sources) manually and would then continue to generate a ‘predicted’ position based on speed and heading inputs. They were also capable of supporting up to 40 other tracks. Nonetheless, on most bridges navigation continued to be an essentially manual activity. He went on to explain that in the first decade of the 21st Century the advent of ECDIS radically changed the way surface warships conducted their navigation and enabled the submariners to automate the complex techniques they used to manage and minimise the so-called ‘Pool of Errors’. Indeed, so much so that the technique has become an invaluable tool for the surface navigator as well. He noted that the RN had been able to specify the functionality it required of its ECDIS, which might be summarised as ‘if we can do it on paper we want to be able to do it with ECDIS’ and thus the software involved is somewhat more capable than a standard commercial solution. These developments have realised a significant improvement in Situational Awareness, allowed rationalisation of Bridge navigation procedures and layout and ensure a better quality input to the Combat System from the navigation system. Lt. Cdr. Egeland-Jensen acknowledged that in order to derive full value from these benefits a more onerous training burden is necessary and requires regular exercising of the techniques and the reversionary modes and that may not be easy to deliver in the commercial world.

Industry view of developments and opportunities

Mr. Sean McCarthy (Satellite Applications Catapult) opened his presentation by explaining that the Satellite Catapult was concerned with Intelligent Transport, the Blue Economy, Sustainable Living and the Exploration of Technology, not just positioning. He explained that the Catapult team were looking at GNSS for PNT, Communications satellites with a view to hybrid global communications (meshed systems) and Earth observation by remote sensing. He went on to observe that, in fact, of the GNSS market Location Based Services account for about 53% of usage, Road transport about 38%, Aviation and marine usage represent about 1% each and timing users just 0.1%! He continued by recognising that in the heavily regulated commercial sector change is complex and slow. However, he suggested, the Marine Leisure sector is represented by 29 M units which might provide an opportunity for quicker trialling of new innovations among the ‘early adopters’ and the super yacht market where ‘new’ is the ‘must have’. Areas which could benefit are: data fusion to improve situational awareness (Meteorological information/AIS), crowd sourcing of up to date data (Bathymetry) and augmented reality (Mobile phones, head-up displays (HUD) (for example, Sony work to a 6 month development cycle!). Mr. McCarthy concluded by suggesting that developments that might be aided in this way would have significance to autonomous vehicles and robotics, and might lead to an efficient source fusion engine which could enable a resilient multi-system receiver on board ships that would provide Position and Timing continuously and seamlessly.
Summary

To round off the day, rather than a panel discussion Adm. Lambert invited comments from the floor by way of summarising what had been heard. The comments might be collated into the following headings:

- There is a plethora of alternative navigation systems on the market.
- Users are generally NOT demanding (so they get what the manufacturer offers?). But the introduction of the CIRM user forum may help alleviate that.
- Awareness of GNSS vulnerability is growing (slowly).
- There appears to be a need for ‘type specific training’.
- There is a need for a reliable power supply to support all these systems.
- There is a lack of cross-sector exchange of ‘lessons identified’.
- The length of time it takes to introduce new technology and standards through the IMO process actively obstructs the adoption of new technology.
- The introduction of S-Mode is a necessity.
- It is not apparent that all ship-owners appreciate the risks resulting from ever diminishing margins of safety (turning tight round seamarks, vanishing UKC, etc., operating large vessels in ports designed for smaller ships).
- In the future, as autonomy encroaches, who will the seafarers be and what skills will they require?
- Are there lessons for the Marine sector to learn from the Aviation sector especially regarding autonomy and remote piloting?
- It is likely that, in fact, the force majeure of commercial supply chains and port operators will compel the IMO to respond to evolving reality.

Conclusions

It was agreed, in conclusion, that:

1. The event had been worthwhile,

2. There should be further events but engaging with a wider stakeholder community,

3. All present should ‘spread the word’.