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Possibilities of more accurate navigation with the utilization of new solutions in radar technology

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Abstract

Many radio-navigation systems dating from the seventies and eighties of the last century were replaced by a single Global Positioning System (GPS) a dozen or so years ago. However, for several years the opinion that the GPS monopoly is becoming dangerous has been expressed increasingly often in navigational literature. Even when supplemented with other systems from this group, such as Global Navigational Satellite Systems (GNSS), it cannot be treated as the source of reliable and universally accessible navigational information. This results from the similar sensibility of all GNSS systems to the same disturbances as a consequence of using a similar band of radiofrequencies and a similarly low powered signal. There is a growing recognition in the maritime world that GNSS will not provide the resilience required because of these common vulnerabilities.

The World Wide Radio Navigation System should be seen as a combination of systems, which can cooperate and work effectively even when GNSS does not work. Lately different authors commonly point-out the potential advantages of a modified Loran (e-Loran), however it still remains only a potential option – particularly in the southern hemisphere, where this system has never existed. Meanwhile as the general threat of the disturbance of GNSS systems increases, the matter of initiating alternative possibilities becomes more urgent. A proposal which combines lower financial outlays with adjustments to the existing techniques and the law in force is desirable. In this context radar seems to be the attractive option, however for utilization as an alternative to GNSS it should reach considerably higher technical performances.

In the paper the general limitations in the use of existing radar as a means of ships' positioning are presented, and information published about the investigation into the methods for overcoming these limitations is discussed. The accessible information appears to prove that a greater accuracy of position can be achieved with modified radar in the future, especially if the suitable navigational infrastructure is present on shore. However, the level of accuracy of this method does not seem to compare favorably with GNSS.

Introduction

Nobody is in any doubt that accurate navigation is one of the requirements for safety at sea. At present this field is dominated by Global Navigational Satellite System (GNSS) technology, which is in use all over the world in different variants by a wide spectrum of users at sea, on the ground, in the air and in space. Although nowadays satellite navigation systems are the primary method of navigation, all GNSS is vulnerable to interference, both intentional and accidental, because of its extremely low signal strengths and use of the same band of radiofrequency. For this reason, reliance on a single source of positioning with considerable risk of disturbances is not acceptable. Therefore the provision of a backup Positioning, Navigation and Timing (PNT) service is essential (IMO, 2008). At present modernized Loran is suggested as a back-up positioning system, however the question of accuracy is still discussed, and in some opinions, radar can play a similar role. This is because equipment that already exists can be utilized and potential users are already familiar with this technique. As an example the General Lighthouse Authorities' (GLA) Radio Navigation Plan (GLA, 2007) points out four directions for technical development strategy:

- The introduction of Galileo and modernized GPS service;
- The deployment of Automatic Identification System (AIS) as an aid to navigation (AtoN);
- New technology radar that may not trigger existing racons (radar beacons);
- The prospect of the European-wide provision of eLoran.

According to this source, the new radio navigation service, will, among other things, be characterized by new technology S-band racons. However, radar used at present does not assure comparable accuracy with GPS. The standard navigation radar accuracy is 1% of range and is determined by the accuracy of echo shape but mainly by rather low bearing accuracy, depending on the antenna beam shape and accuracy of the ship's heading. Accuracy is highly dependent on the distance to the land and, in fact, we should assume it greater than 1 degree. At the moment, accuracy of distance determination by radar is better, which is around 30 m or less, but this is still worse than satellite technology (Bole, Wall & Norris, 2014). So there are a number of problems that would need to be resolved. These problems are less essential when we use radar for collision avoidance. When radar is used for positioning tasks, discussion about radar accuracy is insufficient, as the biggest part of position accuracy is determined by the accuracy of information about land objects' position, the accuracy of determining this provides radar energy reflection and possibilities for recognizing the object on the radar screen. Part of this problem lies with the properties of the screen and the quality of the radar picture. It would also be desirable to provide the system with computational possibilities, so the user can get positioning information on latitude and longitude in digital form, as with a GPS receiver.

Nowadays radar picture interpretation needs specific knowledge and significant experience of a well-trained operator, but even then the recognition of the object on shore is sometimes impossible. Indeed in many places racons (radar beacons) are established, so the identification of land objects and determination of bearing and distance is possible, however the accuracy of position still remains some ten times worse then GPS. It is interesting that for many years methods for comparing radar pictures with digital terrain models have been discussed as an alternative positioning option, but this remains at the experimental stage (Wąż, 2010).

One reason for this situation is the way in which radar works. The rule of the measurement of time between sending and receiving the returned impulse cannot be recognized as modern. It should be noted that similar rules of measurement are utilized in satellite systems, which achieve accuracies many times higher. The secret remains in the modulation of the transmitted signal with the code, and the correlation of the received signal with the source. A condition of the composition of such a system lies with the precision of racon clocks, as well as ships' radar. It is nowadays possible because we have at our disposal perfect time measurement via GPS. In addition we can confirm the time-scale to a sufficient degree by also using AIS.

New concept of radar positioning

Ideas for new rules of using radar for positioning depend on the possibility of measuring the exact distance from the enhanced radar to the enhanced racon and calculating the position with the use of information about the racon position (GLA, 2012). Both need some manipulation of the radar signal, which is accessible now with modern electronics. Radiofrequency applied in radar technology (3–10 GHz) is not so different from GPS (1.5 GHz). If we can modulate this signal in a similar manner to GPS technology we can measure distances with accuracy to within some meters. In satellite technology Phase Shifting is currently preferred, in radar bands Frequency Modulation is currently preferred, however other concepts are also discussed (Bole, Wall & Norris, 2014).

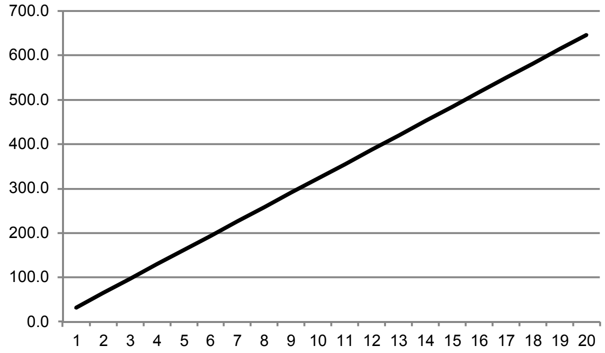

Figure 1. Error of azimuthal Line of Position (in meters) as function of distance (in miles) (when error of azimuth – 1 deg.)

It is important that, in this case, the accuracy of the measured distances do not depend on racon-radar distance or radar range, as it is with the present impulse radar. So if we can reach accuracy of two distance measurements to within a few meters, a similar accuracy of positioning will be retained. But when measurements of only distance and bearing to one point are used, the error ellipse will be determined by heading error and antenna beam-form (Urbański, Kopacz & Posiła, 1976), so the error will be bigger than 30 meters, but for a distance greater than some miles this method gives us error of position of at least a dozen meters (Figure 1).

Such an infrastructure demands the use of the measurement of two distances, as the influence of measurements of direction (bearing) on error of position depends on distance (Figure 2).

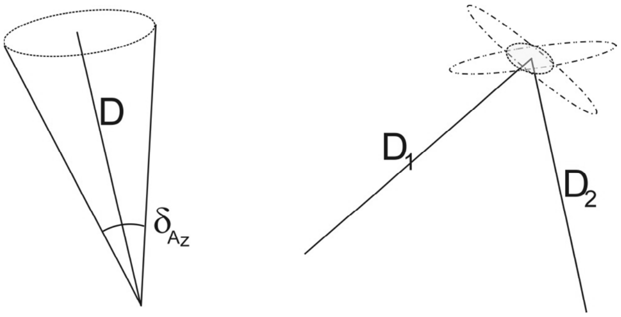

Figure 2. Differences between accuracy of position determined from azimuth-distance method and two distances (*D* – distance, δ_{Az} – azimuth's error)

The question of the size of zones of the activity of such service (coverage of the system) is therefore raised. Coverage of one racon has a circle shape and its size depends on the ratio of sea/land in this area. The common area of the two circles is only a small part of them (Figure 3). So this is not an effective solution, but in some configurations it can be more useful, especially in estuaries, harbor approaches, etc.

When two eRacons are available and the positioning accuracy does not depend on the distances from the eRacons, then it can be comparable to pure GPS (without augmentation). It is clear this is not a solution for open sea navigation, but in restricted waters and particularly sensitive areas like approaches to harbors this can be play the role of back-up system.

Equipment specifications

Proposed solutions need additional elements in radar and in racon circuits for the modulation of the racon signal and its demodulation on the radar side. As an example, FSK modulation is presented (Figure 4), but this solution must be verified. It is important that the signal transmitted by the racon should deliver information to the user about the position of the racon, the time stamp and an identification signal. On the radar (user) side this signal should be demodulated and decoded and then the position of the user can be calculated.

An experiment similar to these foundations was conducted by GLA and Furuno in the North Sea east of England, near Lowestoft and Southwold lighthouses with the prototype of X band Solid State Shipborne radar in 2014 (Ward et al., 2014). These lighthouses are situated about 10 NM apart on a relatively low-lying coastline and trials were carried out at distances up to 10 NM off the coast. The experimental radar was installed onboard Trinity House Vessel "Alert". Configuration of

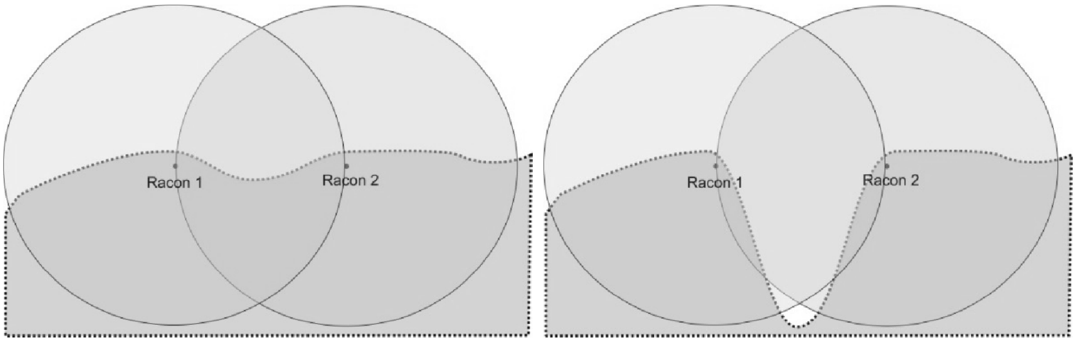

Figure 3. Coverage of two distance positioning systems

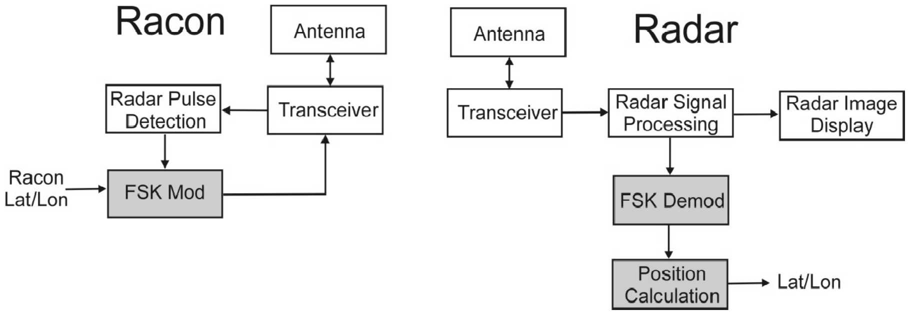

Figure 4. Possible system configuration, shaded back-ground indicates additional components

experimental equipment consisted of radar scanner and frequency down-convertor. The intermediate frequency signals were fed down to a digitizer for further processing on board and recorded for investigation later. The data processing associated with the radar used distances from the racons to calculate position, combined with the latitude and longitude encoded using FSK modulation on the dash of the Morse D character of the racons.

The locations of the racons and the ship's radar were not optimal, as there was some degree of masking and risk of reflections from the structure of the lanterns. This would have influence on the results, however some general conclusions about the new positioning system can be deduced. During the trials the consequences of the sub-optimal installations were evident, but a usable range of 10 NM is probably to be expected. The maximum ranges at which the racons could be seen was about 20 NM in spite of the low height above sea level of the racon transmitters. Position accuracies also varied considerably, mainly depending on the geometry of the system, but a position combined from two distances has an accuracy of about 5–10 m. It is important that the racon positions were surveyed using a GNSS receiver to an accuracy of better than 1 m and that these positions were transmitted in encoded form by FSK modulation on the leading dash of the Morse 'D' character. When only one racon could be received, accuracy was from 50–100 m.

Conclusions

There is a growing recognition in the maritime industry that GPS alone cannot provide robust positioning and multiple GNSS will not provide the resilience required, because of the common vulnerabilities. So we need one or more alternatives to GNSS, which could be terrestrial radionavigation systems such as eLoran, but there is no sense in finding different alternatives, for example short range backup using radar, or even a non-radio (optical) option (Naus & Wąż, 2014). This is important in the absence of certainties regarding eLoran accuracy and the need of the precise dock / harbor / approaches system. This is according to IMO and IALA positions (IALA, 2011; IMO, 2008).

Positioning by means of radar is technically feasible. Mentioned trials (Ward et al., 2014) have shown that the required performance can be achieved with radar positioning, within certain range limitations. It could be a backup option with accuracy of within about 10 m off the coast. The installation of radar AtoNs (modified racons) to provide a position-fixing infrastructure would require no regulatory changes, other than agreement on standards through ITU and IALA. Indeed the cost could be substantial, but it will be many times lower than Loran. This is an essential question in the face of the entire lack of Loran infrastructure in the southern hemisphere. On the other hand, modified radar infrastructure can play a back-up role for GNSS but only on some restricted waters, it cannot play this role on the open sea.

The presented option demands the introduction of new technological solutions, in the form of solid-state radar with a new solution in signal modulation, as well as the introduction of a new class of racons. Additionally, if this option is chosen, then a transition plan would need to be agreed for the move from conventional (magnetron) radars to the newer (solid-state) radars, as discussed changes cannot be evolved into conventional devices. It is probable that such a transition could take many years because of the replacement cycle for onboard equipment on commercial vessels.

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