Automatic Radar Positioning
Backup to GNSS

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ABSTRACT

IMO's e-navigation strategy includes risk-control option #5 – "Improved reliability and resilience of onboard PNT systems". The main objective is to provide position, velocity, and time data (PVT) for navigators and navigational systems (ECDIS, Track Control Systems, AIS, and INS). Although Global Navigation Satellite Systems (GNSS) clearly play a significant role, there are increasing concerns about relying solely on satellite-based information. In this regard there is a need for resilient positioning in terms of reliability, accuracy, and integrity during critical phases of navigation. The provision of resilient PNT data relies on the exploitation of existing, modernized and future radio navigation systems, sensors and services, including terrestrial based sources.

This concern was again expressed in an IALA (International Association of Marine Aids to Navigation and Lighthouse Authorities) bulletin relating to ACCSEAS (Accessibility for Shipping, Efficiency Advantages and Sustainability) in the context of E-Navigation.

"Susceptibility of GNSS to interference, demands that backup systems are put in place to provide resilience for seamless positioning during GNSS outages. Under interference conditions, GNSS can provide hazardously misleading information – errors in position that may go un-noticed by the mariner but that are large enough to compromise safety of navigation and with no alarm raised. The need for independent, dissimilar backup systems is recognised by the IMO (International Maritime Organization) architectural framework for e-Navigation."

This paper describes a precise radar positioning system that was originally developed for stand-alone operation in confined waters, but has evolved to become an interface to existing shipboard radars. Advanced software continuously computes range and bearing to known objects and derives a fix from their geometry. In addition, accurate heading information is achieved that is not affected by gyrocompass lag or magnetic anomalies. Positioning accuracy of 2-5 m (95%) can be achieved with more reliability than GPS during severe weather and electro-magnetic interference conditions. As a totally independent, low-cost, robust backup to GPS/GNSS, the system requires no additional navigation equipment or infrastructure external to the vessel.

KEYWORDS: GNSS, Radar, Backup, Positioning

1. INTRODUCTION

The implementation of GPS/GNSS has had a significant impact on precise positioning for maritime navigation. Highly accurate and reliable positioning is provided at a low cost to users throughout the world. Although GPS by itself may not always deliver the required performance, the application of differential corrections through DGPS or regional SBAS (Space-Based Augmentation Systems) brings this to horizontal position accuracies of better than 2 m in major areas around the world. This is particularly important for ships navigating in harbor approaches and river/inland waterways, and during critical maneuvering and docking. It is the continuous availability of this kind of accuracy that enables the mariner to enter situations requiring a high degree of reliability.

While the use of and reliance upon GPS/GNSS has increased, so has the potential for disastrous consequences in the case of service interruption. Concerns about the vulnerability of a GPS-based transportation infrastructure have prompted a number of studies and conferences in recent years, together with recommendations for independent backup systems, including terrestrial options.

This paper briefly reviews these developments and describes a previously developed and tested -- but little known -- precise radar positioning system. With the awareness of similar developments underway in northern Europe, Russell Technologies Inc., together with the University of British Columbia and the original developers, is in the process of updating and porting this advanced pioneering technology to current hardware and software.

2. GPS/GNSS VULNERABILITY

As the majority of users rely increasingly on GPS/GNSS, the impact of an interruption of service is becoming more apparent. This fact was emphasized in a report published as early as 2001 by the John A. Volpe National Transportation Systems Center, entitled: "*Vulnerability Assessment of the Transportation Infrastructure Relying on the Global Positioning System*." [1]

The Volpe Report was written in response to a directive (Executive Order 13010, 15 July 1996) from *The President's Commission on Critical Infrastructure Protection* (PCCIP), -- a top level White House technical advisory group. US DOT and DOD were directed to undertake a thorough evaluation of the vulnerability of the national transportation infrastructure that relies on GPS, and to assess the risks resulting from the degradation or loss of the GPS signal. The findings of the study reported that unintentional or intentional GPS disruption could be reduced but not eliminated. GPS cannot serve as a sole source for position location for certain critical applications. Further, backups for positioning and precision timing are necessary for all GPS applications involving the potential for life-threatening situations or major economic or environmental impacts. The report also mentions that some of the backup options include a combination of: (1) terrestrial or space-based navigation; (2) on-board vehicle/vessel systems; and (3) operating procedures.

In addition to the concerns expressed in the Volpe Report, there have been many other warnings, meetings and reports about the issue of backup. Although GPS is a 24-hour a day system with world-wide coverage, its operational low power is easily disrupted. A presentation at the U.S. Coast Guard Navigation Center (NAVCEN) stated: "Jamming techniques are well known" and that "Many jammer models exist" and that "appropriate backup systems or procedures should be maintained."[2] It was further stated that "GPS will become an increasingly tempting target as its civil uses proliferate." Further, regarding Vulnerability Mitigation, one "must insure alternate sources of positioning information" are available. [3] **The U.S. *President's Commission on Critical Infrastructure Protection* described GPS navigation as the greatest single risk to America in the modern electronic era.** [4]

3. RADAR AS A BACKUP TO GPS

There are some who believed that there is no realistic backup for GPS other than inertial navigation or Loran-C, or a combination of the two. However, prior to GPS, there were a number of international efforts focused on coming up with a practical and economic solution for precise, highly-reliable, land-based positioning. In order to reduce the complexity and cost of these types of installations, a small company undertook development work on a system called *RadarFix.* The plan was to adapt standard marine radar to become a highly-accurate automatic positioning system by accurately determining range and bearing to shore-based targets, and determining position by solving for geometry. With the integration of a personal computer and software to standard marine radar, *RadarFix* could extract measurements from existing radar targets of different shapes in a sophisticated manner to yield accurate range and bearing information. Effectively, it can subject the geometric shape resulting from the combination of measured targets to a pattern-matching process with a previously established database. Detailed parameters about the size and shape of these targets are entered into this database, together with precise coordinates. This allows the radar to work not only with isolated point sources, but to use information from larger structures, such as faces and corners of buildings, edges of docks, and line-ends evident on jetties. Figure 1. The resulting position accuracies are 2-5 m (95%).

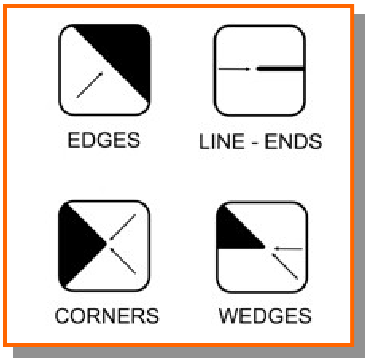


Figure 1: Complex radar targets

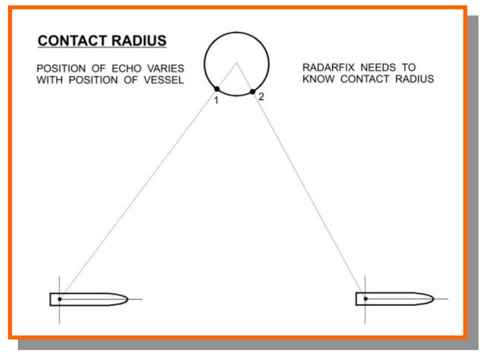


Figure 2: Relatively simple radar target

Although the system could analyze a number of radar images, it was clearly limited by the nature and complexity of the targets that the image was based on. When the radar target consisted of an isolated point source, such as a fixed light surrounded by water, it required little processing time, and measurements needed little refinement. Figure 2.

When the operating area consisted of a number of such targets, *RadarFix* quickly acquired those targets and "locked on" to provide reliable positioning information. In operating areas where targets were mostly complex, measurements took longer, resulting in a minor loss of position accuracy and reliability. In some cases, if it was a low-lying, open area, there were few targets to choose from. However, unless it was operating in open water, away from land, the system always found some targets to work with.

At the time, database creation required careful description and surveying of the radar targets to be used. Since most of the surveying was done with conventional means (e.g., using optical instrumentation), there was a practical limit in the number of targets that could be surveyed. Tests and trials would then determine which targets were most suitable for positioning with respect to background clutter and proximity to other radar targets. This was not always a simple matter when faced with limited processing power, since attempts to differentiate an intended target from adjacent background clutter can take up a significant amount of the allotted processing time.

Generally, the governing rule with *RadarFix* is that, as the number of measurements increases, the system becomes more accurate and more reliable. However, this could occasionally push the older processors to their limits. As part of the user interface, *RadarFix* continuously evaluates the reliability of its performance and displays a quality index as shown in Figure 3.

Figure 3: This RadarFix integrity monitoring display shows range/bearing residuals to three targets

4. *RADARFIX* R&D

At the same time that *RadarFix* was under development, a company in Vancouver, Canada, was also looking at the possibility of using radar for positioning, together with electronic charting systems. The main interest was in implementing radar image overlay onto an electronic chart display, as well as using the acquired radar data for positioning purposes. Recognizing that target-to-clutter discrimination was one of the major challenges, they concentrated on the development of a clutter suppression concept in conjunction with a new, inexpensive, passive reflector design.

Shaped differently than the conventional trihedral, these uniquely modified reflectors not only offer a greater radar cross-section overall, they also provide a wider response (beam width) horizontally, and a narrower response in the vertical. Figure: 4


Figure 4: Modified reflector, as used at the time with RadarFix

It was decided to combine the two technologies and team up on some future projects. The compromise of using reflectors versus existing radar targets in difficult operating areas was made mainly to save surveying time during set up. Trihedral reflectors are a known quantity and they always respond as a point source. Alternatively, existing structures may not always perform as anticipated, which necessitates the survey of a larger number of existing potential targets than that required with the use of reflectors. The necessity of having to conduct conventional optical surveys in the pre-GPS days often limited the number of existing potential targets chosen for a given area.

5. PORT AUX BASQUES INSTALLATION

Although some *RadarFix* installations already existed, the first combined operational trials were conducted on the East Coast of Canada in 1989. Requirements called for a fully automated startup/operation where a single push of a button by the user was required to operate the system. With a combination of reflectors and existing targets at the northern terminus of Port aux Basques, Newfoundland, the system was installed on the 150 m (492 ft) ferry *MV Atlantic Freighter*, operating between Newfoundland and Nova Scotia. Port aux Basques is notorious for its hazardous approach, high winds, snowstorms, and generally harsh environment.

Following successful trials aboard *MV Atlantic Freighter*, systems were installed onboard two of Canada's largest ferries, the *MV Caribou* and the *MV Joseph and Clara Smallwood.* Both of these vessels have a registered tonnage of 27,212 GRT and an overall length of 179 m (587 ft). Although *RadarFix* was employed during the entire voyage in all weather conditions, it was particularly relied upon during the harbor approach and docking (berthing) phases in periods of restricted visibility. Figure 5.

MV Joseph and Clara Smallwood

While outside of radar range, *RadarFix* was running mainly on Loran-C and other integrated sensors. Although Loran-C by itself will generally not provide an accurate position, *RadarFix* opens up its "search windows" relative to predefined targets, in order to ensure target detection. During the approach, as soon as own-ship reaches a position that is within sight of selected targets or reflectors, *RadarFix* begins "locking on". Once the system has acquired most of its selected targets and reflectors, its integrity monitoring display indicates that it is performing with a high level of accuracy.

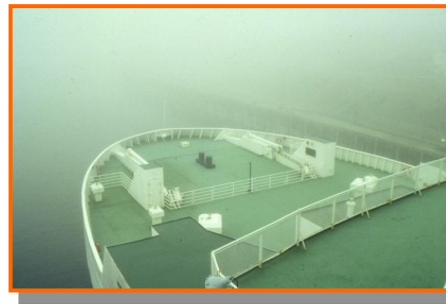


Figure 5: *MV Caribou* docking (berthing) with the use of RadarFix in heavy fog at Port aux Basques

One of the more interesting aspects of *RadarFix* is that, while locked on, it is capable of providing much more accurate heading information than that available from the ship's gyrocompass. During the approach to the Port aux Basques dock, ferries rapidly reduce speed - from 18 knots to a halt, followed by a 180 degree turn before they back into the dock. This kind of maneuver causes significant gyrocompass errors, sometimes exceeding three to four degrees. The resulting own-ship presentation on the electronic chart shows the vessel's stern, or the bow, several meters up on the dock, since the heading outline of own-ship is usually based on the input from the gyrocompass. *RadarFix* heading information is not affected by such maneuvers because it gets its orientation from the relationship to the shore-based network of targets/reflectors. Changing the heading input on the electronic charting system from the ship's gyrocompass to that of *RadarFix*, resulted in a correct orientation display of own-ship in relationship to the dock.

Another significant aspect of *RadarFix* is its ability to work in reverse. That is, it can determine or establish an accurate position for any additional new target once it is locked onto a network. For example, during the installation and after some trials at Port aux Basques, it was decided to add one more reflector at an isolated area on a hill. After the reflector installation, a surveyor was hired to determine the exact position. In order to find the reflector, he was given the coordinates determined by *RadarFix* from own-ship sitting stationary at the dock. Upon completion of the survey, it turned out that the position determined by *RadarFix* was different by only 2.4 m in latitude and 1.85 m in longitude from that of the survey. This capability makes it possible to keep adding more targets once the system is up and running, without the need for additional surveys.

6. CANADIAN COAST GUARD TRIALS

After several months of successful ferry operations in Port aux Basques, Newfoundland, the Canadian Coast Guard - Québec Region - expressed an interest in testing and evaluating *RadarFix*. Their test objectives included:

1. Evaluating the system in an operational environment
2. Comparing the accuracy of *RadarFix* and *Miniranger*[1] RPS (microwave positioning system)
3. Evaluating the system's operational and technical potential, including implementation and maintenance cost.

The Canadian Coast Guard - Québec Region, has its own surveying capability and extensive experience using precise positioning techniques. The *Miniranger* microwave positioning system had been in use for a number of years in this region in support of Coast Guard operations in confined waters. In particular, it was used onboard icebreakers (for river ice control and system management), buoy tenders, and sounding/dredging vessels. Figure 6. They also have access to external resources with extensive geodesic expertise from either private sector or university consultants.

Figure 6: Coast Guard icebreaker, Québec City

[1] Motorola

Trials were conducted in the fall of 1991, Figure 7, with a final report publication in April 1992 [5]. A key aspect of the trials was to evaluate the dynamic positioning capability of *RadarFix*. However, to do so was not a trivial process. The positioning of a moving object on an open space of water, with the use of optical survey equipment -- even at low speeds -- is challenging. For the *RadarFix* trials, two test areas were implemented along the St. Lawrence River: The first one was on "Lac St. Pierre", a 30 km long by 10 km wide stretch of shallow river, located between Montreal and Trois Rivières. The second area is close to Québec City, where it extends beyond both Québec bridges that cross the river. Overall, twenty (20) reference sites were installed with modified trihedral reflectors. To complete the precision measurements, optical survey equipment was set up at four shore-based survey stations[2]. Four survey teams established themselves at these stations on both sides of the riverbank, where they took simultaneous position fixes to a prism located on the test vessel, at regular intervals ranging from 30 to 45 seconds. Each one of these four readings was then subjected to geodetic corrections and a statistical analysis to define the value standard of these measurements. Finally, they were compared to *RadarFix* derived positions.

Figure 7: Canadian Coast Guard survey vessel

As described in the Coast Guard report (translated from French):

"In static mode, the system precision is about 1 m. The lack of data on static values does not allow a fine determination of its accuracy, but we can confirm with a sample of these results that the system precision will be kept below 5 m with 95 % confidence without any difficulty under normal operational conditions, which would be representative of the buoy tending operational requirements."

7. *RADARFIX* DEVELOPMENT

There are some major differences in the functionality and performance of previous versions of *RadarFix* compared with the possibilities of today.

Target Selection

- One of the most time-consuming and complex aspects previously was setting up a *RadarFix* network. This included surveying the reflector/target sites and providing a detailed description of potential targets. Establishing survey control was costly, which normally resulted in the use of fewer targets than necessary for optimum results.
- With today's availability of highly accurate differential GPS/GNSS, as well as accurate heading information, this is no longer the case. As an integrated input to *RadarFix*, these sensors provide a constant position and bearing reference for the acquisition of any number of targets. While target position determination used to be a one-time opportunity (i.e., all measurements were made during the setup), it is now an ongoing process. The system can continuously check, verify, update and refine target positions. It will allow the addition of new targets on an ongoing basis, as well as further refinement of target shapes and positions through many hundred radar observations from different perspectives, with the benefit of a continuous accurate position and heading reference of own-ship.

Computer Power

- Older personal computer processors could only process a limited number of targets.

[2] WILD Series 2000, Model DI-20

- Today's computers have much greater processing power and memory at little additional cost. The number of targets that *RadarFix* can now process simultaneously has increased by orders of magnitude. Increasing the number of targets improves position accuracy and reliability.

Use of Existing Targets

- Many of the original *RadarFix* installations had specially designed radar reflectors to discriminate against a background clutter.
- Experiments and trials in some operational areas revealed that by utilizing the number of existing targets, it is possible to achieve the same level of accuracy and reliability as that accomplished using built-for-purpose reflectors. The result is that special reflectors are not always necessary and that the standard marine radar, as installed on the vessel, will deliver reliable positioning performance with *RadarFix*.

8. *RADARFIX* AS A BACKUP TO GPS/GNSS

The main weakness of GPS is in the low energy of its signals. There are a number of reports of inadvertent GPS jamming, but it is relatively easy and inexpensive to build a transmitter powerful enough to overpower GPS signals and many jamming devices are now readily available on the Internet.

RadarFix can serve as a totally independent, low-cost, and robust backup to GPS/GNSS, without the need for any additional navigation equipment or infrastructure external to own-ship. There are a number of reasons.

- Radar signals are more difficult to jam. What makes *RadarFix* particularly well-suited as a backup is the wavelength it operates at – that of the ship's radar -- is more difficult to compromise than GPS/GNSS.
- Shipboard radar systems are independent from, and work in a totally different way to, that of GPS or GNSS -- or any other satellite navigation system. Any service interruption to GPS will likely not affect *RadarFix* or other shipboard radar operations.
- Since *RadarFix* works with existing radar installations on ships, all that is needed is a sensor interface between the radar and a computer, together with *RadarFix* software. Figure 8
- The shore-based infrastructure that *RadarFix* needs to perform in most operational areas (harbor and harbor approach) consists of existing radar targets. In difficult operating areas, inexpensive reflectors can always be added as an augmentation to the system.

Figure 8: Shipboard Radar Interface

- *RadarFix*, and radar operations in general, are highly localized in relationship to own-ship. The horizontal beam pattern of conventional marine radar is very narrow and of high-intensity with a continuously rotating antenna. This is in contrast to radionavigation systems like Loran-C, where shore based transmitters and towers can be damaged or destroyed, thereby affecting vessels in a wide area.
- The *RadarFix* position output is used transparently as a standard position input for most navigation displays and charting systems, such as ECDIS, Track Control Systems, AIS and INS. In case of primary sensor failure, integrated inputs are switched automatically during the backup process, along with a status alert indicator to notify the user.

9. CONCLUSION

RadarFix is essentially a computer interfaced to the existing shipboard radar, which uses software to achieve precise positioning in confined waters. *RadarFix* continuously computes range and bearing to known objects and then derives a fix from their geometry. Additionally, accurate heading information is provided that is not affected by gyrocompass lag or magnetic anomalies. Although the initial installations and sea-trials included specially-designed radar reflectors, subsequent testing showed that this was no longer required in most applications. The positioning accuracy achieved is 2-5 m (95%). *RadarFix* can serve as a totally independent, low-cost, and robust backup to GPS/GNSS, without the need for any additional navigation equipment or infrastructure external to own-ship.

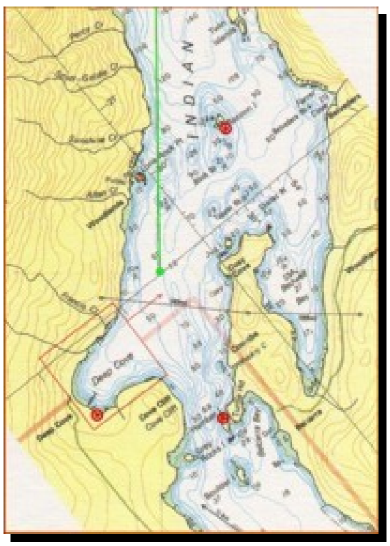
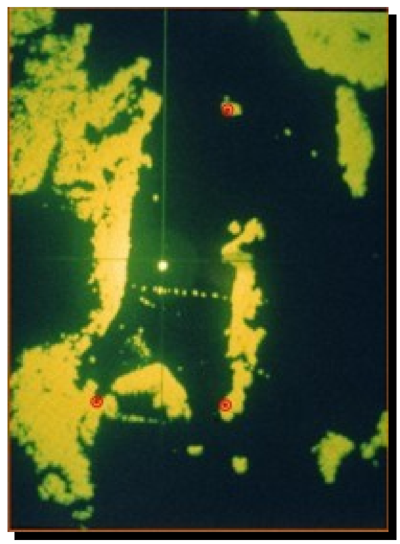
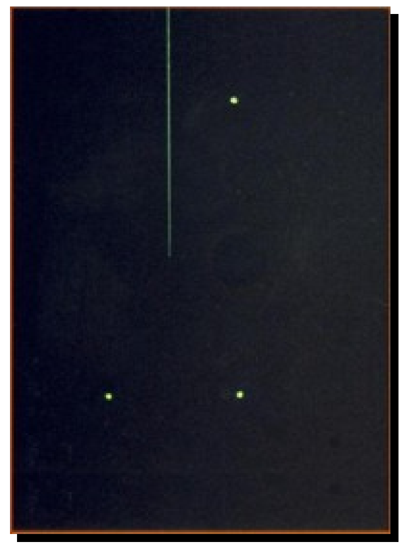


Chart of test area with red circles showing radar-target positions



Normal radar image of test area. Red circles show radar-target positions



Results after automatic processing by *RadarFix* of the test area on the left

These three images of a test area demonstrate the ability of *RadarFix* to differentiate between sought-after targets and random clutter. Most clutter emanates from the steep surrounding mountainous terrain.

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