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Position Reference for DP
A New Look from a Systems Engineering Approach

Thomas R. Stockton
*S*ystems *E*ngineering *I*nternational

Abstract

Position reference processing for Dynamic Positioning (DP) is presently carried out within the DP system with the position reference sensors interfaced to the DP controllers.

The implicit objective of position reference for DP is to be able to maintain the vessel on location by providing 100% availability of vessel position information sufficient for DP closed loop control. If this were explicitly stated, then the approach taken might be somewhat different from what is being done now, especially when an inertial navigation system (INS) is part of the position reference equation.

How did we get to where we are now, and is it time to take a new look at position reference for DP from a systems engineering perspective?

Overview

- What I'll be talking about
- Why?
- How does DP Position Reference work today
- How did we get here
- Starting Anew – A Systems Engineering Approach
- The Integrated Inertial Position Reference system
- Summary and Conclusions

Acknowledgement

I'd like to thank Keith Vickery of ZUPT for his wealth of inertial knowledge, willingness to share it with me, and being available for discussions.

I trust I've maintained technical correctness in my simplification of the technical details...

An effort to understand the trees well enough to paint a picture of the forest.

How DP Position Reference Works Today

Position reference processing for Dynamic Positioning is presently carried out within the DP control system with the position reference sensors interfaced to the DP controllers. The approach used by the various DP vendors, although by no means the same, has three main characteristics.

- For a particular vessel a mix of position reference sensors, which have different operating principles, is selected.
- Measured vessel position is determined as the “blended” combination (weighted average) of the measurements from the various on-line position reference sensors.
- A vessel mathematical model, in the form of a Kalman filter which relates vessel movement to the forces acting on the vessel, is used to remove short period wave induced motions from the measured position and provide short term “dead reckoning” of vessel position when all position reference sensors are unavailable.

How Did We Get Here (Technical)

Initially DP position reference was provided by analog acoustics, taut wire, and radio ranging. The problem was that the position measurements were noisy so that averaging (or blending – weighted averaging) of measurements from multiple sensors was used to reduce the measurement noise and increase accuracy.

- So noisy posRef (position reference) measurements was the technical problem to be solved and blending was the solution.

Also, as position reference sensors evolved and different failure modes were experienced, software logic was added to the DPCS (DP Control System) position reference processing to identify and reject a faulty position measurement so as not to corrupt the blended solution.

How Did We Get Here (Regulatory)

Quotes from Stein Bjørnstad's 2009 PhD dissertation to the BI Norwegian School of Management "Shipshaped – Kongsberg industry and innovation in deepwater technology, 1975-2007".

"As with classification standards in general, DP classification reflected the foremost concern at the time of its creation. In the late 1970s, computers were likely to crash and computer redundancy correspondingly important." – thus Class 1, 2 ,3

For Class 2 & 3, position reference fault tolerance was handled by redundancy, requiring multiple reference systems operating on different principles. This can be seen in the DNV's tentative DP rules, circa 1977.

So, the defining DP system design guidelines/rules *are over 40 years old*.

Don't you think things have changed since then?

And further quoting from Stein Bjørnstad...

"The main effect of the classification regime was to simplify the process of acquiring technology and lower the cost of a transaction. Ordering a dynamically positioned vessel became less difficult when oil companies could rely on the classification societies to specify what they needed and ensure that the delivery was according to specifications. The shipping companies *de facto* outsourced the task of specifying requirements and assuring the quality of the suppliers.

Secondly, the classification regime made customers aware of a gold standard in dynamic positioning and in effect marketed expensive systems with multiple computers. By 1997, a triplex computer console could run for 192 years on average without a fault."

Regulatory

"A final effect of the classification regime was less benign: Albatross [Kongsberg] lost a source of inputs. When oil companies began asking for vessels by reference to a class certificate, customers and suppliers no longer had to search for the ideal solutions, but relied on the classification societies to specify what technology was right. Because the shipping companies could rely on semi- officially sanctioned presuppositions as to what they needed, it became more difficult for Albatross and other technology providers to suggest alterations and tailor solutions to specific challenges. The practice of issuing DP class certificates absolved suppliers and customers from the time-consuming, but highly creative, process of mapping requirements and specifying solutions. Such interaction had helped Kongsberg Albatross develop its solution, and the lack of such interaction did nothing to advance product development.

The main conserving effect of the classification regime was to ensure dynamic positioning remained a stand-alone product, not to be swallowed up e.g. by advanced autopilots or general vessel automation. Dynamic positioning remains as a stand-alone solution in part because it is unfeasible to triple *every* piece of electronics on board a vessel. However, such protection from competition also served as a barrier to the further development of the technology: because classification societies tightly prescribed the requirements of a DP system, it became somewhat awkward to integrate new functionality."

This was not solely the case with Kongsberg, it applied to the other DP suppliers (GEC, Honeywell, Alcatel, etc.) as well.

And…

The shipyards have there own standard DP vessel designs, and what they offer is what you get.

If you want something different, it is painful and expensive.

Today's DP PosRef Problems

Let's take a look at the failures associated with PRSs (Position Reference Systems) and DPCS handling of PRSs called out in TECHOP 14...

TECHOP 14 Failure Effects

3.2.2 The following anonymous examples give a brief outline of the DP community's experience of failure effects associated with PRS and *DPCS handling of PRS*.

- Signal degradation caused by Ionospheric phenomena.
- Clock errors: (Example - Leap second event).
- *GNSS drift*: The fault symptom is an apparent slow drift of the GNSS measured position and is interpreted as actual vessel motion by the DP control system. *There is a long history of GNSS drift problems*, and in the early days of GPS it has been observed where both installed GNSS references appear to slowly drift in unison. GNSS signal drift is frequently in the same direction and at a rate slow enough to pass DP system "signal rejection" checks. In addition to reference signal standard deviation, additional parameters need to be checked. The SD of observed, slowly-drifting GNSS signals is good due to the GNSS' relatively noise-free signal characteristics as compared to acoustic.
- DP events have occurred in which the loss of two GNSSs was caused by the failure of a single UPS. The two units were powered by the same UPS.
- *DPCS ability to identify a faulty position reference sensor was defeated* by false indication of high GNSS quality and Integrity.
- *Degraded signals* due to shadowing: There have been reports of vessels experiencing degraded differential correction signals caused by shadowing. The shadowing can be attributed to derricks, cranes, radar masts, etc. This is an issue for OSVs coming side drilling vessels or platforms where both corrections satellites and positioning satellites can be shadowed at the same time.
- *Corrupt GPS or GLONASS data*: Historically there have been instances when GPS or GLONASS satellites transmit corrupt data that cause position jumps or even lock-up the GNSS unit. These anomalies are rare but still a possibility. Systems that were not able to discriminate and reject satellites transmitting corrupt data were susceptible to errors leading to loss of position.
- *Corrupt Differential Data*: There have been instances when corrupt differential data cause position jumps or other issues. Most service providers have addressed this issue by improving quality control.

Failure Effects Continued...

● *DOP holes*: There have been instances where DOP [Dilution of Precision] holes have resulted in poor geometry and position degradation. This can be mitigated with the choice of equipment that is capable of using multiple satellite constellations.

● *Degraded signals* due to local interference: There have been instances of vessel equipment causing interference with GNSS equipment. Examples of vessel equipment responsible for interference include:

- Inmarsat communications satellite systems. Satellite phones.

- Third party satellite communication systems (logging, etc.).

- Harmonic frequencies generated by faulty equipment e.g. floodlight and fluorescent light ballasts, Helicopter Emergency Beacons, etc.

- Re-radiating (faulty) antennas.

- Re-radiating (faulty) Radio Frequency (RF) cables.

● *Degradation of Acoustic PRSs* due to acoustic noise:

- Internal / operations generated (Example – drilling operations, thruster cavitation, ROV operations).

- External sources of acoustic noise: Any source not caused by the vessel or its operations. (Examples - cavitation from supply boats alongside, seismic surveys in the vicinity, acoustic signals other sources in the area, Flow in subsea pipelines, ROV operations on another vessel, autonomous underwater vehicles).

● *Degraded performance of Acoustic PRSs* dues to: (Examples - marine growth on transducer/transceiver, gate valve for transducer deployment leaking, or not operated regular basis. Loss of beacons, rigging failures, dragged off position by other vessels / activities being performed).

● Configuration errors – operator induced: (Erroneous settings on PRSs, DPCSs).

● Configuration errors – DPCS related: (Examples - DP freeze test for Acoustic PRS).

and Continued...

⇒ Inadequate number of transponders appropriate for the industrial mission (Example – Position solution degradation from LBL to USBL being identified as a position jump)

● *Degradation of relative positioning capability*:

- Laser based systems (Examples – Poor reflective surfaces being used, inadequate number of targets, erroneous identification of targets, poor siting of equipment, inadequate spatial separation of targets).

Microwave based systems (Examples – Inadequate number of targets, poor siting of equipment, inadequate spatial separation of targets and maintenance of transponders).

⇒ Obsolescence (Hardware and Software).

✳ **Lack of 'systems thinking'** (Failure to consider PRS, sensors and DPCS in a holistic manner).

⇒ Lack of transparency in the error ellipsoids, No harmonized standard or requirements, *lack of alignment* between PRS OEM and DPCS OEM *on requirements*.

⇒ Choice of PRSs (Examples – inappropriate mix of absolute and relative PRSs, unsuitable for industrial mission being performed, inappropriate for water depth, inadequate number of transponders / targets).

● Choice of mode of DPCS control (Example - Follow Target Mode versus Auto Position.)

⇒ Operator cognitive burden (Example – *Lack of attention to human factor's engineering*, overload of information, access to settings not required for day to day operations, lack of automation resulting in erroneous and/or unwarranted operator actions / intervention).

Some more from TECHOP 14

2.2 SCOPE

2.2.1 MTS TECHOP_ODP_14_(D)_(PRS, DPCS and Handling of PRS) provides information on:

- Application of the seven pillars to PRSs.
- Functional objectives to be achieved (PRS & DPCS).
- *The emphasis and importance of protective functions* and verification and validation of the same.
- The significance of following OEM guidance (location of equipment, operational parameters).

⇒ The need to automate functions to the extent practical to alleviate the cognitive burden and response requirements of the DPO.

- ***Leveraging the advancement and development of technology to shed the burden of legacy impositions / constraints.***
- Leverage OEM vendor expertise to analyze PRS performance data and proactively prevent failures / incidents.

3.3.10 *Slow drift of PRSs and detection of the same continues to be a challenge*. Mitigation strategies include balancing out the number of PRSs in use based on different principles to minimize potential for rejection of good sensors by slow drifting sensors. (Example – 2 GNSSs plus two Acoustic PRSs versus two GNSS and one Acoustic PRS. No more than two GNSSs should be used in conjunction with a single Acoustic PRS).

So, What are the Takeaways

(Hiding in Plain Sight?)

- Position reference for DP has not been approached from a systems standpoint. It has evolved over the years into being a group of position sensors which are processed by software in the DP controller.
- Degraded performance of position reference sensors is going undetected and corrupting the DP position used for control...
  - The most insidious is sensor slow drift
- The present configuration (obviously) does not handle this.

When designing and implementing real-time software, you have to think of what might happen and account for it in the software, if not - then whatever happens, happens.

And that is where we are today.

From Nils Albert Jenssen's 2016 DP Conference Lunch Presentation 'The Cybernetics of DP in an Historical Perspective'

Starting Anew – A Systems Engineering Approach

The implicit objective of position reference for DP is to be able to maintain the vessel on location by providing 100% availability of vessel position information sufficient for DP closed loop control. If this objective were explicitly stated, then the approach taken might be somewhat different from what is being done now, especially when an inertial navigation system (INS) is part of the position reference equation.

If one were to consider the DP position reference problem from a systems standpoint, instead of a group of sensors standpoint, then the requirement might read something like…

A Systems Engineering Approach

Requirement: A position reference system that provides extremely high availability of vessel position information (near 100%) for DP control.

Note that there is no mention of individual sensors, only that the position reference system should provide high availability vessel position information. Neither is there any requirement that the position reference processing be done in the DP system. In fact, as will be discussed, there are advantages to not having the position reference processing within the DP system.

Inertial

To realize the full benefit of inertial navigation for DP, the addition of inertial should not be restricted to the concept of just adding another position reference sensor to the DP sensor suite. Instead, an *integrated systems approach* should be taken where the sensors are modeled in the navigation software - where the information provided by each sensor is used to best advantage to arrive at a composite estimate of vessel position.

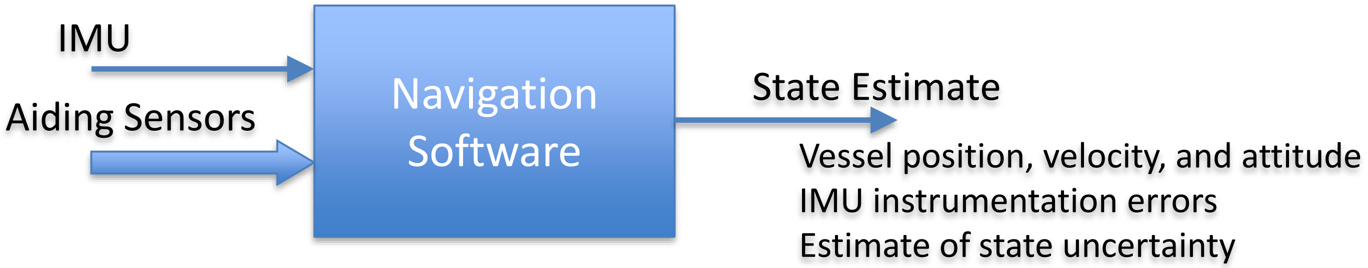
This opens the door to using information in the position reference solution that in itself would be inadequate for DP closed loop control, specifically for MODUs – ERA/riser profile and Acoustic Doppler Current Profiler (ADCP) information.

This systems concept is presented below as the Integrated Inertial Position Reference system (IIPRs) for DP.

Inertial Navigation

There are three parts to the Inertial Navigation solution

- The IMU (Inertial Measurement Unit)
- Aiding sensors
- The Navigation Software which models the IMU and aiding sensors and produces the state estimate



The Navigation software (Unscented Kalman Filter, Gaussian Mixture Model, Extended Kalman Filter, Particle Filter... there are multiple approaches) is what ties it all together.

This methodology has been used for quite some time in the avionics and defense industries.

Other DP Related Inertial Sensors

(that you didn't know were inertial)

Inertial sensors are already being used on DP vessels

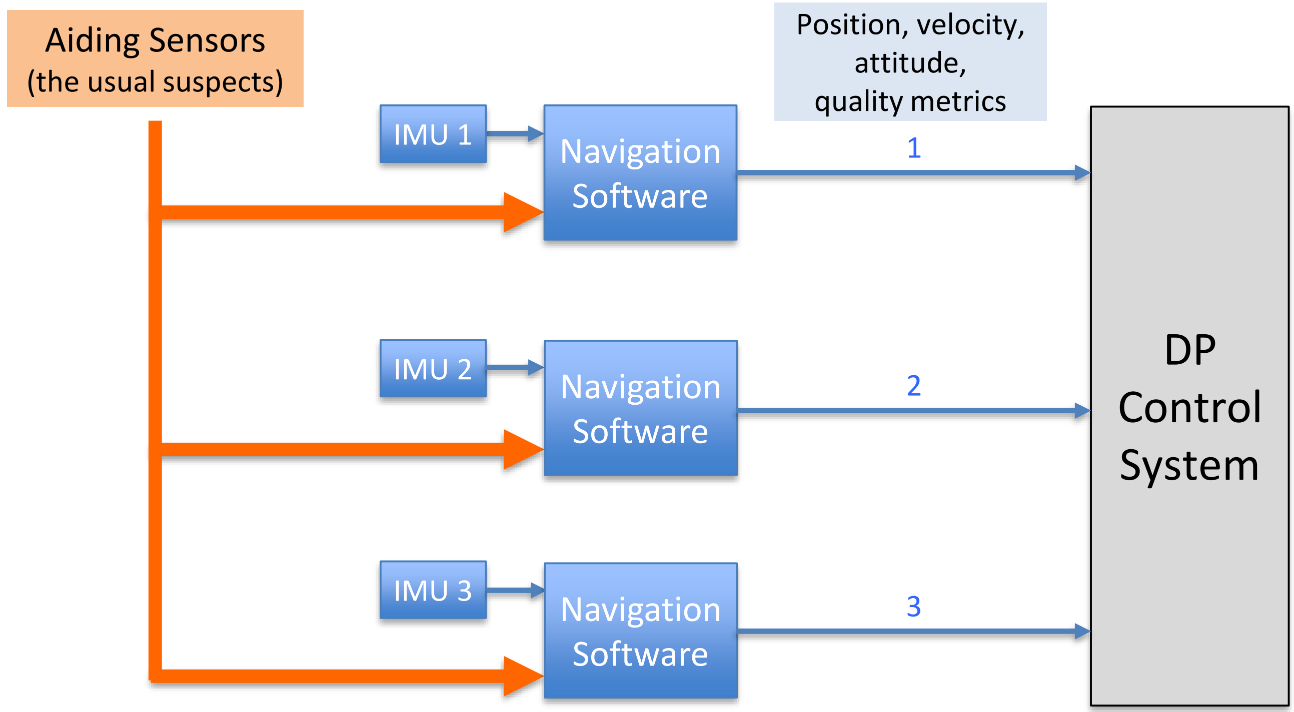
- **MRUs** – IMU with AHRS software (attitude, heading reference system) providing pitch, roll, and heave
- **Gyrocompass** – Inertial sensor with "gyrocompassing" software which provides vessel heading

The Integrated Inertial Position Reference System (IIPRs)

- The IIPRs sits outside the DP system
- All position reference sensors are fed into the system
- Navigation software pulls it all together
  - Optimal estimate of the system state

    vessel position, velocity, attitude, deterministic sensor errors
  - Estimate of the uncertainty in the state estimate (quality metrics)
  - Valuation & rejection of faulted aiding sensors
- Enhancement of aiding position calculations via tight coupling
- For MODUs – riser as aiding

The Integrated Inertial Position Reference system (IIPRs)



Aiding Sensor - Tight Coupling

Tight coupling means that the aiding sensor provides instrument raw measurements (observations) to the Nav Software instead of the calculated position. The position calculation is done in the Nav Software.

The Nav Software can then improve upon the position that the aiding sensor would have calculated via it's knowledge of vessel attitude and position.

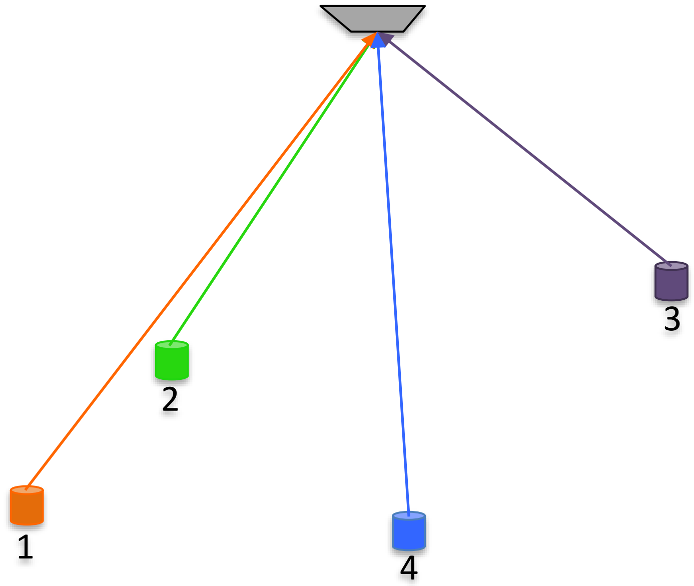
An illustration with LBL acoustics...

Tightly Coupled LBL

Position of the vessel is calculated from the slant range (the distance) from the acoustic transceiver to the transponders and the known locations of the transponders.

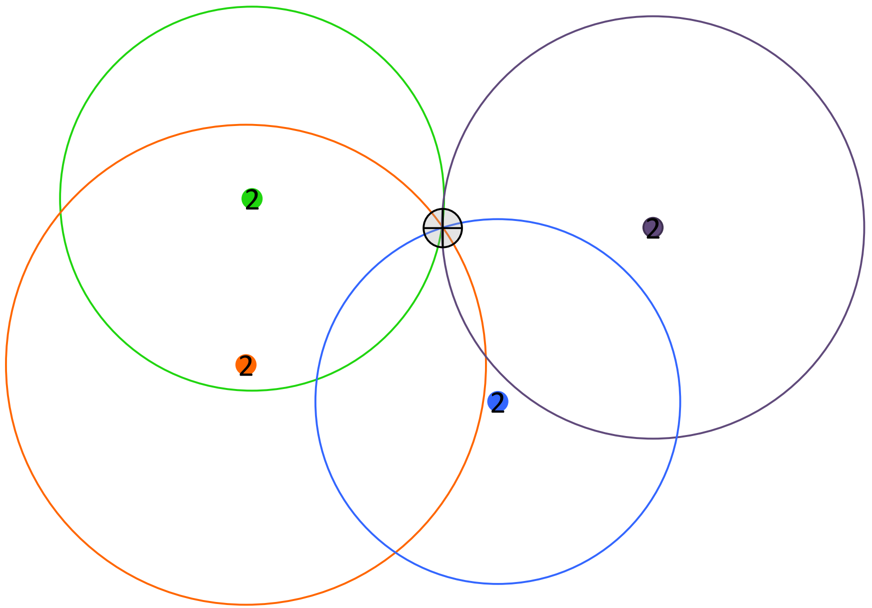
In three dimensional space, a fixed distance from a point (transponder) defines a sphere.

The intersection of the sphere with the surface of the ocean (i.e., intersection of a sphere with a plane) defines a circle.



LBL Position Calc

Vessel position is where the circles on the surface of the ocean intersect

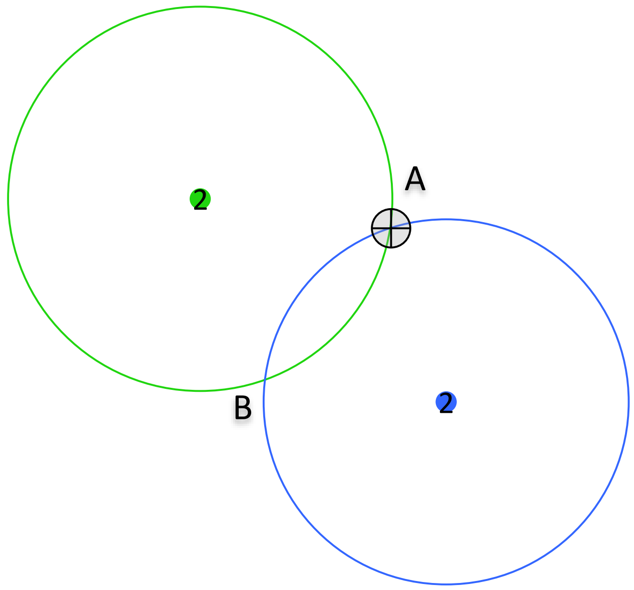


LBL Position Calc

So what happens if we loose 2 transponders – down to two?

To the LBL acoustics, the solution is indeterminate, it could be either point A or B.

But the Nav software knows that the vessel is at A, so the tightly coupled LBL solution is A.



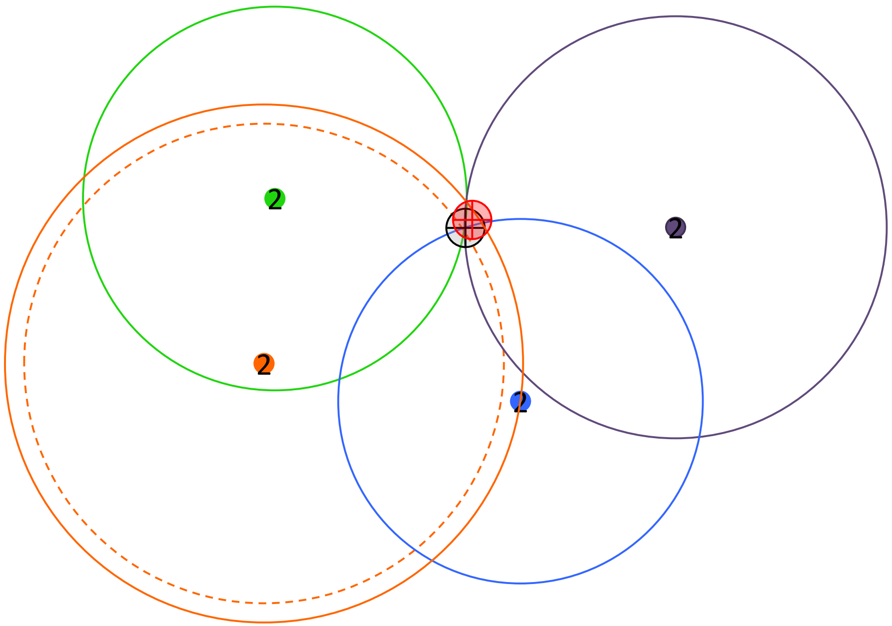
LBL Position Calc

So what happens if the slant range to transponder 1 is faulted?

The LBL acoustics calculated position would shift to be in the center of the intersections.

But the Nav software knows where the vessel is, and what the slant ranges should be for that vessel position, so it can flag the faulted slant range and toss it out of the LBL solution.

Similar tight coupling functionality exists for GNSS sensors (i.e., detecting faulty measurements).



IIPRs Situated Outside of the DP System

Having the IIPRs and position reference processing in a stand-alone processor, independent of the DP system, has distinct advantages.

- All position reference processing is done in one place, it is not split between the position reference sensors and the DP system.
- The IIPRs provides the means of providing state-of-the-art position reference for any DP vessel, regardless of the DP system.
- System development can be carried out in the lab with final validation and testing carried out on a test vessel prior to installation on the target DP vessel.
- Improvements to position reference, either from new or improved algorithms or new position reference sensors, can be incorporated in the IIPRs and thoroughly tested prior to deployment. IIPRs upgrades to DP vessels are accomplished without having to change either the DP hardware or software, therefore eliminating the need to re-certify the DP system.

  To accomplish this the IIPRs interfaces (aiding sensors, IIPRs → DPCS) need to be standardized.

Summary and Conclusions

Integrated inertial position reference has the potential for changing the DP position reference paradigm. To do this one must cast off the current concept of DP position reference consisting of a suite of position reference sensors and instead think of a position reference **system**. This systems approach is applied in the concept of the Integrated Inertial Position Reference system (IIPRs).

- The systems approach to DP position reference embodied in the IIPRs provides the means to solve today's DP posRef problems.
- It provides a versatile platform, which is independent of the DP system, for continued improvement of DP position reference as technology advances.
- Inertial capability can provide continued position estimates (20 minutes to 15m drift) after loss of all aiding sensors, but the tightly coupled IIPRs design goal is to have Nav Software and a suite of aiding sensors such that aiding is never completely lost.
- For MODUs, while hooked to the bottom, the inertial/riser model combination provides the potential for nearly indefinite positioning if simultaneous GNSS and acoustics loss would occur.

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