A Vision for Submarine Navigation

Enhanced operational decision making through process automation and data visualization

By LCDR Michael V. McLaine, USN and ETC(SS) Christopher C. Johnson, USN

11/5/2012

About the Authors: LCDR McLaine and ETC(SS) Johnson currently serve on the staff of Commander, Submarine Development Squadron 12 Tactical Analysis Group. LCDR McLaine served as the navigator on the USS OHIO (BLUE) and ETC(SS) Johnson is a qualified assist navigator awaiting assignment to his first ANAV billet.

Future Navigation System Vision

It's not just about the next new weapon systems, there is an awful lot we can do in innovation to make our daily lives easier which frees up our minds to start to appreciate the higher level decisions that are more appropriate use for our minds. So, if you think you are pulling a sled to the south pole on a day to day basis, think about innovating your way out of it.

VADM Richardson, Junior Leader Innovation Summit, 6 June 2012

Introduction

The dust has settled within the submarine force after our fast-paced transition from paper to electronic charts and it is now apparent that we need to examine the untapped capabilities available from an all digital navigation system. Despite the adoption of a digital standard, the process of creating a navigation plan and reviewing its impact on operations has, at its core, changed very little post-transition. If anything, the shift to digital charts has made the complexities and uncertainty associated with nautical charts more apparent. For example, whereas we previously may have used only a single large scale harbor chart for a particular area of water, we now use multiple incongruous electronic data sets for the same geographic space presenting far more decisions to be made at each data point. Yet, our current basic chart annotation tools are not designed to facilitate decision-making or reduce human error let alone interact with these data sets. As a result, the submarine force still relies on significant man-hours to create the navigation plan and multiple layers of human oversight to ensure its accuracy.

While we continue to expend so much time and effort to reach each final navigation plan it is clear that we are not fully exploiting the power of the data in our navigation systems. Now is the time for the submarine force to make use of 21st century software solutions to reduce the time spent producing a navigation plan from man-days to minutes while also reducing the risk of human error. This paper sets forth one vision of how technology that exists today could be utilized to enhance and improve the navigation process; while this vision is not meant to be definitive, it is intended to inspire the submarine force and its partner agencies to reach for the next generation of navigation capabilities. At the end of this paper we also present recent successful efforts to automate the bathymetry data analysis, just one element of creating a navigation plan. This example demonstrates the feasibility of exploiting the data in the way the vision below portrays.

A Vision of the Navigation Experience

Underway somewhere in the eastern Atlantic in the near future, a submarine receives tasking directing it to go east of its current position where no navigation plan exists.[1]

> The tasking message is ingested automatically into the ship's computer system and the associated waterspace assignment is displayed on a large scale, high definition, multi-touch screen.[2] The navigator walks into control after being notified of the new order and approaches

[1]No plan exists because the system is so automated that the idea of sharing "plans" between ships is outdated and actually slows the planning process.

[2] The tasking message is formatted automatically ashore by an enhanced waterspace tasking module. This module graphically represents all waterspace in space and time with enhanced error detection. See SBIR by 21CSI called "SAILFISH" as an example.

this display to activate the Navigation Planning Aide (NPA). With a touch of a button, the computer parses the water into suggested submerged operating envelopes (SOE) using the CO's stored risk parameters. Within each area an arrow points to the most restrictive water the computer found and used to create the area's limitations in depth and speed. Using his multi-touch gesture to zoom out, the nav sees the final destination a full day's transit away and the mosaic of tens of tiled SOEs that stretch the length of the display. Starting in an open sea basin, he'll have to plan to take the ship through a busy international strait and out into a deep basin. To begin the track plan, he zooms back in to larger scale and begins his plan. He drops his first waypoint for the track on one end of the table over the ship's current position and "throws" the second waypoint like a virtual hockey puck across the glass and out of view to the east. On the way down the display, the "puck" rebounds off the side of the assigned waterspace and, slowing at a life-like pace, comes to a stop out of view of the display. To catch up to where the track ends, the nav quickly swipes the glass to pan the chart to the east.

As the charts seamlessly pans underneath him, the bathymetric uncertainty layer's glyphs catch his eye and he places his hand down to stop the panning so he can investigate this area. The orbs, representing the source data uncertainty in location and depth, are flittering on the display as if humming to a frequency tuned to the size of the depth uncertainty (figure 1).[3] There are an unusual number of large, rapidly vibrating orbs here. While the SOE has automatically taken the most restrictive glyph into account, the nav knows the CO will have no interest in transiting through that area when adequately charted water is nearby. His left hand quickly grabs the 'exclude tool' and drags it over the shallow area. The displayed SOE's smoothly adapt to the shape the moment it starts to touch them, and as the navigator makes his final adjustment with two hands to stretch the polygon over the poorly charted area the SOE's seem to shimmer as they jostle for position. The track is nudged out of the way by the exclusion area as it is put in place.

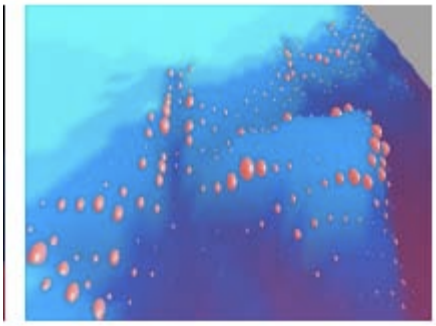

Figure 1 Actual bathymetric uncertainty "glyphs" from a 2004 NRL study

Happy with the display, he swipes again to follow the track to the east. A Mobile Drilling Unit (MODU), downloaded and ingested automatically when the shipboard database sensed a mismatch ashore during the last PD trip, is displayed in the middle of the waterspace. The puck had slid to a halt on its eastward path, but not before bouncing off of the MODU and coming to rest to the northeast of the obstruction. Coded by software policy as a stay out area, the puck knew not to enter the MODU's circle. Speed restriction markers and waypoints dynamically appeared on the track at the intersection with a depth restricted SOE to the north of the MODU. Knowing that the speed of advance to get on station is going to be high, the nav needs to keep the track in as deep water as possible. Moving the puck to the southeast of the MODU to deeper water, the track line and waypoint "jumps" over the MODU and the speed restriction markers disappear as the track crosses over into an unrestricted SOE, demonstrating the software's ease of interaction with objects.

[3] Figure 1 taken from "Multi-Dimensional Visual Representation for Underwater Environmental Uncertainty", 2004, (http://www.dtic.mil/dtic/tr/fulltext/u2/a499616.pdf)

With the waypoint safely south of the MODU, the nav grabs the puck with two hands and "tears" it into two and throws this newly created third puck in the same manner down the track into shoaling water at the mouth of the strait. Without the "override" touch of the nav's hand, the puck conforms to its interaction rules and bounces back at him after striking the territorial waters near the strait. After acknowledging the warning about the law of the sea, he grabs the puck and drags it through the territorial line and places it down on the other side of the strait.

At this point the nav focuses on the complexity of the strait's bathymetry and the resulting chaotic look of the SOE's. The rule set the SOEs follow, defined in the CO's Risk Area (CORA) tables, is for deep water and is not set up for the steep gradients in the shallow waters of the strait. [4] To make more sense of the situation in the strait, the nav applies the shallow water CORA inside the 100fm curve. Like the stay out area before, the SOEs dance around each other to conform to the new rule. Not quite happy with the displayed solution, the nav adjusts the contour interval setting to a larger value to space out the transitions between SOE's. Again, the SOE's move with precision and without delay, some collapsing all together and consumed by others as they trade space while the nav makes his adjustment. One SOE still stands out as problematic, so the nav grabs the edge of that SOE to expand it so that it looks just right while the adjacent SOE's bend to accept the nav's input. One SOE has a suggested "stay out" area over a wreck, with a tap of the finger to accept the area the bottom of the SOE drops to a deeper depth. Satisfied with the result and his track, the nav knows that this plan will require a transit depth strategy to safely make it through the strait. Behind him, the XO grabs the 1MC and announces "There will be a war council in control in 10 minutes."

To shift to the 3-D mode, the nav twists his hands on the chart and contour lines turn into a color coded view of the canyon in the strait. He pushes and pulls until he can see the entrance to the strait from the side. The SOEs look like irregular stone steps arching over a short hill. Grabbing the track, he inserts a depth marker and a vertical line drops to the floor of the ocean. The plumb line ripples the bottom of the SOE like it was a pond at the intersection of the two, making it clear how little room the ship will have in relation to the bottom. Tapping the merchant traffic density layer on, the track clearly will stand the ship into danger. The nav pulls the waypoint down in depth and away from the heaviest traffic and pans into shallower water and the next SOE, dropping more waypoints along the way, each with their own plumb line, and dragging them into place in depth and location up and down the ladder of SOE's.

Within a few minutes he has his final touches on the track. Zooming out again and happy with the overall track plan, he runs the electronic planning checklist. The checklist shows the MODU layer as green to indicate the database is up-to-date and displayed, the same status is indicated for the other required layers.[5] There were no errors when the computer created the required navigation lines from interrogations with the chart. A list of precautions and warnings in the plan appears in its own tab. As his finger taps on each one for review, the chart spirits away to the geographic location of the offending object. Some require adjustment; others will only be used to brief the CO in a few minutes. Checklist complete, he recommends the plan for

[4] CO's Risk area (CORA) is a new concept defined as the area completely within navigable waters and within all assigned waterspace to which the computer applies the CO's risk factors to create SOEs. While these values are variable and completely customizable, this area is generally set to values in line with submarine force policy.
[5] While not explicitly stated here, all time and geography based warnings and notices that could be a hazard are synchronized in the same manner as the MODU's are verified. MODU's are used as an example to represent the larger processes.

approval. Turning his attention to the operational plan, the nav drags an archived sequence of events for a strait transit into place on the mission planning timeline. He overlaps the required actions for entering TTW and shallow water onto the navigation plan. In parallel, he sees the other department's actions fall into place on the timeline as they complete their portions of the plan.

With everyone around the plot, the nav starts the brief, outlining the basis for the plan and quickly "flying" through the strait. Each principle turns on his own layer and builds on what the nav has said. Someone points out how the track can be improved based on this combined input and the nav quickly adjusts the track before the speaker is done. With no other questions, the XO dismisses everyone and the CO and nav talk over the operational plan one last time, clicking through the warnings and reviewing the track plan in detail. The CO sees the depth uncertainty area the nav has blocked out and says he would rather have that area as sea room for interfering contacts. The nav grabs and swipes away the stay out area, with the resulting cascade of SOE's falling back into place.

Satisfied with the plan, the CO approves it for use. The electronic night orders are updated from the plan and OOD's navigation display shifts to the new navigation plan taking the warship to the East. Not 30 minutes since receiving the tasking, the OOD orders, "Helm, right full rudder, Steady on course 090!"

Highlighting the Differences Between Vision and Reality

Changes in Concepts

Although the implementation of this vision may seem radical, the premise is not. In essence, it is simply the transfer of raw data analysis from humans to a computer algorithm. Trust in computer algorithms is not new to the submarine force; they are utilized in systems throughout our submarines. What is radical, however, is the positive impact implementing this vision would have on submarine operations.

First, operational planning would benefit from the reduction in man hours expended in creating a navigation plan. Utilizing this system, the captain would have an opportunity to quickly understand the water he is operating in through the rapid generation of SOEs, the core of any navigation plan. Instead of receiving a plan after days of development, he would be able to rapidly assess his risk in assigned water and give "commander's intent" early in the process. This type of system retains the ability to quickly re-plan if necessary.

Second, tactical decision making would be better informed through the visualization of waterspace in three dimensions.[6] When a captain can truly "see" the ocean floor and the associated layers of information, rather than a collection of numerical data points, his real time situational awareness is enhanced and he has a better appreciation of the surrounding operating environment. For example, depth changes required by a SOE shift would no longer appear as just a number on a screen and waterspace shifts could be visualized before they happened.

[6] This paper refers to "3-D" in the sense that there is perceived physical space, not necessary the application of true 3-D from stereoscopy.

Finally, implementing this vision would minimize the human error that inevitably occurs with the repetitive interpretation of raw data. Computers, designed specifically to deal with large quantities of data, would handle these tasks with ease.

A look back at the bathymetry model presented in the vignette above further showcases the positive impacts of shifting to an all digital solution. Today, to create a navigation plan, the picture of the ocean floor exists only in the heads of the planners. They must interpolate the shallowest sounding in an area after repeatedly changing charts, never getting a chance to see all the data at the same time. This process is repeated time and time again for each new plan and every time a chart update is downloaded.[7]

Software that eased this burden would enable the navigation team to focus instead on the level of uncertainty and risk associated with operating in an area. If SOEs appeared with a touch of a button, the iterative and data intensive portion of the navigation planning process would be eliminated. While the vignette above focused mainly on SOE development, an extension of the argument calls for an ability to develop all portions of a navigation plan with the same relative ease.

Road Map

To achieve this vision an application of artificial intelligence and software needs to support four broad improvements. The first is extraction of the planning process from existing navigation software into a customizable application theoretically called the Navigation Planning Aid (NPA). Second, a data pipe is required to transfer the contents of the plan between the two systems based on a common interface standard. Within the NPA, the software must interact with a navigation certified database, the third advancement. Finally, the software should employ a series of algorithms designed to enhance the current human processes for chart development while allowing for instantaneous interaction and visual feedback. This software unburdens the navigator and minimizes the possibility of human error resulting in missing a shallow spot or other planning error.

Near Term Capabilities

Within the APB 13 cycle the ground work for this vision is already in place. The Mission Planning Application (MPA) currently in development is an obvious base from which to build on segments of a navigation planning aid. Opening the data pipe between the MPA and the navigation software will allow the track to appear, ready for approval without any editing, in the navigation system. This achieves a "plan once, enter once" goal. By sharing the data interchange format for **ALL** of the possible objects within the navigation system, the MPA can be the source for every single overlay required in a certified plan used on the navigation system. Today, this cross connect between fire control and the MPA has been demonstrated through the use of a Extensible Markup Language (XML) schema. By having a tool that can be morphed into the NPA and opening the pipe between the legacy navigation software and the NPA, two of the goals needed to meet the vision are already in place.

[7] This reality is in contrast to the idea that there should be one unified model of the bottom created from the best depth estimate a shore based cartographer can assign from the best data available.

To advance the automated planning concept, two basic programming functions would greatly enhance the value of the MPA and be a strong step forward to creating a NPA. The first is an algorithm that can simply be described as "drain the ocean" to a user specified value of depth. The second is a polygon loop tool used to define a geographic set of points that graphically outputs the shallowest sounding, depth curve, or feature for any of the sources of navigation data within that area. Both algorithms are possible for the APB-13 cycle. The first algorithm demonstrates a capability to interact with any model of the bottom and find the contour that defines of depth across all areas of water of concern. The second is an algorithm that automates the current human process used to find a shallow sounding in each SOE using the current source of approved sounding data (DNC/TOD/MATT). As of the beginning of November 2012, this tool has been prototyped and is ready for testing. A combination of these tools could be used within the MPA to ensure that the track was created as navigationally sound the first time and not require rework in the navigation software. Secondly, SOE's could be constructed with the loop tool and exported as well for final review and approval within the navigation system. This tool eliminates rework and errors in the SOE development process.

Mid-Term Capabilities

To realize the full potential of the navigation vision we have to revisit the data. To eliminate the complexities from multiple charts that cover the same geographic area, the NGA "product" that gets delivered to the boats needs to be a single unified database. There must be only possible representation of any one feature on the surface of the earth. As argued here, the ambiguities that arise from incongruous depths form the strongest argument for this shift to a database. Graphically, the depth portion of the database is represented as a "surface", just as you might see the ocean floor in a common geographic tool such as Google Earth. On this type of surface there is only one depth at any one point, there is no ambiguity.

Fortunately, this shift is already occurring through the efforts of the NOAA, Naval Oceanographic Office (NAVO), and NGA. The International Hydrographic Office (IHO) is in the process of defining a new series of navigation standards, called the S-100 series (or S-10X), to replace the S-57 standard dating from the 1990's.[8] The first IHO standard to be ratified in this series is the "bathymetric surface model specification", or S-102. The S-102 standard represents the depth information within a chart through a 3-D "surface", filling in the voids between individual soundings seen on today's charts. When combined with the other navigation S-10X layers (buoys, lights, etc.), a complete navigation picture is formed. NAVO submitted their Digital Bathymetric Database-Variable (DBDB-V) data structure as a model for S-102 to the IHO and this format was subsequently ratified on 16 April 2012.[9] If the S-100 series of standards is adopted by the U.S. Navy as the standard for future navigation systems then the bathymetry surface is available today for experimentation under NAVO's DBDB-V.[10] Looking forward,

[8]DNC's do not conform to the S-57 data standard due to S-57's inflexible nature to support military operations. See footnote below.

[9] IHO invitation to vote on S-102 standard, accessed from http://www.iho.int/mtg_docs/circular_letters/english/2012/Cl10e.pdf.
IHO ratification notification of S-102, accessed from http://www.iho.int/mtg_docs/circular_letters/english/2012/Cl41e.pdf.

[10] This standard allows for Additional Military Layers (AML), the flexibility lacking in the original S-57 standard.

the submarine force should articulate to the NGA not only the desire for a navigation certified surface under the S-102 standard, but the consolidation of its product lines into this single unified database concept.

Regardless of how DBDB-V is managed in the future, the S-102 data standard will be maintained now that it is internationally adopted. This is an opportunity to start coding on top of this standard to create a series of tools that go farther than “draining the ocean” and the “find the shallowest spot” loop tool. This effort could rapidly achieve the navigation vision by using the existing DBDB-V database to create the visualization of the bottom discussed in the vignette. Replacing the data with NGA’s product when it is available is simplified since the format of the data would be same.

To automate the process of ingesting navigation related products into the NPA, the messages a submarine receives have to be machine readable. This will require coordination with the fleet Task Forces across the globe to make message traffic that is both human and machine readable. Providing a similar tool ashore to create layers and messages will solve the interoperability problem that results in the “air gap” between systems afloat and ashore. Having a common interface standard between the afloat and ashore units will remove the human in the loop that can reintroduce errors at multiple levels. For example, we double check MODU’s in our navigation system only because they are hand entered, we don’t question the validity of the originating message itself. The process for all off hull generated navigation products that get sent to the boat needs to be one that unburdens the crew and places the responsibility ashore for data verification.

The process for updating the charts, navigation publications, technical manuals, and navigation products needs to be one of push and not pull from the boat with an auto reconciliation feature to manage changes. Again, this unburdens the crew and allows them to focus on the mission.

Summary

The current paradigm of chart preparations is a result of implementing an analog chart development process over the digital transformation to electronic charts. A significant reduction in time to prepare a navigation plan will be realized by fully embracing software solutions to the most laborious and data intensive parts of chart development. A computer algorithm can perform the task of find the shallowest sounding within a given waterspace in the fraction of the time it would take a human to do the task, and with a near zero rate of error. Separating the planning functions from the ECDIS-N certified navigation software is the cleanest way to begin to implement the improvements outlined in this paper. Separating the two allows the NPA to be updated within the APB cycle and leaves the tested and certified ECDIS-N software alone.

Appendices of Additional Navigation Concepts

Fix Sources

In the transition to ECDIS-N, the submarine force lost an ability to conduct bottom contour fixes on the U.S. Navy's electronic navigation system. The ability to plot on the chart a fix from any source became limited by what came packaged in the menu structure of this software. Today, the submarine force is artificially limited to a handful of fix sources for automatic display because the interface with AN/BYG-1 does not account for the possibility of fix sources coming from fire control. The Navigator of the Navy's instruction for ECDIS-N only specifies that the Line of Position fix must be physically generated inside any ECDIS-N system.[11] The implication is that nothing restricts the submarine force from creating fix sources inside the fire control or sonar systems and passing these one-time or continuous fixes to the navigation system for verification. For example, GPS and the Radar's (BPS-15) fix source commonly referred to as "RADAR ON VM1" are both continuous latitude and longitude pairs that the navigation system displays for review, neither originate from with the system itself.

Bathymetric Fix

A module that resides on fire control could be built to mine the navigation charts for contours, link to the fathometer, and provide a near continuous bathymetric fix source to the navigation system.

Celestial Fix

Another possible module could use ISIS and link with the Navy's celestial progam, STELLA, to provide celestial fixes.

Auto-Fischer Plot Fix

In a radar fix technique known as Fischer plot,

The navigator adjusts the scale of the radar to match the scale of the chart in use. Then he places a clear plastic disk, sized to the radar, on the center of the radar screen and quickly traces the shape of land and location of any navigation aids onto the plastic overlay with a grease pencil. Taking the plastic with the tracings on it to the chart, he matches the features traced from the radar with the chart's features. A hole in the center of the plastic allows the navigator to mark the position of the ship at the time the tracing was done.[12]

This capability was lost in the implementation of ECDIS-N. While other technological solutions were developed in place to achieve a radar fix, none are as elegantly simple as the Fischer Plot. All current

[11] "The ECDIS-N shall provide the capability to enter bearing and distance LOPs from ownship to charted aids to navigation and conspicuous objects, and to resolve these LOPs into a fix or running fix in the case where LOPs are not obtained from near simultaneous observations. The ECDIS-N shall be able to resolve LOPs entered as either true or relative bearings." OPNAVINST 9420.2 dated 15 Feb 2001. Accessed from doni.daps.dla.mil on 15 Sep 2012

[12] http://msi.nga.mil/MSISiteContent/StaticFiles/NAV_PUBS/APN/Chapt-13.pdf pp 196-197

RADAR piloting techniques are heavily reliant on the human operator for prior planning and in-situ execution. Executing an electronic version of the Fischer Plot provides a way for a ship to restore this simple and effective fix technique.

Using the current series of 8.x series of VMS as a mental model, a simple interface that allows the user to "grab" the radar overlay and drag it until it matches the background chart would result in a Fischer Plot fix. The center of this electronic RADAR overlay is own-ship, and when the overlay is matched with the background chart a fix is established.

This can be extended one step farther to implement a software solution that is conducting a best-fit algorithm during each sweep of the radar to arrive at a fix automatically. This solution is akin to a continuous fix using "RADAR on VM1", without the messy worry of ensuring that the NAVMARK and navaid were properly planned and hooked. No prior chart work or RADAR planning is required, the software will fit the overlay even at different scales then shown on the RADAR PPI.

Auto-updating COSOEs

The NPA could ingest organic (fathometer or HFA) and non-organic (chart updates or message traffic) sounding data in real time and apply the changes to the chart. When these new soundings affect the CO's risk parameters, i.e. shallower than the MES, the NPA will propose a new COSOE to accept. Since the CO is approving his parameters and not individual COSOEs, accepting a change that meets his limits would not require his approval as the computer is doing its job to meet all limitations. Denying such a change would require the CO's permission. Envision a dialogue box that says "based on new data ingested from xyz source and located here (data hyperlinked with arrow pointing on chart to location), would you like to accept a new maximum operating depth of 200ft? Current depth is 250ft and is out of area of suggested COSOE."

Submarines currently manually apply text changes to charts as they collect sounding discrepancies and receive sounding discrepancy messages while operating in all variations of chart qualities. While helpful, the process is laborious and requires another human analysis to scan the chart corrections against the existing MES to ensure the COSOE is still valid. The "safety checker" feature of VMS provides no operator backup to this process. The automated "risk area" solution would identify unsafe conditions instantaneously and increase the submarine's margin to safety.

The conditions under which organic sounding data would be applied will have to be tightly controlled. Defining the criteria under which such data would be applied to the charts is beyond the scope of this paper but can be reasonably assumed to have a workable solution.

Resolving Conflicting CO's Guidance

By doctrine, CO's are required to maintain their guidance for ships in one place, the navigation plan in use. In reality, the difficulty of changing COSOE's is often a subconscious block for many teams and guidance is placed in the night orders instead. With a "risk area" approach, changing a CO's parameters is as simple as updating the dialogue box that contains the constraints and parameters used to create COSOE's. Simply change the parameters shared globally across the COSOEs and the computer applies the changes instantaneously.

Augmented Reality

On the bridge of a submarine, the Officer of the Deck (OOD) is removed from many of the tools available to a control room watch stander. The OOD synthesizes his visual picture with voice reports from control, his VMS display, secondary radar, and prior experience to arrive at a mental model of what he observes. This "seaman's eye" is developed over hundreds of hours of seagoing experience and is the critical "orient" in the "Observe, Orient, Decide, Act" (OODA)[13] loop.

An example of the difficulty a junior bridge team has *orienting* is seen by observing an OOD in the Virtual Submarine Trainer (VESUB). The OOD sight is repeatedly drawn to VMS, his best integration sensor. An inexperienced officer spends so much time looking down vice up because the visual picture alone does not tell the whole story. He must supplement his visual picture with the data fused and displayed as information on VMS. We rely on the OOD to correctly synthesis all available data, to orient himself, to make his decision.

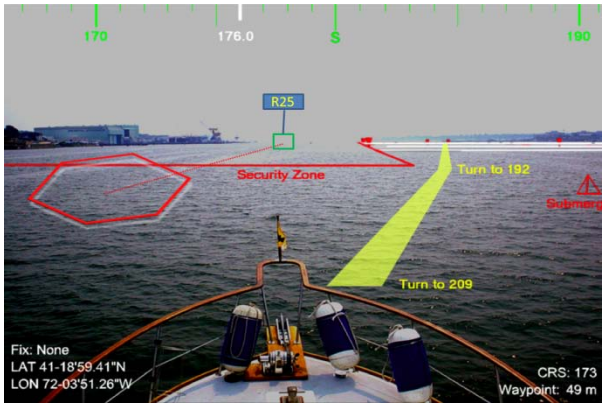

Figure 2: Example of augmented reality for surfaced navigation.

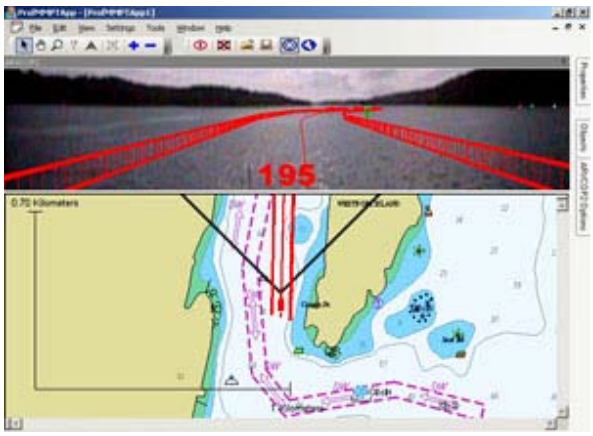

Figure 3 http://tsinc.com/Augmented_Reality/index.html

The simple fact is that what he thinks he sees is completely subjective and only as good as his prior experience will allow. Only the most seasoned mariners can accomplish this orientation quickly and with little error. These experienced operators intuitively apply a mental model to what they see with their bare eyes. To shorten the time it takes to orient on the bridge augmented reality technology solutions could be used to integrate and display a unified picture to the OOD. What the OOD might see is depicted in figure 2.[14] A set of eyeglasses projects onto the horizon an overlay with important navigational and contact management information on top of the natural visual picture.

This demonstration illustrates the convergence of navigation and contact management information into a single visual environment. As the OOD swivels his head the overlays seamlessly update. In the depiction above, the OOD can clearly see the navigation track, aids to navigation highlighted, chart features displayed in three dimensions on the surface of the water, and a Predicted Area of Danger (PAD) off of his port side from a RADAR contact. In heavy fog or at night, this display could overlay RADAR returns and fire control fused contacts onto the OOD's display.

The effect achieved is a rapid reduction in the OOD's time to achieve a complete picture of his environment. Decision making becomes clearer as the complete picture is seen in one view.

[13] The OODA loop is a decision model popularized by Col John R. Boyd, USAF. http://www.airpower.maxwell.af.mil/airchronicles/apj/apj94/win94/man1.html

[14] Modified from http://wisdomtools.net/upload/CaseImage_vAtoN_New_London_Demo.jpg

Figures 2 and 3 depict an industry solution already on the market

Figure 4 Screen shot from http://www.arvcop.com/images/ARVCOPsellsheet.pdf

Piloting with autonomous & continuous visual fixes

During the piloting evolution many activities are occurring that unnecessarily pull the attention of the navigation team away from evaluating the current and future situations before them. Most of these processes can be significantly improved by allowing a computer to perform the basic mechanics and the Navigator/ANAV to evaluate. Advances in electro-optical technologies that are onboard submarines today open the possibility of continuous visual fixes. While relying on continuous visual fixes may seem archaic in the age of satellite navigation, the possibility of navigating in a GPS-denied environment is becoming more and more of a concern. The possibility of a material casualty causing a self-inflicted loss of GPS is always a possibility. We have also seen GPS fixes that were Figure of Merit 1 (FOM1) but were miles away from actual position. Visual fixes will remain a staple of Naval navigation despite the march of technology, but the tools to implement this fix can be improved upon.

Currently the basic mechanics of the visual round include:

1. NAVAID Identification/Verification
2. Establishing the order of the round(Optimal Bearing Spread, etc.)
3. Periscope Operator takes a round, manually acquiring NAVAIDs (Hey Anav is this it, it looks like a church steeple right, nope I don't see it…O wait there it is) and reports the bearing to the QMOW who then manually inputs the round.

3a. Photonics Operators on 774 Class have NAVAIDs sent over from the ECDIS-N System which puts

them down the approximate bearing of the NAVAID. When the NAVAID is “shot” the bearing is sent to the ECDIS-N system and manually edited/accepted by the QMOW.

4. The fix is then reviewed for accuracy and accepted by the NAV/ANAV.

Quality and accuracy of the Visual Fix can vary both from round to round and operator to operator, sometimes resulting in anything from a near continuous fix to the absence of a fix for several minutes.

The Periscope/Photonics Operator is not always familiar with the port that is being navigated and can sometimes have difficulty picking out the NAVAID from rest of the structures on the shoreline. We sometimes rely too heavily on GPS instead of trusting what is visually happening around us.

Combining a “Computer Vision” type software program with an Augmented Reality system.

Imagine a submarine conducting a port visit to Bahrain for the very first time. On the approach inbound the limits of the channel are displayed as well the expected track. Buoys are automatically tracked with ranges and ID numbers displayed on screen. Tankers and merchants are entering/exiting port while others are at anchor, the range/speed/course are superimposed with expected Predicted Points of Collision visually laid out on screen for the watch team. A contact approaches the ship faster than expected, selecting the contact reveals it is the Harbor Pilot. While proceeding inbound the ship has a loss of GPS, a relatively minor event as the ship has been taking continuous visual fixes in the background with the automatic identification and tracking feature, and smoothly transitions to visual as the primary fix source. NAVAIDS are being automatically dropped/gained/shifted for optimal bearing spread, and distances are being displayed using the laser range finder and HOE calculations.

If the ship finds itself in a scenario where visibility is significantly reduced, objects that are geo-tagged can be superimposed on the screen as well as the track. This will allow the watchteam to spend more time safely navigating with right level of situational awareness vice trying to mentally construct the 3D real-time picture from 2D information and then reacting to the situation consistently ending up behind the problem.