QPS Nautical Charting Workflow:
Walking a ping from the surveyor all the way to the pilot

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Abstract

A Nautical Charting Workflow that fully encompasses the journey of a ping from the surveyor all the way to the pilot offers tremendous advantages. The fully-integrated solution allows for the preservation of data formats throughout the entire workflow, and eliminates errors associated with data conversion and metadata loss along the way. Quality Positioning Services (QPS) achieves the fully integrated workflow, walking a ping from the surveyor all the way to the pilot, and the benefits in terms of efficiency and streamlining processes are realized:

- Actual pings are captured in the integrated navigation software **QINSy**, built on a philosophy of real-time corrections and quality assurance to ensure high data quality capture.
- Acquisition projects open directly in **Qimera**, a processing software with intuitive, guided workflows, and designed to automate mundane tasks, thus common, human errors are eliminated.
- Survey data migrates seamlessly into **Fledermaus**, a multi-purpose software specializing in 4D geo-spatial analysis, and it promotes above all clear communication and presentation of data.
- Soundings and contours are extracted automatically from gridded bathymetry in **Qarto**, the ENC production software, built for a rapid turnaround—some survey-to-ENC workflows have been measured in hours.
- Updated charts go live in **Qastor**, a precise navigation software for piloting with Under Keel Clearance (UKC) and vessel docking capability, which can be further interfaced with AIS and meteorological data for real-time updates.

Further process efficiency is gained by real-time processing in QINSy, which allows for rapid decision-making capabilities for surveyors while they are still in the field. While there are great benefits to the fully-integrated solution, the workflow components are also perfectly modular for the utmost client flexibility. The QPS Nautical Charting Workflow is especially beneficial for ports with high traffic volumes and heavy update needs. The Port of Rotterdam, an early-adopter of the QPS Nautical Charting Workflow components, is a prime example, and is presented as a case study. The advantages of the solution are shown in terms of timeliness in the "Sonar-to-Pilot" workflow and rapid product turnaround.

Introduction

Nautical charting workflows to ensure both timely and robust information to pilots and mariners are more important than ever. Many vessel types have steadily increased in capacity over the years, for example, container ships, bulk carriers, and cruise liners. Modern Ultra Large Container Vessels (ULCV) carry up to 21,400 TEU, more than seven times the capacity of container ships from 40 years ago (IHS Maritime and Trade). Increased capacity has increased vessel drafts accordingly—modern ULCVs can draw up to 14 meters or even more. Deeper drafts restrict the water in which these vessels can operate, and places upon the charting authority a higher precedence for timely and accurate products to ensure safety of navigation. Furthermore, the need for high-resolution charting products is also highlighted, as the advanced knowledge conveyed in finer contour intervals increases navigable water and also reveals any "over-depth", which is the vertical distance between maintenance depths and actual dredged depths (van Reenen and Raines, 2015). Essentially, high-resolution chart products allow more room for vessels to operate into and out of port, increasing the throughput of goods. Real-time tide and meteorological updates to charts also increases the flexibility of vessel movements and further improves port operation and commerce overall.

Given these characteristics for modern vessels operating in the busiest ports of today, we identify key ingredients listed below that are considered necessary for a nautical charting workflow to best achieve optimal port solutions. Note these same ingredients are generally well-reflected in the strategic plan of most any hydrographic agency, for example, the NOAA Office of Coast Survey (NOAA, 2015).

Accuracy + Timeliness + Robust information = Maximized throughput of goods

The Maritime Traffic Management department of Saab is a well-established and trusted partner for ships, pilots, and ports around the world, and holds in the highest regard their mission to enhance safety, security, efficiency and environmental protection on waterways and at sea. Saab Maritime Traffic Management encompasses the full spectrum of maritime solutions, from Port Management to Vessel Traffic Services, and products range from Automatic Identification System (AIS) transponders to Portable Pilot Units (PPU) in support of Precise Navigation. QPS fits within this framework by offering advanced software applications that support all phases of ocean mapping and safe navigation. The QPS Nautical Charting Workflow prioritizes those key ingredients identified above in order to achieve optimal port solutions, and this paper will discuss in detail how this is accomplished.

Nautical Charting Workflow

QPS offers solutions encompassing the full workflow from sounding acquisition to safe pilotage. There is great value in the integration of products—a "Sonar-to-Pilot" turnaround time of a validated ENC for pilotage can be accomplished in as little as one day. Alternatively, each of the products are also perfectly modular for client flexibility in their workflows to utilize seamlessly a wide variety of manufacturers.

An overview of QPS products is given in Figure 1.

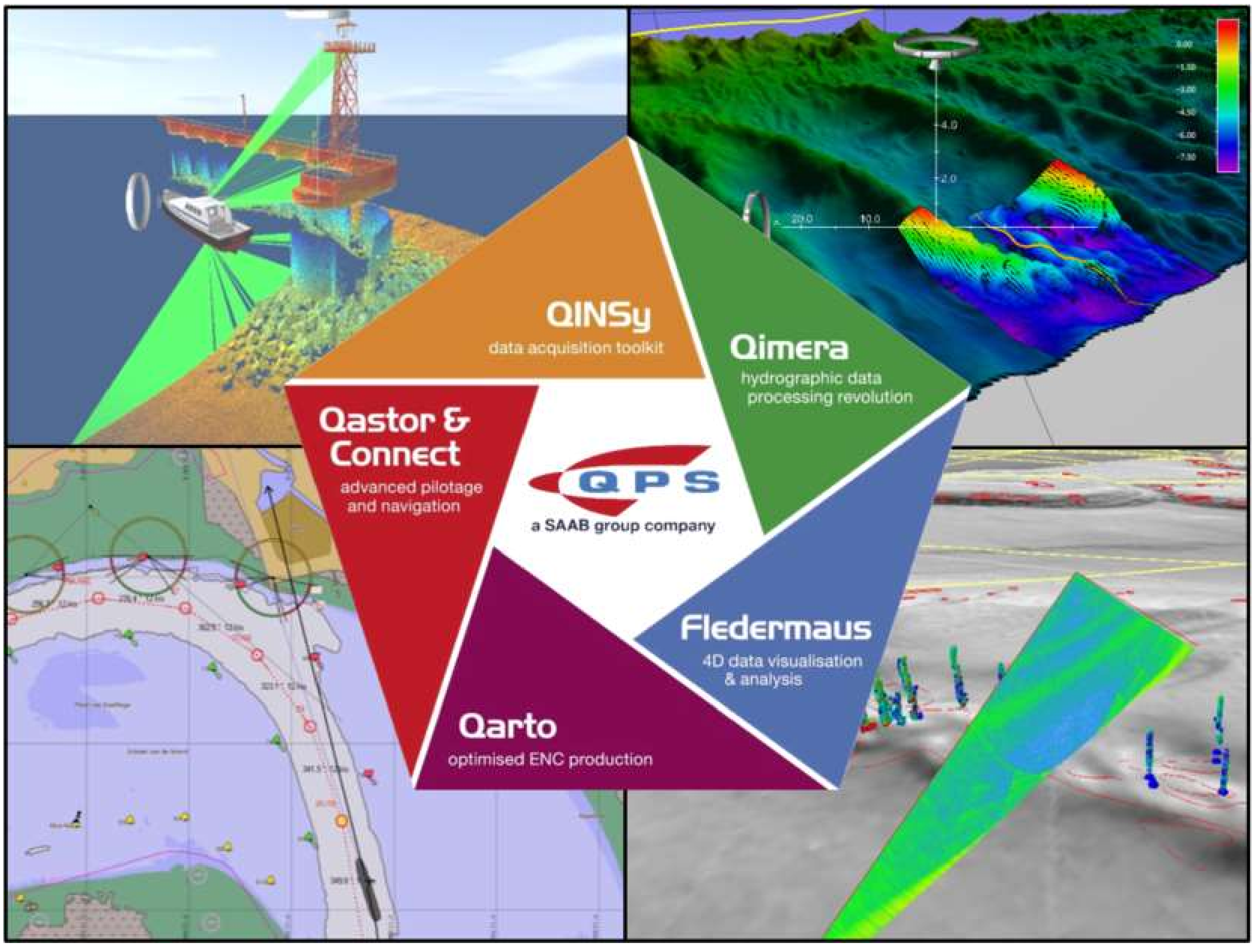

Figure 1: An overview of QPS software (*moving clockwise from the top-left*): **QINSy** provides high client flexibility with the integration of multiple sensors, motion, and positioning; **Qimera** users can apply post-processing, data cleaning, or QA/QC techniques quickly and easily; **Fledermaus** offers advanced visualization and presentation, in addition to backscatter and water-column processing; **Qarto** provides rapid ENC update capabilities, which then go live in **Qastor** for pilotage and safe navigation.

A simplified map of the QPS workflow demonstrates how the software is integrated from "Sonar-to-Pilot", and this is given in Figure 2.

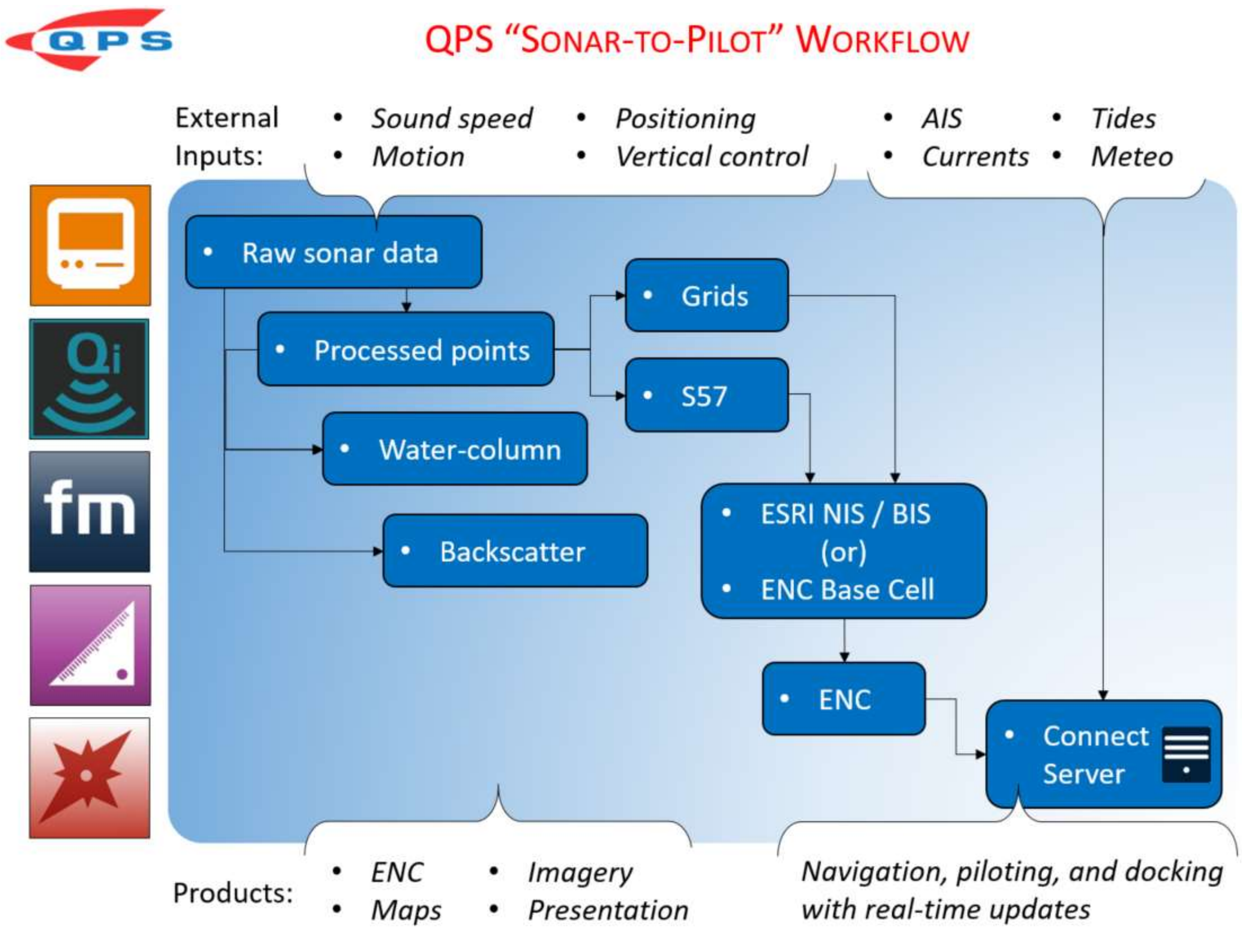

Figure 2: The QPS "Sonar-to-Pilot" workflow. With sound speed, motion, positioning, and vertical control inputs, **QINSy** acquires and processes raw sonar data. Remaining post-processing and quality assurance tasks are handled in **Qimera**. Additional verifications and presentations are accomplished in **Fledermaus**, with complementary backscatter and water-column products also generated. Validated grids and S57 features from survey are stored in ESRI databases (NIS and BIS); alternatively, an ENC base cell is utilized. **Qarto** interfaces with the ESRI databases, or the gridded data and ENC base cell directly, and an ENC is produced with the updated bathymetry, which in-turn goes live in **Qastor** via the Connect Server. The server also allows for real-time updates of AIS, tides, currents, and weather, for optimal situational awareness when navigating, piloting, and docking.

QPS software is built upon the below methodologies in order to achieve optimal port solutions.

1) employing real-time processes and information updates whenever possible,
2) adding automation, but only where it is best-suited,
3) implementing timely and relevant research tools from academia, agency, and industry,
4) supporting a wide variety of manufacturer input and output formats,
5) partnering with ESRI for an optimal database solution,
6) applying cutting-edge technology and visualization techniques, and
7) doing all of this in manner such that the software remains as simple and intuitive as possible for the user.

To follow is a description of how each software draws upon the above methodologies in order to achieve the key ingredients for optimal port solutions.

QINSy

The philosophy upon which QINSy is built is to ensure the optimal acquisition of data in real-time, rather than needing to apply numerous actions in post-processing. Efforts taken upfront during acquisition to ensure the collection of good data is considered much more efficient than discovering and rectifying errors during post-processing, possibly requiring the need to resurvey.

QINSy ensures the optimal acquisition of data by employing real-time functionality, including tools for quality assurance and swath calculation. These give absolute confidence to the surveyor in the data collected by allowisinng her to observe processed data in real-time, and has the additional benefit of alleviating post-processing bottlenecks that can occur while employing multiple vessels, and/or dual-head multibeams. Examples of the real-time capabilities for swath calculation and online quality assurance are shown in Figure 3. QINSy also features the QPS sounding grid, a single-file, multi-resolution and multi-layer shaded bathymetry grid with no pre-defined boundary requirement.

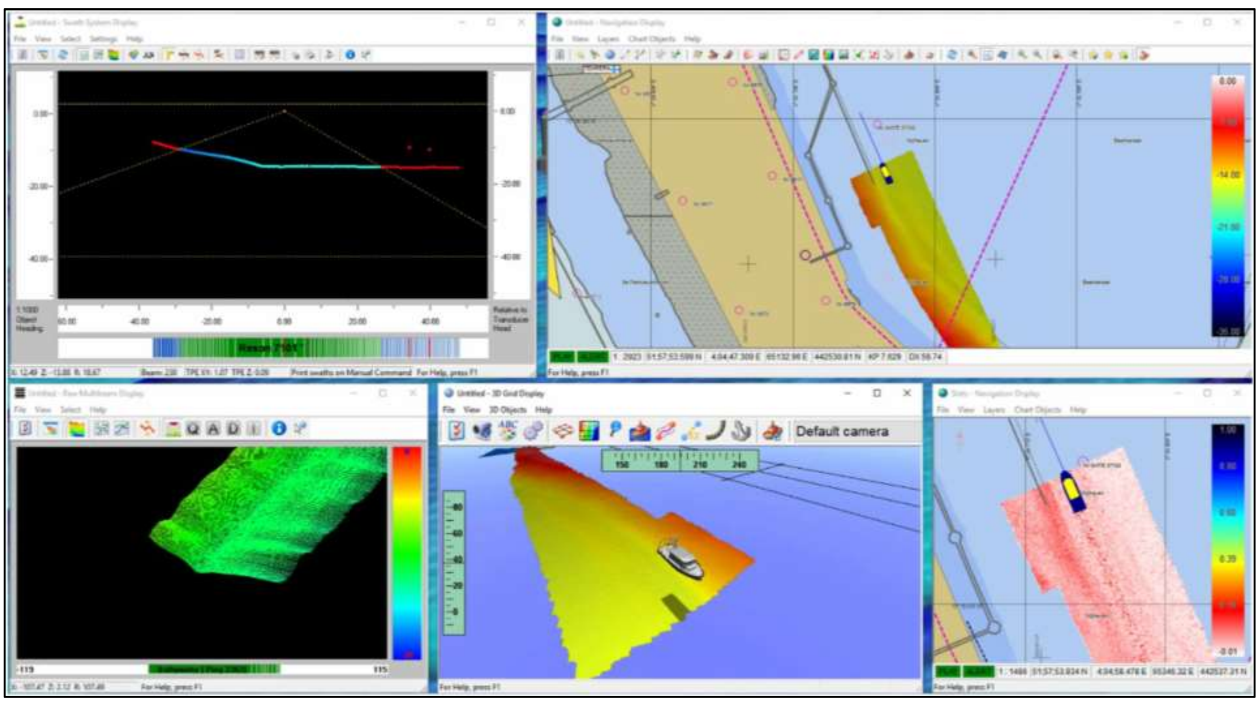

Figure 3: Standard displays in QINSy during acquisition include the raw (bottom-left) and processed (top-left) multibeam, and real-time gridding, both the bathymetry (bottom-middle and top-right) and standard deviation (bottom-right) layers. Seeing the gridded solution in real-time, as depth or as a statistical layer, immediately alerts the surveyor to any data quality issues.

In addition to its capabilities as a hydrographic data acquisition, navigation, and processing software, QINSy also has specific functionalities tailored to support laser systems, side scan sonar, dredging, seismic surveys, ADCP, magnetometer, sub bottom profiling, pipe-laying and inspection, rig moving, rock dumping, and has the flexibility to meet most any requirement related to offshore construction or oil and gas applications.

Qimera

Tedious and manual processes continue to persist in nautical charting workflows, thus it follows that human errors remain very common. These errors are also quite costly, as they have been proven to dramatically increase the time required for data throughput to chart (Evans, 2015).

Qimera adds tremendous value in the nautical charting pipeline simply by minimizing the opportunities for human operators to make those errors. The fundamental basis on how Qimera is designed is to automate to the furthest extent possible the mundane and error-prone tasks associated with hydrographic data processing, leaving humans responsible only for those tasks for which they are best-suited. The Four Design Pillars of Qimera (Beaudoin and Doucet, 2017) each have unique ways of improving both safety and timeliness in nautical charting workflows:

1) deep and intelligent data extraction from raw sonar files eliminates manual data entry to the furthest extent possible,

2) a guided workflow suggests to the user the necessary steps following their actions,

3) processing state management removes any ambiguity above what processing has been applied and what still needs to be applied, thus eliminating incorrect or redundant processing actions, and

4) a dynamic workflow ensures all necessary processing steps are kept up-to-date automatically, thus alleviating the need for users to conduct processing steps individually.

Altogether, the design of Qimera is an effective safeguard against the human errors and simple blunders most commonly made in hydrographic data processing workflows. Therefore, the accuracy of final products is improved, while also considerable time savings are realized. For further ease of use, Qimera also features automated patch test utilities, and Qimera Live, a function for near real-time processing. Automated data cleaning routines save further time—note that these can be set per client discretion—to run automatically over large batches, or step-by-step such that there are eyes on all soundings rejected.

There is value in the integration of Qimera with QINSy, wherein QINSy projects (and any processing accomplished in real-time) open directly in Qimera with no data conversion required. Per the first design pillar, all metadata found in all imported data formats are used, and nothing is lost—this includes vessel configurations and sound speed profiles. Thus, this information does not need to be imported separately or entered in manually, effectively preventing any human errors in the transcription or import. Naturally, Qimera will draw the most value from those data formats considered “rich” in metadata.

University research has been incorporated into Qimera quality assurance tools, such as the Wobble Test, which removes dynamic motion residuals from hydrographic data (Hughes Clarke, 2003), or the latest feature, which is the S57 functionality modeled after the NOAA QC Tool (Wilson, Masetti, and Calder, 2016)—Qimera features a built-in linkage between S57 features and the corresponding bathymetry to ensure parity between these data submissions and thus eliminating a very common source of error (Gonsalves, 2015). An example of the S57 update functionality in action is shown in Figure 4.

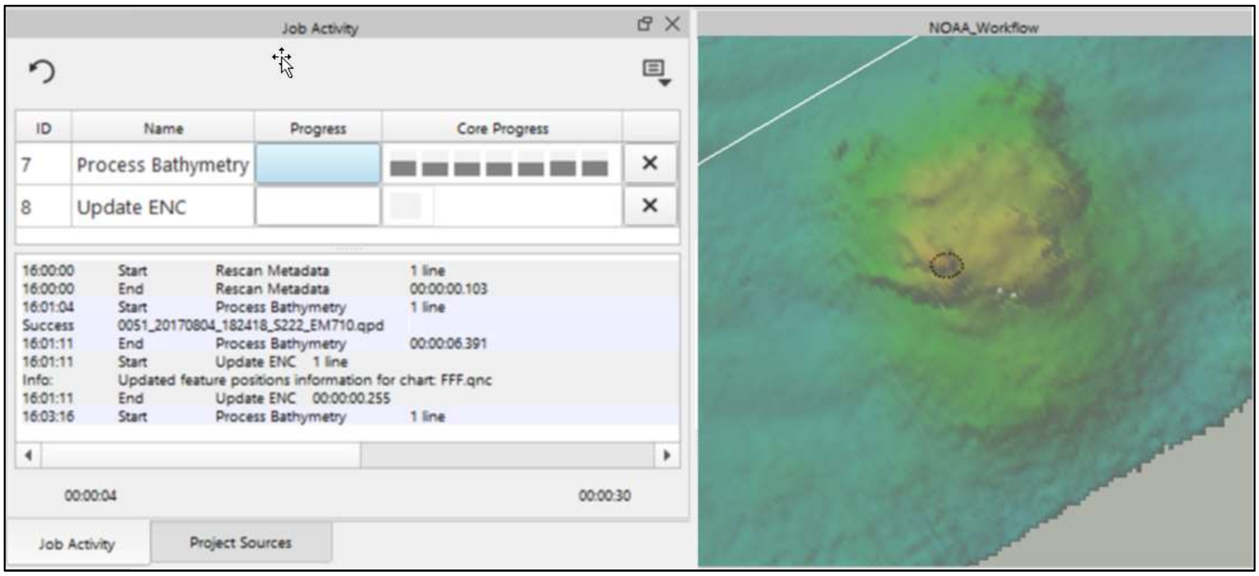

Figure 4: As shown in the Job Activity window above, post-processing steps performed to bathymetry in Qimera automatically updates the wrecks, rocks, and obstructions on a corresponding S57 feature file. This is accomplished via a link between the S57 attribute value of sounding (VALSOU) and either a particular sounding or grid node. This functionality leads to considerable time-savings in those surveys that encompass a multitude of features.

Finally, there is the integration of the technology into Qimera that was previously only available in Fledermaus. Water-column processing, for example, can be a critical component of nautical charting, as it has been demonstrated to improve safety of navigation by ensuring a more accurate least depth over wrecks in the case that a mast (or similarly narrow object) is missed in multibeam bottom detections (Wyllie, Weber, and Armstrong, 2015). In the Qimera workflow, users can quickly attain more conservative (and therefore safer) least depths atop wrecks and obstructions. An example is shown below in Figure 5. Additionally, backscatter processing capabilities, traditionally accomplished in Fledermaus, will likewise be ported into Qimera, so users can experience similar values in the direct integration with the bathymetric processing software.

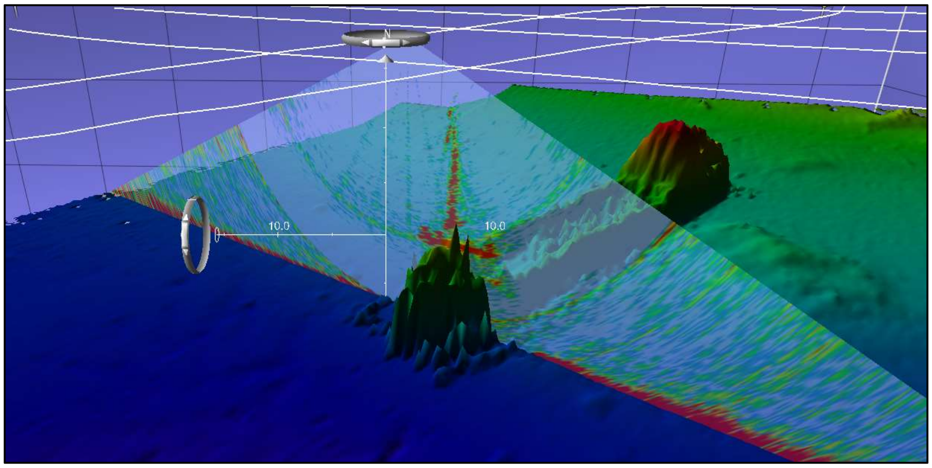

Figure 5. Water-column processing above a wreck reveals a mast with a more accurate least depth to be incorporated into bathymetry, ensuring the utmost in safety of navigation for those nautical charting products later derived.

Fledermaus

As a multi-functional toolbox, Fledermaus supports the nautical charting workflow in a variety of ways. Advanced 3D visualization and profiling tools are a well-established means of quality assurance to gridded bathymetry, as are sounding selections and shoal-biased thinning techniques. Most notably, however, is the wide variety of data types and formats supported by Fledermaus, which allows for an integration of multiple layers in 3D or 4D space, revealing important connections not previously realized, and providing ideal visuals for reporting.

From a nautical charting perspective, the advantages of the water-column processing available in Fledermaus are shown above in Figure 5. Seafloor backscatter provides additional information about the seabed that is important in chart products, particularly for ships looking for ideal anchorage sites. Fledermaus Midwater and Geocoder Toolbox are well-established and effective tools to accomplish both means of ancillary data processing that can be important complements to multibeam bathymetry. Users will be able to complete these actions in Fledermaus, or directly in Qimera, thus realizing the value in the integration with the processing software.

Lastly, Fledermaus has direct integration with ESRI ArcGIS for bathymetry and S57 database operability, additional analysis, and nautical chart creation. Examples of Fledermaus in action to support nautical charting is shown in Figure 5.

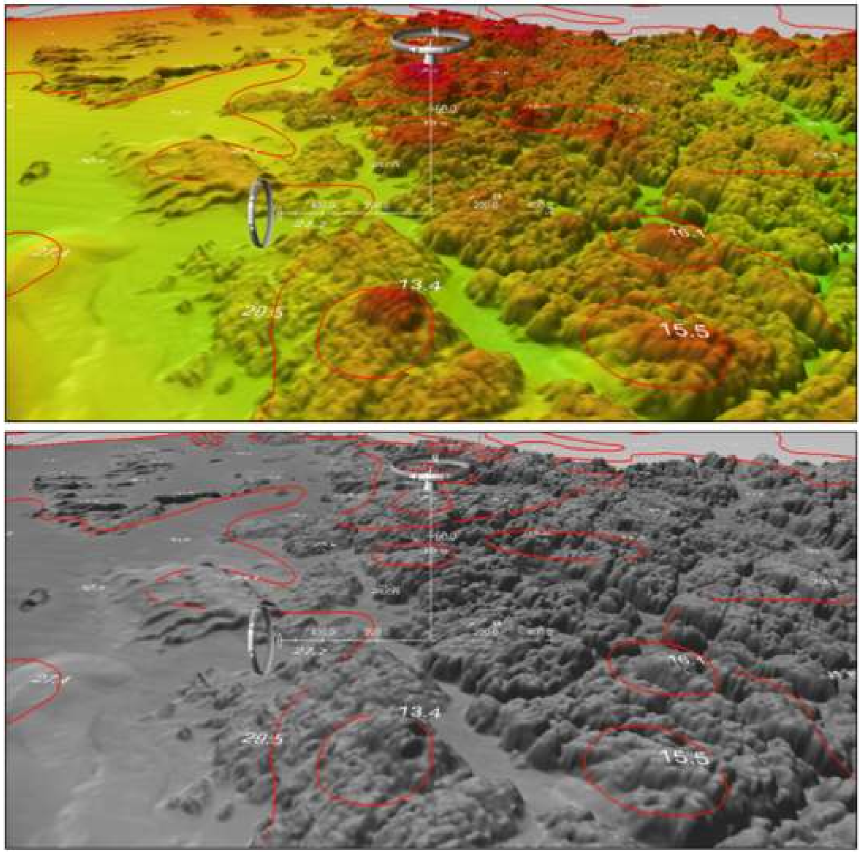

Figure 5: Examples of Fledermaus advanced visualization, in a charting context. Rock outcroppings are shown with ENC soundings and contours overlaid atop gridded multibeam bathymetry (top) and seafloor backscatter draped over the bathymetry (bottom).

Qarto

Qarto offers the rapid ENC production that is necessary for busy ports and waterways that require fast turnaround times. ENC base cells are required—these can be maintained in an ESRI ArcGIS for Maritime NIS (Nautical Information Systems) database, or composed separately. The ENC base cells are updated with those S57 features per present survey findings, but do not include the bathymetric S57 components such as depth contours, areas, and soundings. These are derived instead from a grid directly, or from the grids as maintained on an ESRI ArcGIS for Maritime BIS (Bathymetric Information System) database, extracted per rule file (e.g. most recent data on top).

From the bathymetric source, Qarto extracts the depth contours, areas, and soundings also via rule file that describe contour intervals and sounding radius. The generated bathymetric S57 components are then merged with the base ENC cells, resulting in the updated ENC products. Turnaround time, from survey acquisition to ENC update, is very rapid—as discussed in the case study below, the Port of Rotterdam can accomplish this in as little as six hours (van Reenen and Raines, 2015).

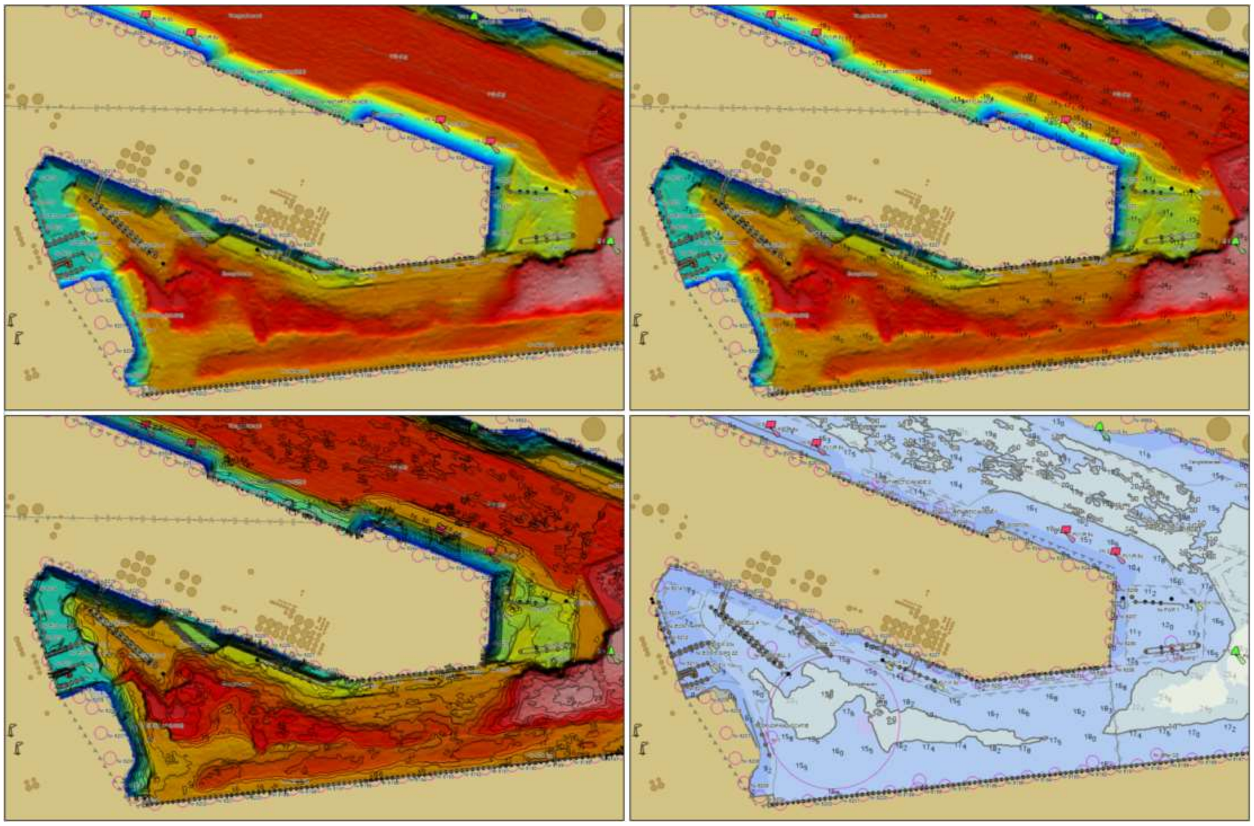

Figure 6: Qarto ENC production process. An ENC base cell overlain with the gridded bathymetry (top left). S57 bathymetric components are extracted per user-specified rule file and include the soundings (top right) and contours (bottom left). A final ENC product (bottom right) in this case features generalized bathymetry.

Additionally, Qarto specializes in the production of high density ENC or BENC (bathymetric ENC) products, which utilize considerably more bathymetric information than a standard ENC. Because some countries may prohibit the use of high density or BENC products, it is also possible to produce the high density bathymetric information as an overlay, atop an official ENC, such that requirements are still met. Qarto utilizes the QPS ENC kernel ("Qernel") for optimized ENC rendering—in standard practice, Qarto generates high density products with 10 cm contour intervals, and while still maintaining the rapid product turnaround time. Furthermore, the products adjust to real-time tide inputs, which results in more navigable water. Finally, Qarto also offers tools to generalize bathymetry, as well as S58 validation checks.

Qastor

The final step in the QPS Nautical Charting Workflow encompasses maritime safety in real-time with Qastor, a precise navigation software for piloting and docking. In addition to route planning and vessel path predictions, Qaster also utilizes the vessel's draft and required safety margin for underkeel clearance, distinguishing between safe and unsafe waters. Also supported is the high density ENC or BENC overlay with much finer contour intervals, thus safe water may be significantly expanded, resulting in much more flexibility in ship movement and greater overall port operations. In the same manner, real-time tide information in Qastor further enhances pilot information and port operations.

Qastor features a chart updating mechanism and receives the most up-to-date ENC products automatically via the Connect Server. AIS, already a standard feature, can be further supplemented to include radar imagery from a port Vessel Traffic System (VTS) for display in Qastor. Meteorological information is also distributed via the Connect Server and available in Qastor in real-time. This includes information about tides, currents, wave height, and wind speed and direction—note that the chart actually adapts to the real-time tide, and this is shown in Figure 7 below. Finally, information distribution via the Connect Server for display in Qastor is expandable, for customized real-time updates from other sources. Automated chart updates with real-time supplemental information results in the most optimal situation awareness for pilots, a critical attribute for safe navigation.

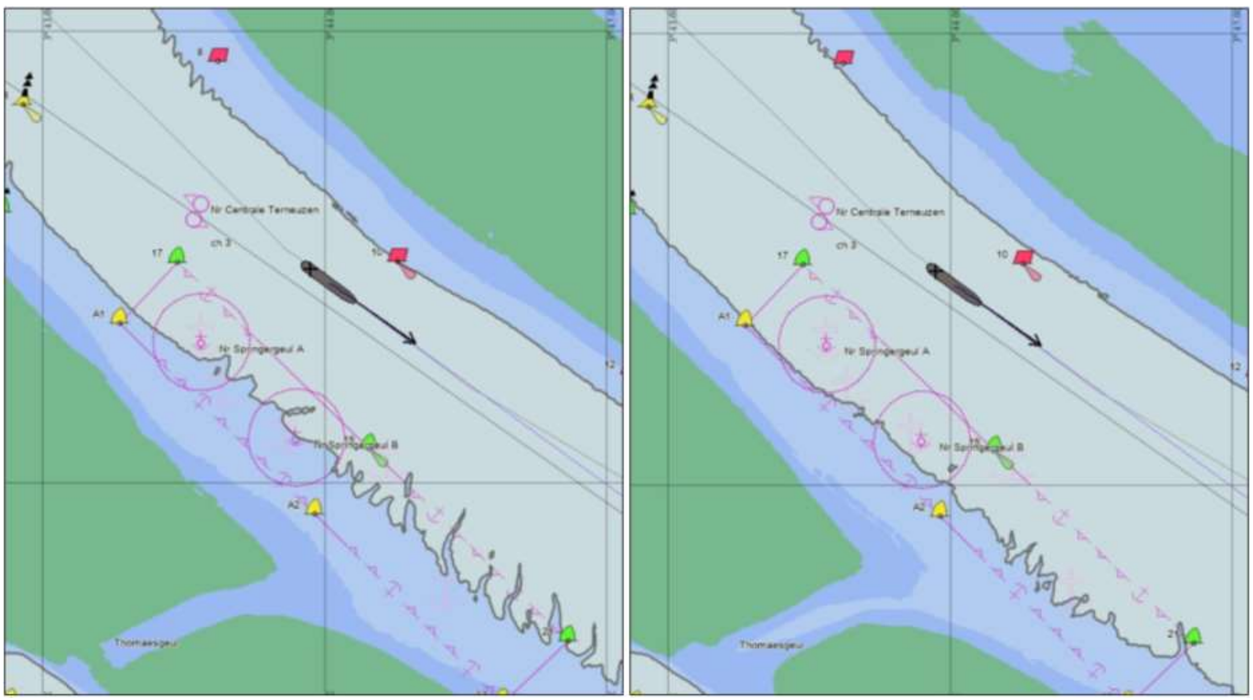

Figure 7: Chart display in Qastor adapts to the stage of tide in real-time. In this example, the tide is low (left), but rises 1.5 m to open up considerably more water (right) for vessels in transit.

Case Study: The Port of Rotterdam

The Port of Rotterdam is Europe’s largest seaport and a leading global one, with over 40 km of waterways and direct connections to large industrial regions. However, the port has high siltation rates—up to 6 million cubic meters of silt is removed each year (van Reenen and Raines, 2015)—and so regular dredging and surveying are required to keep the port accessible (Hill, 2017). Thus, with both high traffic and high changeability, the port was a leading candidate to benefit from the implementation of an ideal nautical charting workflow to achieve optimal port solutions.

Traditionally, the Netherlands Hydrographic Office only produced ENCs for harbor usage, until roughly ten years ago when a pilot project sought to produce to high-density "berthing" ENCs with rapid update rates, such that vessels could maximize their safe water (and "over-depths") with timely, high-resolution information, in order to optimize port operations (van Reenen and Nijsen, 2017). To result was a partnership between the Port of Rotterdam and ESRI to implement the PortMaps system, with QPS as the ENC production module. PortMaps went live in 2015. Due largely in-part to the QPS Nautical Charting Workflow, hydrographic surveys conducted each day in the Port of Rotterdam become a high-resolution ENC the very next, in active use by pilots and mariners alike.

Daily hydrographic surveys are conducted each day via multibeam echo sounder, the areas determined from siltation rates. QINSy handles not just the data acquisition, but the processing as well, which is accomplished onboard the vessel. After final verification, a digital terrain model (DTM) is generated from the fully processed data and sent to the Port of Rotterdam via network connection, where it is registered as a GeoTiff in an ESRI BIS. The updated survey results are compared against prior surveys to monitor siltation rates, which dictates future survey planning, and ensures the port's accessibility (van Reenen and Nijsen, 2017).

For the ENC update, the base cell is exported from an ESRI NIS, and Qarto receives the gridded bathymetry from the ESRI BIS. Qarto merges the ENC base cell with depth contours at 10 cm intervals to produce the high density ENC, which is then published to the various users in the Port of Rotterdam via the Marine Chart Server, part of the PortMaps system. Pilots using Qaster receive the timely, high resolution bathymetry automatically, and their accessibility to the port is maximized. While the "Sonar-to-Pilot" workflow in the Port of Rotterdam can be as little as six hours, it is generally finished over two days (van Reenen and Raines, 2015). A BENC overlay is shown atop a Primar chart in Figure 8 for a vessel utilizing Qastor.

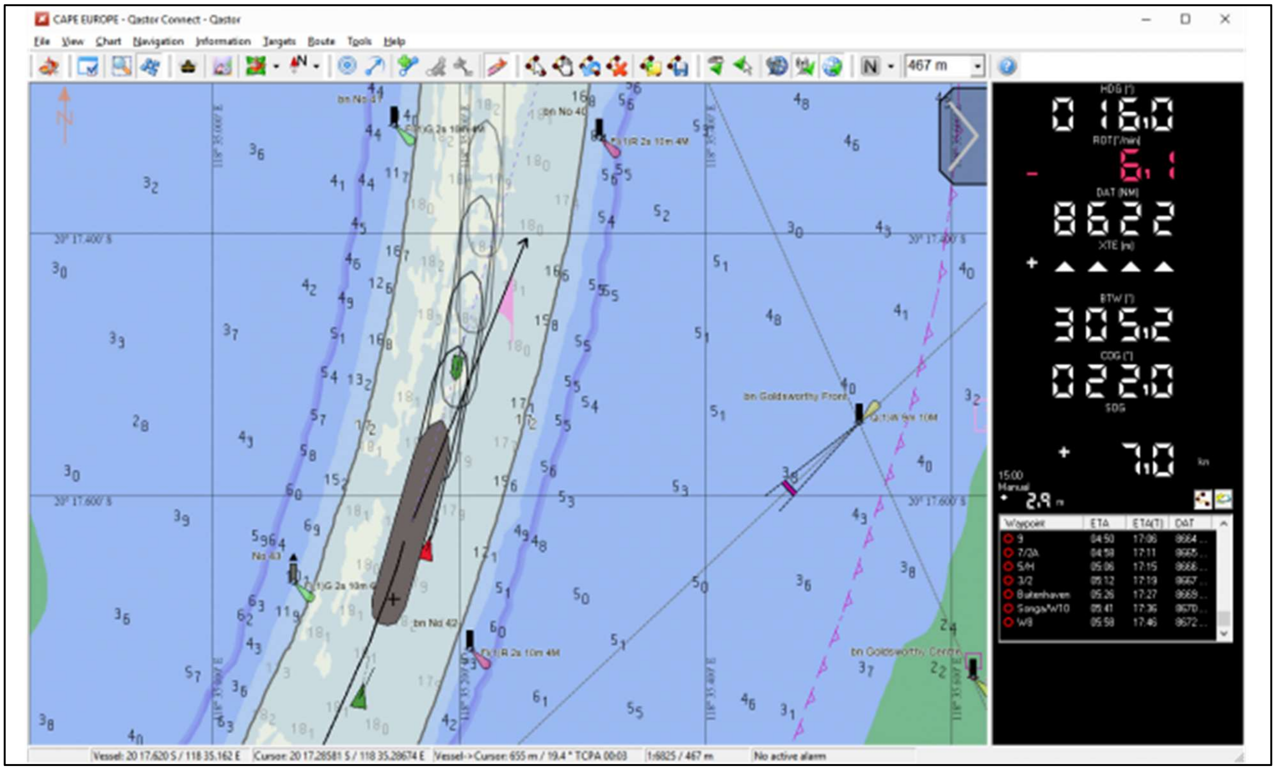

Figure 8: A vessel utilizing Qastor to navigate within the Port of Rotterdam has access to high density bathymetry in the channel via BENC overlay, atop a Primar chart.

Summary

Each component of the QPS Nautical Charting Workflow has capabilities that emphasize particular attributes identified as critical for optimal port solutions. The most prominent of these capabilities are categorized and shown in Figure 9. Note that accuracy is more or less synonymous with safety, because product accuracy is to ensure safety of navigation.

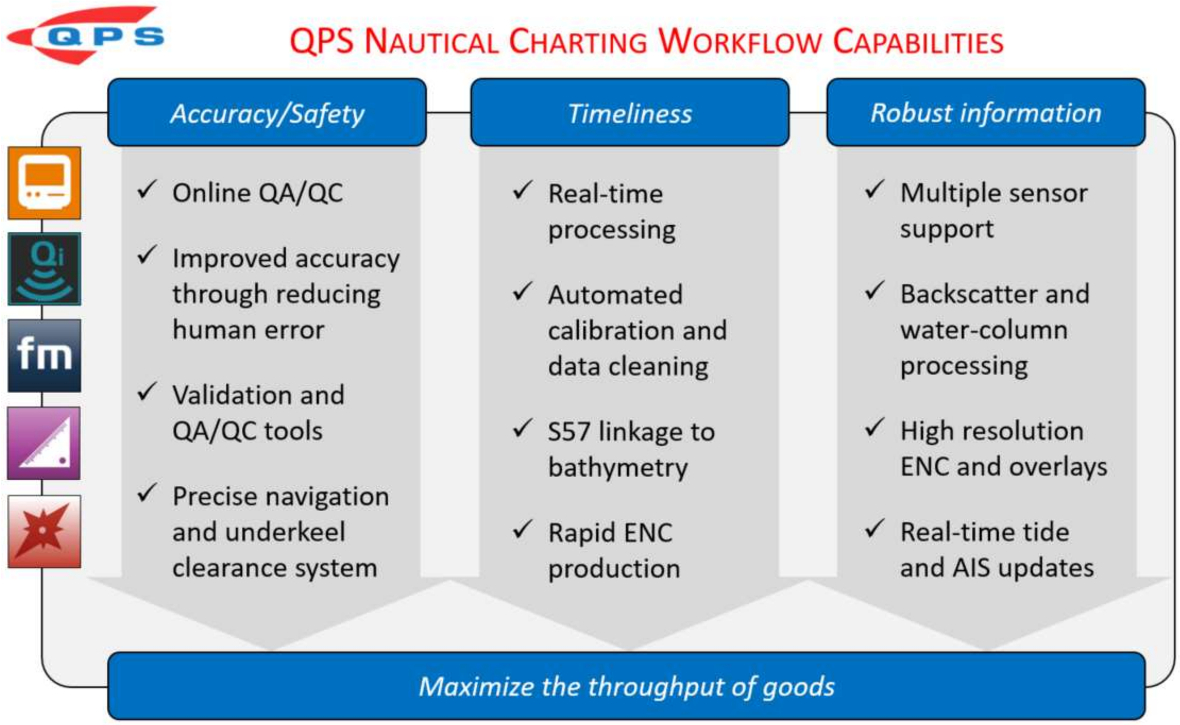

Figure 9: To achieve optimal port solutions, the QPS Nautical Charting Workflow ensures capabilities that emphasize accuracy (i.e. safety), timeliness, and robust information in order to maximize the throughput of goods.

The capabilities achieved in Figure 9 originate from base philosophies of implementing real-time processes and automation, incorporating university research, and overall design themes that improve upon traditional, legacy processes such that users are working smarter, not harder. Furthermore, while there is value in the integration of products, their modularity allows for pieces to be adopted as-needed to fit into any workflow. This is demonstrated in the Port of Rotterdam, where the implementation of parts of the QPS Nautical Charting Workflow has helped achieve unprecedented turnaround times of validated survey data to chart, maximizing port accessibility, the throughput of goods, and marine commerce overall.

Future Work

The QPS Nautical Charting Workflow will continue to incorporate timely and impactful research and technology, such as the efficiency to be gained through variable resolution gridding (Eisenberg, 2017), new methods of grid quality assurance (Wilson, Masetti, and Calder, 2017), as well as to stay on the cutting edge of laser scanning support. Additionally, there is the methodology to extract authoritative data from a database (Wyllie et al, 2017), rather than the simple rule of "most recent data on top", which can greatly benefit product creation for hydrographic agencies with multiple source data inputs. Finally, there is the potential great value in utilizing a bathymetric grid directly into a piloting software, such that cartography is merely a display function drawing from the highest-resolution data available. Ships then have the most navigable water space based on the best information available, and time-consuming cartographic processes to generalize high-resolution data are no longer necessary.

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