Hydrographic Survey Validation and Chart Adequacy Assessment Using Automated Solutions

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Within the HydrOffice framework, NOAA's Office of Coast Survey and the UNH Center for Coastal and Ocean Mapping have jointly developed (and made publicly available) a pair of software solutions - QC Tools for quality control and CA Tools for chart adequacy - that collect algorithmic implementations to automate and standardize a large portion of the quality controls used to analyze hydrographic data. After having described what is Pydro Universe, the community surrounding these tools and the relevant feedback from a recent customer satisfaction survey, this work describes a new chart adequacy algorithm and an experimental approach for bathymetric anomaly detection and classification.

Introduction

The rising trend in automation is constantly pushing the hydrographic field toward the exploration and the adoption of more effective approaches for each step of the ping-to-public workflow [1-6]. However, the large amount of data collected by modern acquisition systems - especially when paired with the force multiplier factor provided by autonomous vessels - conflicts with the increasing timeliness expected by today's final users [7-9]. As such, it is not that surprising that both an improved hydrographic data accuracy and a faster throughput from acquisition to publicly-available data (e.g., chart application) are current priorities for any hydrographic office (HO)(e.g., [10]). Such priorities represent a processing challenge for the largely human-centered solutions that are currently available, and the adoption of automated and semi-automated data quality procedures seems the only scalable and long-term solution to the problem [11-13]. At the same time, there is an inherent value in propagating the application of such procedures upstream in the survey workflow [14]. Capturing potential issues close (in time and space) to their occurrence has the advantages of reducing the efforts required for their solution and limiting their extent. As such, modern surveys should rely more and more on robust data quality procedures that are applied in near real-time.

With the challenge to automate and standardize a large portion of the quality controls used to analyze hydrographic data, NOAA's Office of Coast Survey (OCS) and the UNH Center for Coastal and Ocean Mapping / NOAA-UNH Joint Hydrographic Center (CCOM/JHC) have jointly developed (and made publicly available) a pair of software solutions - QC Tools for quality control and CA Tools for chart adequacy - that collect algorithmic implementations for a number of these tasks. Their aim is to verify whether the acquired data satisfy the adopted agency standards (and, in a more general sense, fit for the intended purpose). These standards usually focus on data quality aspects like data density, coverage, and uncertainty evaluation which are largely automated by the developed tools discussed in this paper, leaving to the experienced hydrographer the duty to review the results and supervise the validation process.

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After a brief overview of the Pydro community (https://svn.pydro.noaa.gov/) and the HydrOffice framework (https://www.hydroffice.org/) in which these tools have been developed, we present the relevant feedback from a recent customer satisfaction survey. This work then focuses on an experimental approach for bathymetric anomaly detection/classification and a new chart adequacy algorithm [5].

Background and Community Feedback

Pydro Universe (https://svn.pydro.noaa.gov/) is both a NOAA OCS Python-based distribution and a collection of open-source hydrographic tools covering a variety of subjects such as data processing, positioning and datums, tides, sound speed, and report generation. Although its origins go back to 1994, the majority of the code underlying Pydro was made open source in 2016. At the same time, the Pydro installers were made publicly available, and an application named Pydro Explorer (Figure 1) was introduced to ease the access to the available tools, discover newly introduced ones, and automate the updates of the various components. The Pydro code and infrastructure are developed and maintained by the NOAA OCS's Hydrographic Systems and Technology Branch. Instructions on how to download and install Pydro are available at https://svn.pydro.noaa.gov/Docs/html/Pydro/downloads.html.

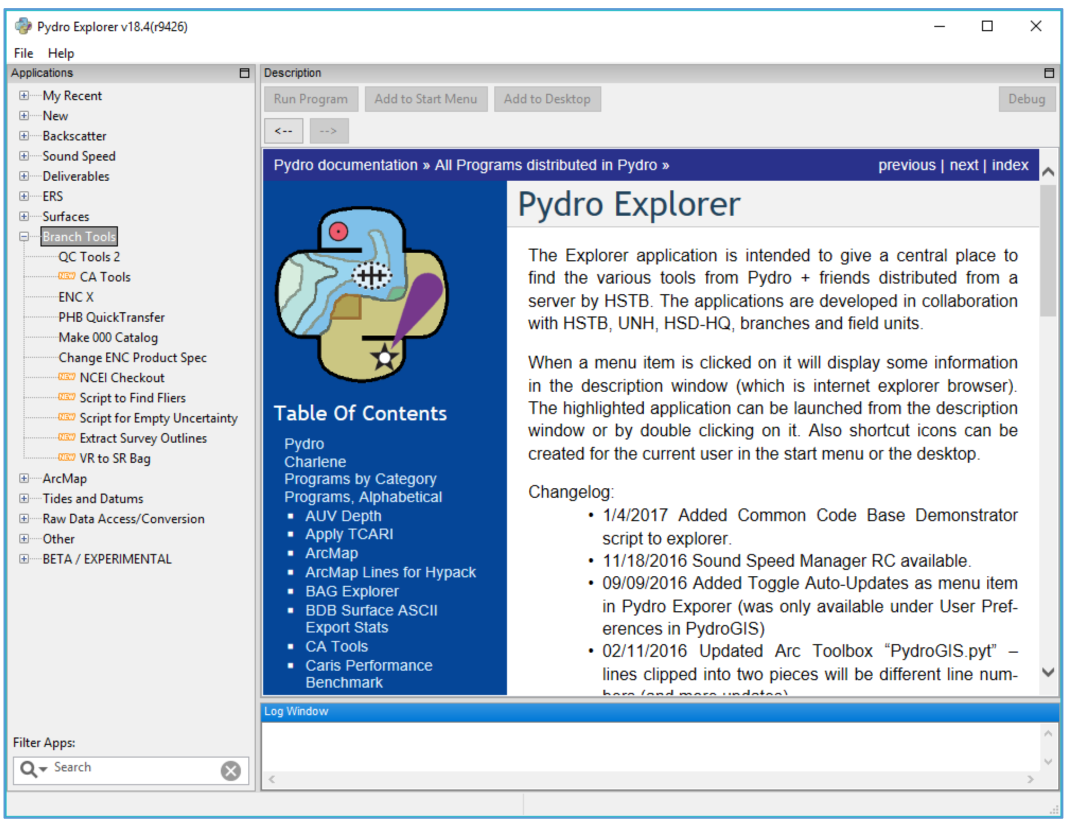

Figure 1 – The Pydro Explorer application helps to access the tools available in Pydro. Each tool is accessible by navigating a tree (on the left side of the application window) where the applications are grouped in themes (e.g., the "Brach Tools" hosts both QC Tools and CA Tools).

Furthermore, and most importantly, the open-sourcing of Pydro has triggered the creation of a growing community of coders and users with a common interest in ocean mapping. Pydro was originally created and is primarily maintained to support NOAA OCS operations. However, now that its infrastructure is accessible to the general ocean mapping community, Pydro represents the ideal environment to test new research ideas and prototype improvements in agency specifications. For all these reasons, Pydro represents the ideal environment for the kinds of applications that are developed within the HydrOffice framework. (For more information about the framework, visit https://www.hydroffice.org/.)

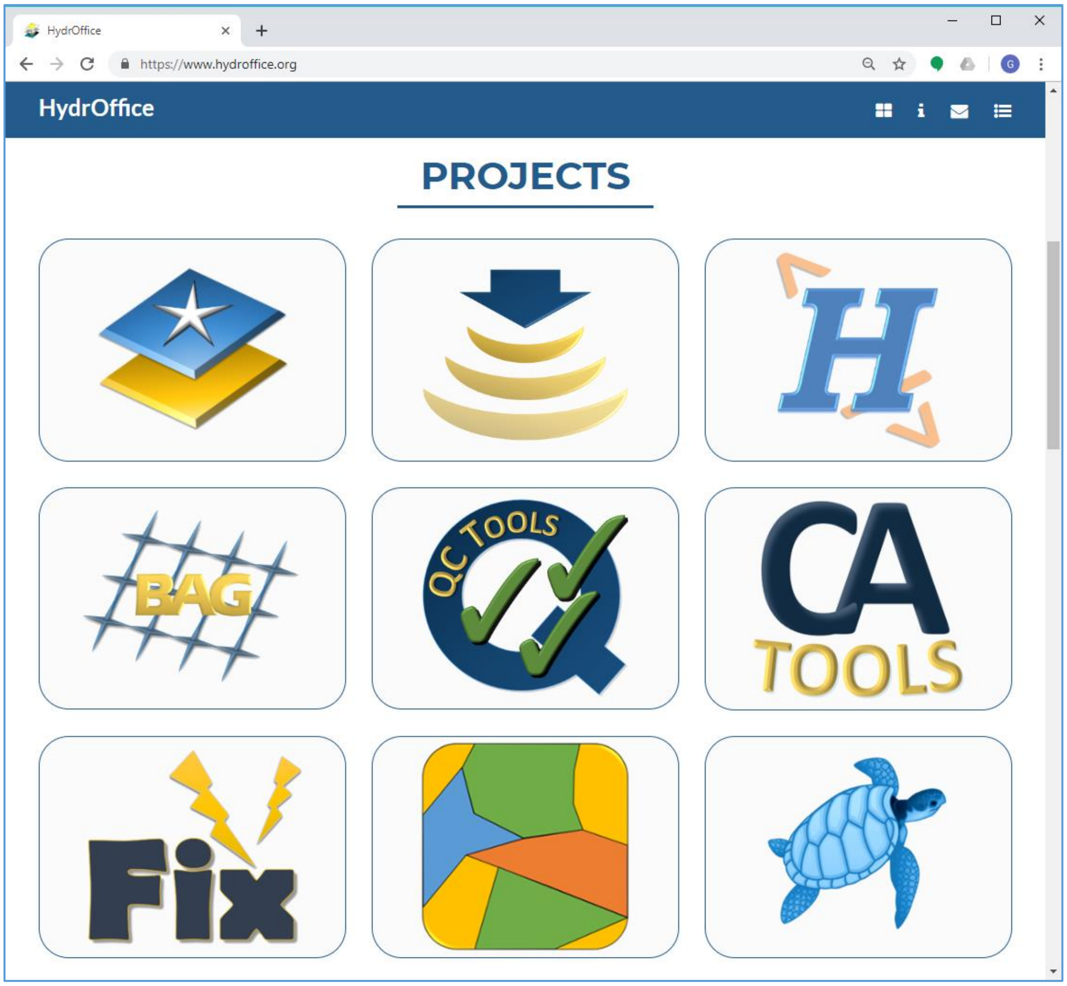

Figure 2 – The HydrOffice main page provides access to a number of projects with related information such as manuals, code repositories, tutorials, and stand-alone applications.

HydrOffice is a collaborative effort – led by the CCOM/JHC – that has been developing since 2015, and its rationale is the creation of a framework of libraries and tools for ocean mapping to quickly prototype and test innovative ideas by lowering the barrier to implementation and, thus, easing the transition from research to operation[15]. In the past years, several applications have been created as part of the HydrOffice initiative (Figure 2) and made available in the Pydro environment as one of the major means of their distribution. These applications span from the management of hydrographic data formats [16-18] to the evaluation of the oceanographic conditions on the survey data [2, 4], from mosaic artifacts identification [13] to seafloor segmentation [19]. This work focuses on two of them – QC Tools for quality control and CA Tools for chart adequacy – that collect algorithmic implementations to automate and standardize a large portion of the quality controls used to analyze hydrographic data.

QC Tools has seemed to gain high popularity in the past years and its development has surely benefited from direct feedback from the Pydro community. However, to obtain a better understanding of strengthens and weaknesses of the application, a customer satisfaction survey was designed and executed during Winter 2018-2019. The users were asked a set of questions (with the aim to focus on specific subjects of interest) but also had the opportunity to provide feedback in an open form.

This paper presents the results of the most relevant among those survey questions:

1. How frequently do you use QC Tools? (See Figure 3)
2. What is your general evaluation of QC Tools? (See Figure 4)
3. How did you learn how to use QC Tools? (See Figure 5)
4. How would you evaluate the manual? (See Figure 6)
5. How do you evaluate the performance of Find Fliers v7? (See Figure 7)
6. What are your favorite tools? (See Figure 8)
7. Which tool would you improve first? (See Figure 9)

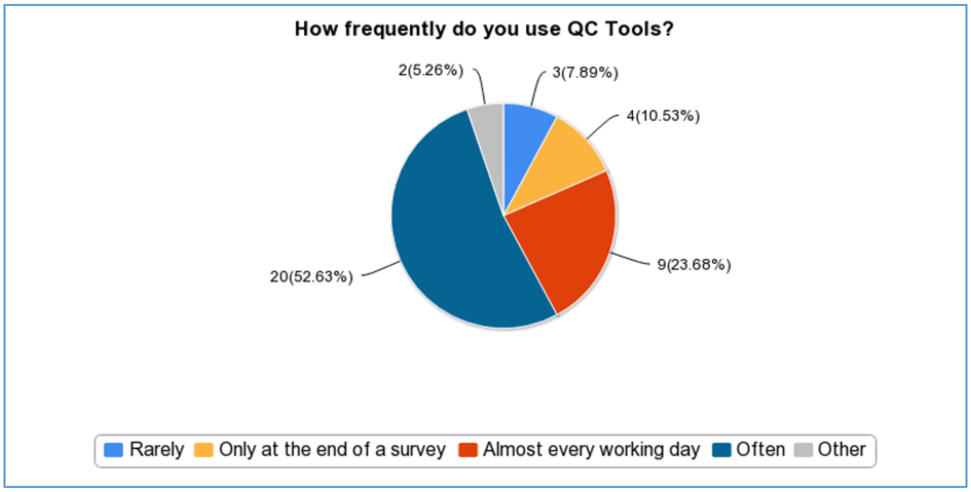

Figure 3 – Survey results for "How frequently do you use QC Tools?" question.

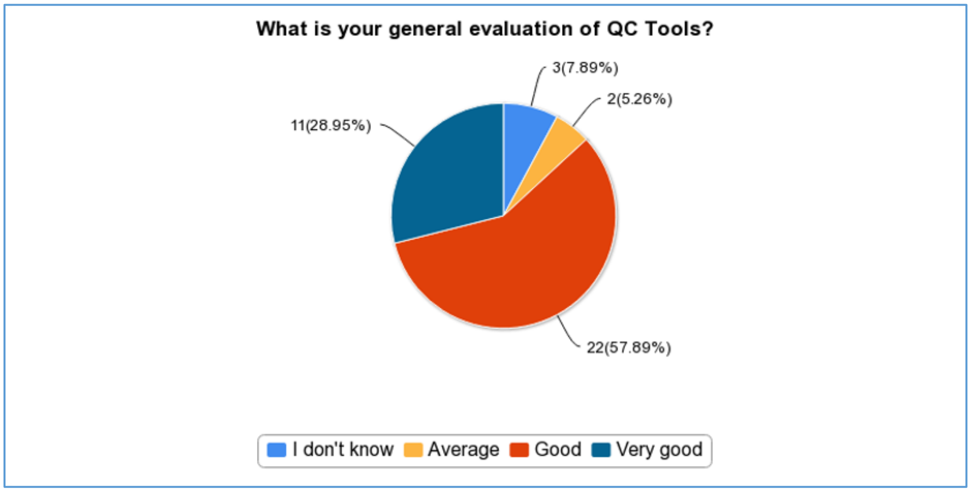

Figure 4 – Survey results for "What is your general evaluation of QC Tools?" question.

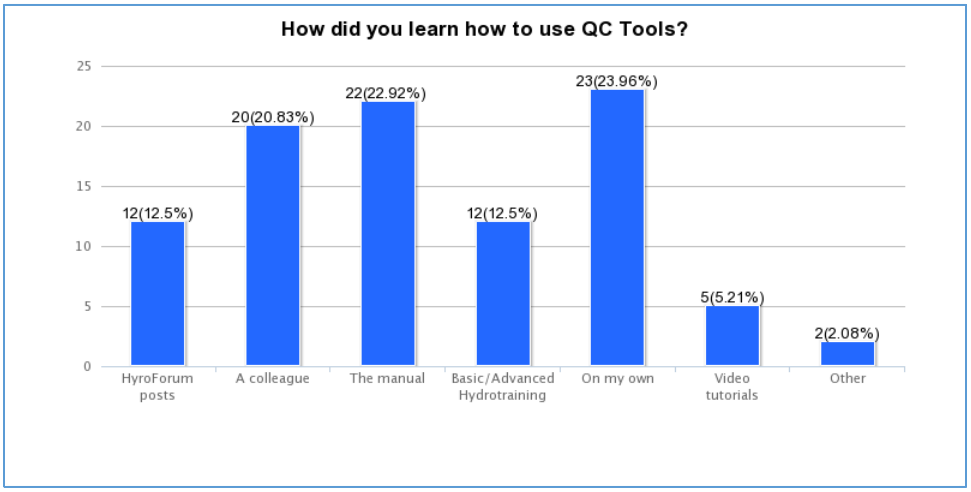

Figure 5 – Survey results for "How did you learn how to use QC Tools?" question.

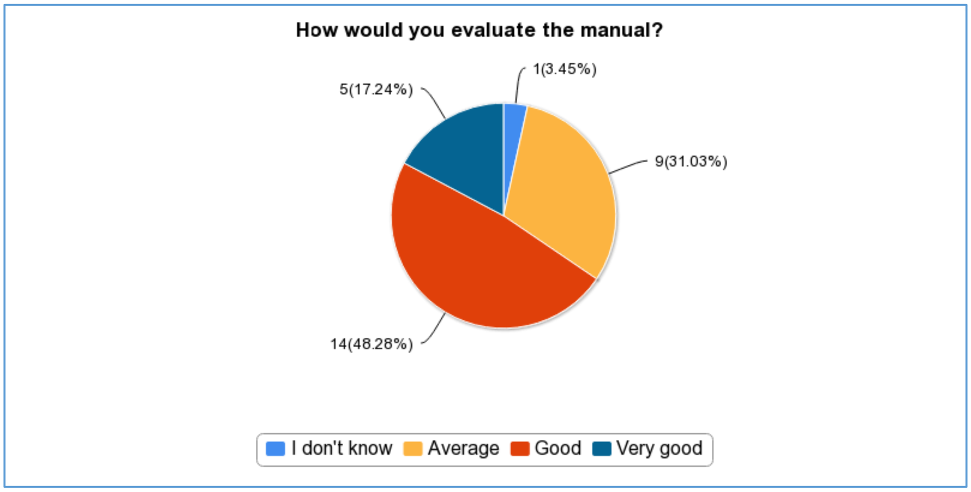

Figure 6 – Survey results for "How would you evaluate the manual?" question.

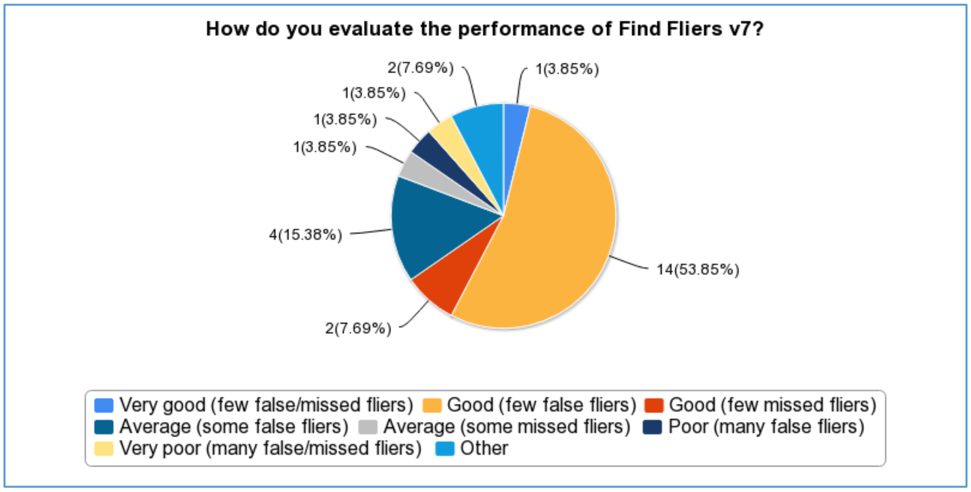

Figure 7 – Survey results for "How do you evaluate the performance of Find Fliers v7?" question.

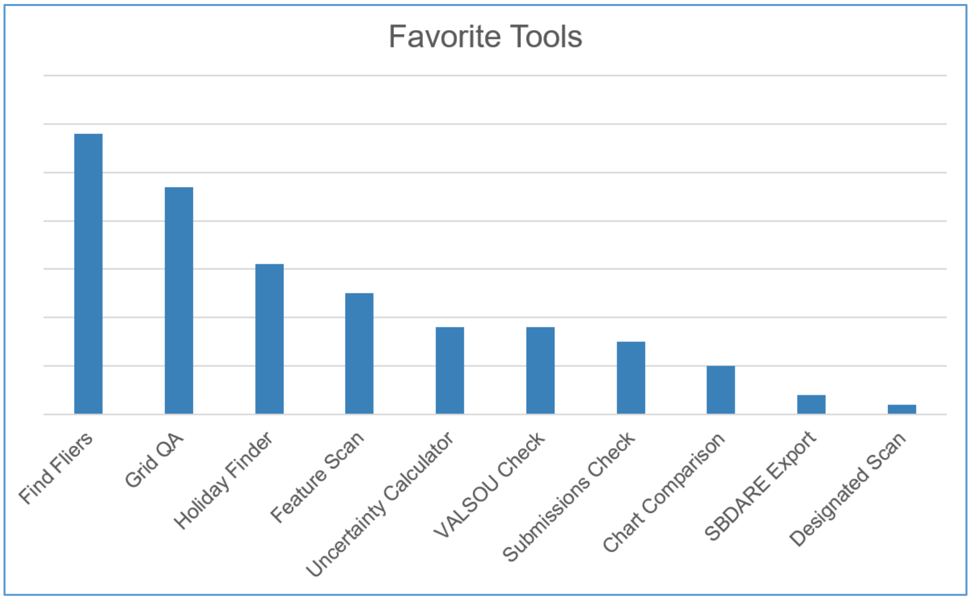

Figure 8 – Survey results for "What are your favorite tools?" question.

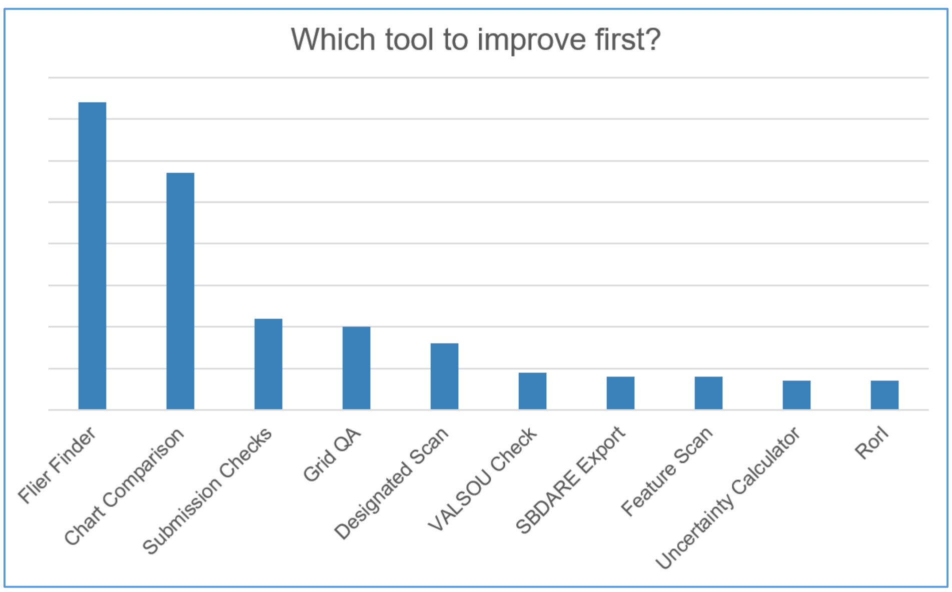

Figure 9 – Survey results for "Which tool would you improve first?" question.

Of the 39 survey respondents, more than 75% use QC Tools "often" or "almost every single working day" (Figure 3), A percentage even higher (more than 85%) evaluated the application as "good" or "very good" (Figure 4). These results confirm that QC Tools has been easily adopted in hydrographic processing workflows and that the users perceive it as a means to improve the processing efficiency and the survey data quality. Furthermore, the results from Figure 5 show that the relative majority of the respondents learned how to use QC Tools on their own, while more than 65% of the respondents evaluate its manual "good" or "very good" (Figure 6). Although there is space for improvements, the target of creating a tool easy to use and understand seems to be adequately achieved.

Figure 7 shows the results of the performance evaluation of the latest version (at the time of the survey) of the Find Fliers algorithm. This algorithm identifies bathymetric anomaly in gridded data (more details on this algorithm is provided in the QC Tools and Anomaly Detection section). Not only such an algorithm is the most favorite tool (Figure 8), but it is also the tool that the majority of the survey respondents suggests improving (Figure 9). At the same time, Figure 9 shows that Chart Comparison is clearly the second suggested tool to be improved by the respondents.

Research and development efforts have been triggered by the described results of the customer satisfaction survey. The reminder of this work presents the efforts to overcome the current limitations of the Find Fliers algorithm, with a new algorithm named Anomaly Detector, and the Chart Comparison algorithm, with the creation of a stand-alone application named CA Tools.

QC Tools and Anomaly Detection

Although a number of challenges may affect the review of survey data to ensure accuracy of the final products, the removal of anomalous grid data that are not representative of the seafloor (Figure 10) is among the most significant [12]. Bathymetric anomalies are particularly problematic to the objectives of accuracy and timeliness because they very likely generate inaccurate spatial representations in the final survey products. Not only a significant amount of time and effort are required to correct those anomalies, but this correction triggers the need to regenerate the grid products, compromising the lineage of the original field submission and thus potentially creating complications during the ensuing review [14].

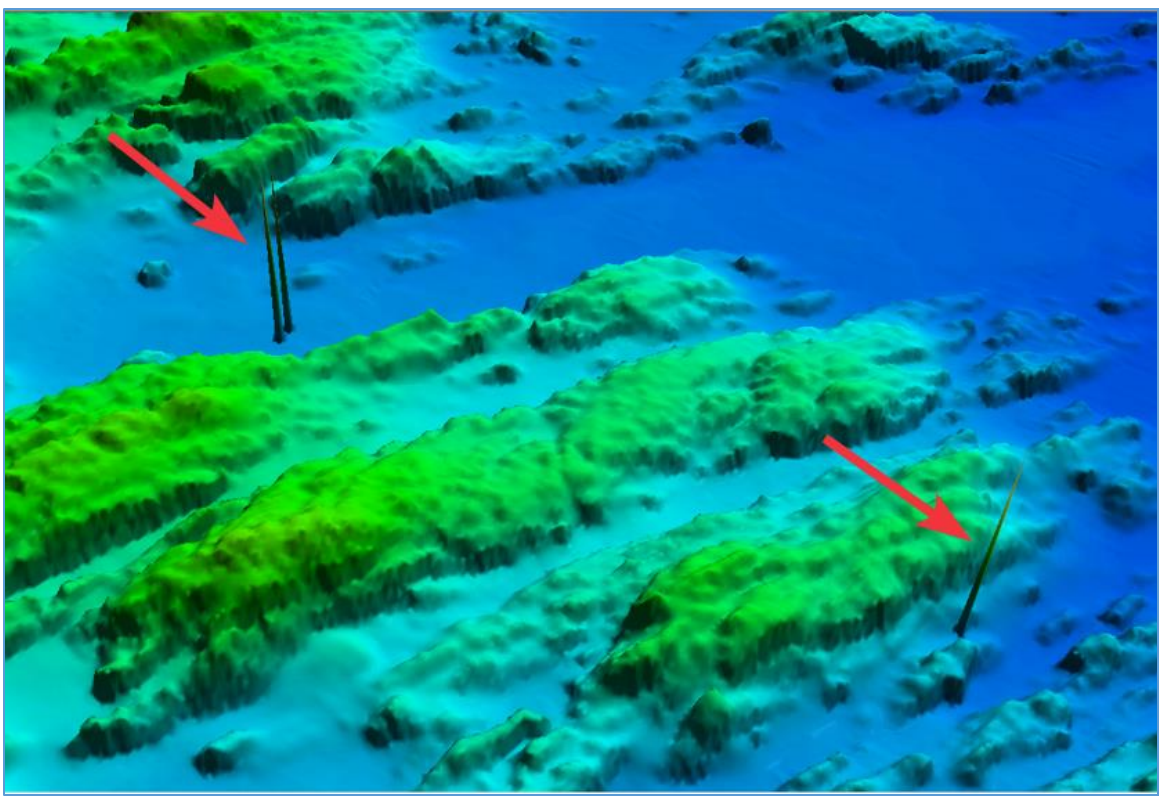

Figure 10 – Examples of anomalous grid data that are not representative of the seafloor (red arrows).

Modern survey review no longer inspects every acquired sounding. Instead, the reviewer identifies areas on the grid where to perform "spot-check" based on grid-based metrics, shoal-biased sounding selections, and 2D/3D visualization. Common metrics of interest are the uncertainty and, in case of CUBE (Combined Uncertainty and Bathymetry Estimator)-based grids, the number and strength of hypotheses associated to each grid node [7]. Hydrographic software packages usually have functionality to calculate user-customized layers applying grid math and to set view filters and customized color maps for all the grid layers. Although useful during grid review, these approaches bring a relevant component of subjectivity into the data processing workflow [11], and may be of limited effectiveness [20]. Thus, there are clear advantages in developing means to automate at a large extent this process.

Flier Finder [14], whose development started with QC Tools (https://www.hydroffice.org/qctools) creation, is specifically tailored to identify bathymetric anomalies (aka, "fliers"). The sensitivity of the search is estimated based on the characteristics of the grid to be analyzed [11]. Flier Finder adopts six different algorithms (see Figure 11) designed to flag anomalies that are "internal" to the grid ("Laplacian Operator", "Gaussian Curvature", and "Adjacent Cells"), adjacent to the edges ("Edge Slivers" and "Noisy Edges") or far detached ("Isolated Nodes"). If a potential grid anomaly is found, a flag is registered indicating that a grid node requires further review. After the execution of the selected algorithms, an optional final step was recently introduced to filter the identified potential anomalies based on point features associated with a depth value, retrieved from feature files in IHO S-57 format, and/or designated soundings from Bathymetric Attributed Grids (BAGs).

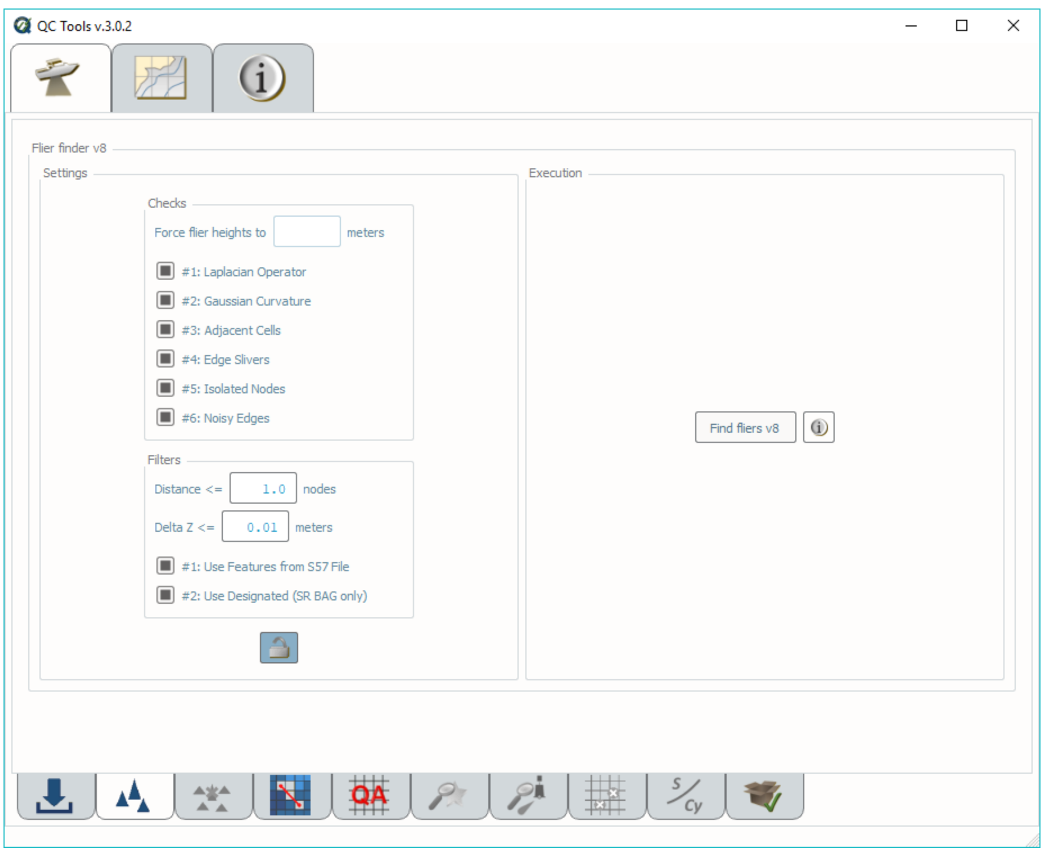

Figure 11 – Screenshot showing the user-interface for Find Fliers v8 in QC Tools. On the left side, the user-modifiable settings (such as which algorithms and filters to apply) are visualized.

A key point of applying automated algorithms like the ones performed by Flier Finder is reassuring the reviewer that all of the nodes in the grid have been evaluated objectively. On the other side, the automated evaluation can only be as good as the algorithms applied during the scan. Thus, there may be missed anomalies or excessive "false positives" (i.e., candidate anomalies where actually none exist, thus requiring review time to disprove them).

The basic idea behind the Flier Finder algorithm is to help to prioritize the manual review on specific grid areas rather than spreading efforts equally across the whole grid. On this aspect, the search height estimation plays an important role to ensure an efficient use of the tool: the number of potential fliers returned by the tool should be as close as possible to the number of real grid anomalies. An excessive number of false positives afflicts the review efficiency; conversely, a too coarse level for search height may have the more adverse effect to miss real grid anomalies.

The recent introduction of variable resolution (VR) surfaces in the NOAA OCS workflow offered the opportunity to revisit some foundational concepts in Find Fliers [21, 22]. With single-resolution (SR) grids, the NOAA OCS specifications prescribe a fixed resolution value to be adopted based on well-defined depth ranges [23]. This approach cannot be directly translated to VR grids. In fact, by definition, the key characteristic of a VR surface is of being able to accommodate gridded nodes at the best resolution based on the collected survey data. This fact has triggered the development of a new algorithm, named Anomaly Detector, that – although based on many of the original ideas of Flier Finder – moves the estimation of the search height to a local level. This calculation is performed by first deriving a set of local proxies (the median, the normalized median of the absolute deviation, and the standard deviation of the gaussian curvature) from the bathymetric layer, then combining those values into a local value of search height and gaussian curvature threshold (Figure 12). These two values are then used in the anomaly detection algorithms.

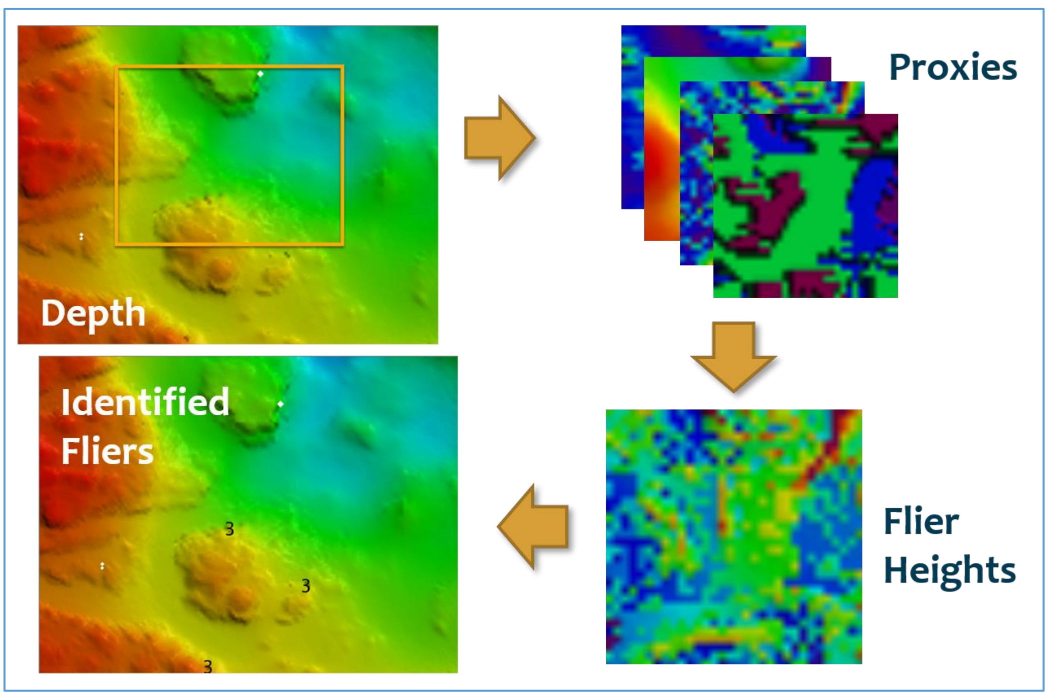

Figure 12 – Workflow adopted to calculate from local proxies and then apply the search heigh for the Anomaly Detector algorithm.

The results of a recent case study demonstrated the effectiveness of automated Find Fliers algorithms in certain conditions [11], as do the recent observations [9] that suggest improved timeliness and data quality in Coast Survey, in-part due to wide adoption of QC Tools, both in the field and in the office. The results from the customer satisfaction survey and the new challenges introduced by the introduction of VR surfaces triggered the design and the creation of the Anomaly Detector algorithm. The encouraging preliminary results support the operational adoption of the Anomaly Detector as part of QC Tools.

CA Tools and Chart Discrepancies

A nautical chart may be compiled from data sources of very variable quality. Some charted areas may be represented based on data from modern surveys, while other parts may have not been resurveyed since the eighteenth century. Since the last surveys in the area, new marine facilities and/or routes may also have been established [24]. With a similar effect of making the chart obsolete, natural events may have heavily modified the condition of the premises [25]. The direct result of this described situation is that the chart quality heavily depends on the data sources (that have been used in its derivation), but also that the fighting against chart obsolescence is a never-ending task.

The execution of a modern survey delivers a large amount of data; the information content must then be extracted and evaluated against the current available charts to identify changes. This operation is never simple also because of the number of transformations applied to a survey sounding before being ready to have its information content represented on a nautical chart [1, 26]. The criterion leading the chart compilation is the usefulness to the mariner in relation to the scale of the chart and the surrounding details [27]. When a less significant feature may obscure more important ones, it is often excluded; conversely, areas requiring more detailed bathy-morphological information may be enriched by a selection of trend-meaningful charted soundings and depth contours to help the mariner to properly interpret the seafloor morphology. This complexity often conflicts with the requirements to quickly identify discrepancies for its rapid dissemination to support the safety of navigation [25], and thus represents a challenge to many cartographic agencies [8, 28]. To identify chart discrepancies, those agencies usually adopt manual or semi-automated processes that are the results of best practices developed over the years. Unfortunately, such processes require a substantial level of human commitment and are prone to errors. The described situation outlines our rationale for the development of a chart adequacy application, named CA Tools (https://www.hydroffice.org/catools), that not only automates the change detection process, but also reduces its subjectivity [5].

The proposed algorithm starts by retrieving a set of depth points from a nautical chart, then it leverages such a set for the creation of a triangulated irregular network (TIN). Historically, a “traditional” triangle test (Figure 13, left pane) that uses the least among the depths at the vertices has been recommended to evaluate the chart discrepancy for soundings [6]. To overcome the inherent limitations of such a test we propose (and apply) a tilted-triangle test (Figure 13, right pane) to the input survey soundings against the 3-dimensional TIN [5, 29]. However, due to the complexity of modern nautical charts, the algorithm also applies additional sounding-in-specific-feature tests. More details on the algorithm implementation are provided in [5].

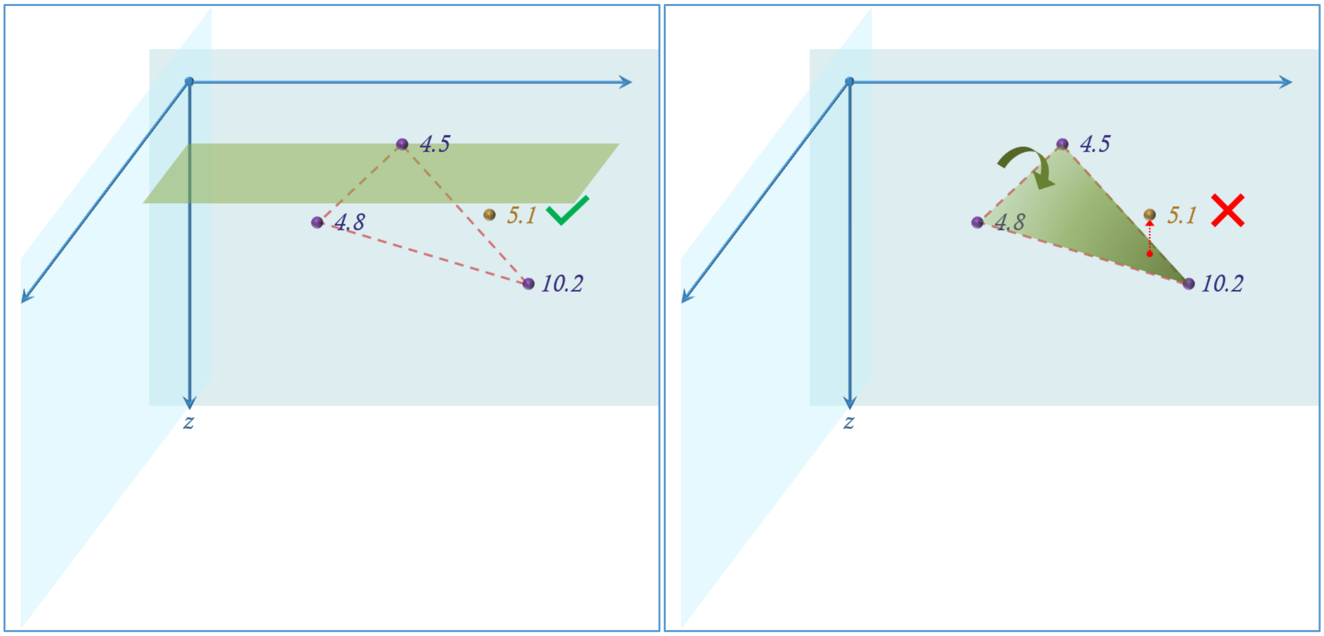

Figure 13 – Example of the application of the traditional triangle test (left pane) and the proposed tilted triangle test (right pane).

In output, the CA Tools provides:

- Danger to Navigation (DtoN) candidates.
- Chart discrepancies.
- "Deep" chart discrepancies (optionally).
- Features that require human evaluation (if any).

The algorithm has been successfully tested with Electronic Navigational Charts (ENCs) and survey datasets (see [5]).

Conclusions

This paper presented the results of a customer satisfaction survey on HydrOffice QC Tools. The survey has been instrumental to identify the two areas of major interest for improvements: identification of bathymetric anomalies and detection of chart discrepancy after new survey data.

By potentially causing inaccurate portrayal of the seafloor, bathymetric anomalies must be remediated before the creation of final survey products. Since there is evidence that traditional methods are not sufficient to ensure the detection of such anomalies (and thus compromise the original field submission), automated algorithms have been developed in QC Tools. This work specifically describes the introduction of the Anomaly Detector algorithm that, by estimating local search height, aims to improve the performance of the existing Find Fliers in the analysis of VR grids.

Supporting maritime safety through timely and accurate identification of nautical chart discrepancies constitutes a key task for marine cartographic agencies. Since the current manual or semi-automated processes require a substantial level of human commitment, we recently developed a new algorithm that aims to both automate the change identification process and to reduce its subjective component.

In parallel to the research effort, a prototype application implementing the algorithm was created and made publicly available in Pydro and as stand-alone application (downloadable from the HydrOffice website).

Finally, although the tools described in this paper focus on the NOAA OCS requirements, their modularized architecture should facilitate the customization and the adoption from any hydrographic and cartographic agency.

Acknowledgments

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