Articles

EVALUATION OF A CROWD SOURCED BATHYMETRIC APPROACH

By Barry Grinker[1,2], Shaul Solomon[3] and Assif Hassin[3]

[1] Technion - Israel Institute of Technology, Mapping & Geo-Information dept., Haifa, Israel
[2] LIA Engineering & Surveying Ltd, Haifa, Israel
[3] DockTeck Ltd., Tel Aviv-Jaffa, Israel

Abstract

Crowd-Sourced Bathymetry is the process of generating a harbor chart through collecting, enriching, processing, and aggregating depth (and other) measurements from a host of vessels, using standard navigation instruments, while engaged in routine maritime operations. This study explores the accuracy and limitations of one particular approach towards utilizing Crowd-Sourced data, comparing the results obtained from DockTech's approach to that of a classic MBES survey. As DockTech is a for-profit startup that sells their product to various stakeholders in the maritime supply chain, a balance between protection of proprietary interest and scientific collaboration is necessary. As such, while specific details in regards to both chosen methodologies and their particular evaluations cannot be discussed, a general overview will be provided and the results of DockTech's solution will be evaluated. This study is based on depth measurements collected by service vessels, active on a daily basis in Ashdod Port over the course of two months. Tug and Pilot boats use stand-alone GNSS navigation and navigation class Single Beam echo sounders for safety purposes when traversing the port and maneuvering between the wharfs. These depths, averaged over a relatively rough grid, were used to produce a chart of part of the port. Data from the service vessels did not include RTK GNSS navigation and hence ellipsoid referenced surveying techniques were not used in lieu of water level monitoring. This chart was then compared to another chart produced from a professional hydrographic survey of the port, using state of the art equipment and strict hydrographic control. The differences were then analyzed according to the latest edition of the IHO S-44 standards. Recommendations were suggested for some relatively simple measures which could enhance the accuracy achieved and the reliability of such a chart, at least for harbor maintenance purposes.

Keywords: Crowd Source Bathymetry, harbor chart, service vessels, passage soundings, IHO S-44 Standards

Résumé

La bathymétrie participative (CSB) est le processus de génération d'une carte portuaire en collectant, enrichissant, traitant et agrégeant des données bathymétriques (et autres) à partir d'un grand nombre de navires, à l'aide d'instruments de navigation standard, tout en participant à des opérations maritimes de routine. Cette étude explore la précision et les limites d'une approche particulière de l'utilisation des données participatives, en comparant les résultats obtenus par l'approche de DockTech à ceux d'un levé SMF classique. DockTech étant une start-up à but lucratif qui vend son produit à divers acteurs de la chaîne d'approvisionnement maritime, un équilibre entre protection de la propriété et collaboration scientifique est nécessaire. En tant que tel, bien que les détails spécifiques concernant les méthodologies choisies et leurs évaluations particulières ne puissent pas être discutés, un aperçu général sera fourni et les résultats de la solution de DockTech seront évalués. Cette étude se base sur des mesures de profondeurs recueillies par des navires de service, actifs quotidiennement dans le port d'Ashdod pendant deux mois. Les remorqueurs et les bateaux-pilotes utilisent une navigation GNSS autonome ainsi que des sondeurs monofaisceaux de navigation à des fins de sécurité lorsqu'ils traversent le port et manœuvrent entre les quais. Ces sondes, moyennées sur une grille relativement grossière, ont été utilisées pour produire une carte d'une partie du port. Les données des navires de service n'incluaient pas la navigation GNSS RTK et, par conséquent, les techniques de levé rattaché à l'ellipsoïde n'ont pas été utilisées en remplacement du contrôle du niveau des hauteurs d'eau. Cette carte a ensuite été comparée à une autre carte produite à partir d'un levé hydrographique professionnel du port, en utilisant un équipement de pointe et un contrôle hydrographique strict. Les différences ont ensuite été analysées selon la dernière édition de la norme S-44 de l'OHI. Des recommandations ont été suggérées pour certaines mesures relativement simples qui pourraient améliorer la précision obtenue et la fiabilité d'une telle carte, du moins aux fins de l'entretien du port.

Mots-clés: Bathymétrie participative, carte portuaire, navires de service, sondages d'opportunité, norme S-44 de l'OHI

Resumen

La Batimetría Participativa es el proceso de generar un portulano mediante la recogida, enriquecido, procesado y agregado de mediciones de profundidad (y otras) por una diversidad de buques, usando instrumentos de navegación normales, mientras realizan operaciones marítimas de rutina. Este estudio explora la exactitud y limitaciones de un enfoque concreto utilizando datos de Batimetría Participativa, comparando los resultados obtenidos por el enfoque de DockTech's con los de un levantamiento MBES clásico. Como DockTech es una startup con ánimo de lucro que vende sus productos a varias partes interesadas en la cadena de suministro marítimo, es necesario mantener un equilibrio entre la protección del interés patrimonial y la colaboración científica. Por ello, aunque no se pueden discutir detalles específicos sobre las metodologías escogidas y sus evaluaciones concretas, se proporcionará una descripción general y se evaluarán los resultados de la solución de DockTech. El estudio se basa en la medición de profundidades recogidas por buques de servicio, activos diariamente en el Puerto de Ashdod durante el curso de dos meses. Las embarcaciones de remolque y practicaje usan navegación autónoma GNSS y ecosondas monohaz de navegación con fines de seguridad cuando navegan por el puerto y maniobran entre los muelles. Estas sondas, promediadas en una retícula relativamente aproximada, se usaron para producir una carta de parte del puerto. Los datos de los buques de servicio no incluían navegación RTK GNSS, y por tanto no se usaron técnicas de levantamientos referenciados al elipsoide en lugar de control del nivel del agua. Después se comparó esta carta con otra producida por un levantamiento hidrográfico profesional del puerto, usando el equipo más actual y estrictos controles hidrográficos. Entonces se analizaron las diferencias según la última edición de las normas S-44 de la OHI. Se sugirieron recomendaciones de cambios relativamente simples que podrían aumentar la exactitud alcanzada y la fiabilidad de esa carta, al menos para fines de mantenimiento del puerto.

Palabras clave: Batimetría Participativa, portulano, buques de servicio, sondas al paso, Normas S-44 de la OHI

1. BACKGROUND

Harbors are relatively shallow confined areas where maneuvering is limited and therefore monitoring their depths is crucial for their safe operation. Changes in depths in certain areas could be caused by natural phenomena such as silting or by artificial causes such as ship or tugboat propellers causing turbulence close to the silty seabed, goods and bulk cargoes falling overboard during loading or unloading etc.

Since the early 1990's, Multi-Beam Echosounders (MBES) have become the standard for mapping the seafloor. Various publications[1], standards (IHO S-44), and reviews (Buchanan et al., 2013; Huang et al., 2017; Šiljeg et al., 2022) have developed over the years, and both the theoretical limits and uncertainty budgets have been explored thoroughly.

While the precision of MBES surveys (specifically Special/Exclusive Order) is detailed enough for most use-cases, the infrequency and cost of such surveys have opened the door for alternative solutions. In more recent years, various other methods are being explored, from Satellite Derived Bathymetries (Sagawa et al., 2019) to airborne LiDAR Bathymetry (Costa et al., 2009). Among them is the usage of crowd-sourced data, and several papers have already come out exploring its potential and limitations (Novaczek et al., 2019; Guidance to Crowdsourced Bathymetry[2]).

DockTech (https://www.docktech.net/) is an innovation company whose goals include developing tools for improving port operations. They came up with the idea to routinely collect soundings from service vessels and use that data to produce periodical charts of the port. In order for these charts to be of practical use for the port authorities, it is essential to evaluate their accuracy. In 2020 the IHO published the version 6 of SP 44, enabling us to evaluate the results relative to the latest International Hydrographic Survey Standards.

Service vessels such as tugs and pilot boats traverse ports daily between the wharfs and in the entrance channels and turning basins. These modern vessels use GNSS navigation and Single Beam Echo Sounders during their deployment for safety of navigation. However, in common practice they usually do not take into consideration hydrographic variables such as sound speed, dynamic draft and heave, crucial in a controlled hydrographic survey. Soundings from these vessels could fall under the category of "Passage Soundings" as defined in IHO publication S 67[3], paragraph 3 - Accuracy of depth information in paper charts.

2. AIM

The principal aim of this study was to evaluate the accuracy of a harbor chart for Ashdod Port, Israel (***Figure 1***), produced from two months of data collected by two service vessels using DockTech's proprietary technology, in comparison to a professional hydrographic survey. This paper also attempts to cover the main challenges that exist with using Crowd-Sourced data. In addition, analysis of the error budget of the proposed method should enable us to improve the methodology by simple, easy to implement practices to achieve better results. Once achieved, a full procedure for producing periodical harbor charts from vessels of opportunity operating in the port will be developed.

The long term goal is to implement the procedure in harbors around the world, to support maintenance management by the port authorities and improve safety for vessels using the harbor. As a minimum, the harbor master will have ongoing information regarding changing depths in the port, enhancing decision making as to the necessity to dredge, move marker buoys etc. Should the procedure's results prove to be sufficiently accurate, it could even be used to update official nautical charts, subject to the national H.O.'s inspection and approval.

[1] https://iho.int/uploads/user/pubs/cb/c-13/english/C-13_Chapter_1_and_contents.pdf
[2] https://iho.int/uploads/user/pubs/Drafts/CSB-Guidance_Document-Edition_3.0.pdf
[3] https://iho.int/uploads/user/pubs/standards/S-67/S-67%20Ed%201.0.0%20Mariners%20Guide%20to%20Accuracy%20of%20Depth%20Information%20in%20an%20ENC_EN.pdf

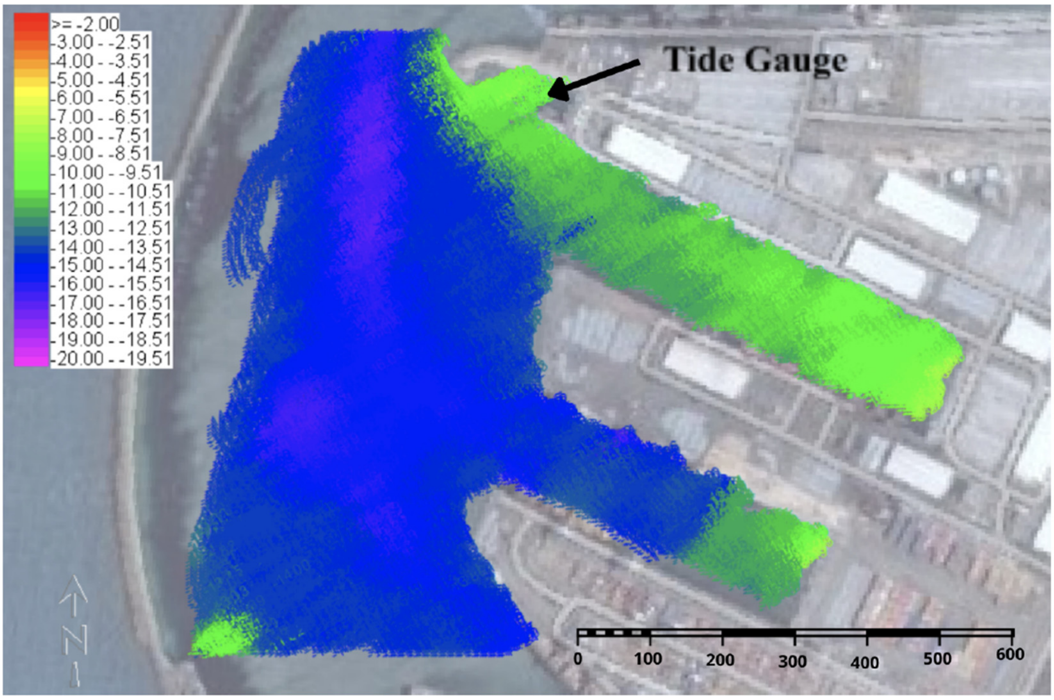

Figure 1. *Ashdod Port Area of Interest.*

Whenever comparing to a MBES, two important caveats are important:

1. Even the highest quality Survey (Exclusive Order) is not without error, and results from an MBES survey are to be viewed with their margin of error. As such, even though we treat the MBES survey as the ground-truth, part of the error could be found in the Hydrographic Survey data itself.
2. As the data collection process is different when using a Crowd-Sourced approach, some error will be generated during the process of converting both surveys to the same grid system. The full extent of the error generated by this conversion is out of the scope of this paper, but perhaps worthy of a future publication.

3. DATA COLLECTION

In order to facilitate data collection for this project, two service vessels in the Ashdod Port were equipped with a tailor made data recording system. The vessels chosen were the Tug Boat Ashdod and a Pilot Boat. The data recording system continuously records all incoming data when the systems are switched on, particularly navigation –Furuno GP-170 GNSS in stand-alone mode and Single Beam soundings – Furuno 200B-8B 200 kHz transducer. General specifications of each of the vessels were also used for the enrichment/processing of the data (see below). For the soundings' horizontal position the data logged includes Latitude and Longitude (in degrees, WGS84 datum) from the GNSS. The vertical sounding is derived from the raw depth measurements - DBT (Depth Below Transducer), and water level and draft are added to get the dynamic DBS (Depth Below Surface). The horizontal position and vertical sounding are integrated in the data assimilation program, synchronized by the GNSS clock.

In addition, water level data was collected continuously in the port area using a commercial Radar Tide Gauge tied geodetically to the ILSD – Israel Land Survey Datum.

In addition, a fully controlled hydrographic survey of the port using RTK GPS navigation and a Norbit iWBMS survey system at 400 kHz, was conducted for comparison. The survey vessel underwent a full Patch Test and GPS Health Test calibration prior to the survey. Survey lines were run parallel to the breakwater in the deeper area and along the wharfs in the shallower loading basins. The swath angle of the MBES was set at 120° and line spacing was determined to provide at least 100 % overlap. Survey speed did not exceed 4 knots.

4. DATA PROCESSING

While the focus of this paper is not on the particular methodology and tools DockTech uses to collect and process the data, a general discussion as to the shared and unique challenges involved in CSB is relevant. Again, some core elements of the analysis will be skimmed over, either due to protecting DockTech's proprietary technology, or when discussing MBES, skipping over what is considered general knowledge to keep this paper not unnecessarily lengthy. For further discussion, see (Montella et al., 2017; Stephens et al., 2020; Jia et al., 2022)

For the sake of this paper, we shall divide the types of processing necessary into three categories:

Adjustment of static offsets: In order to standardize the depth measurements, vertical and horizontal offsets between the transducer and the surface water-level (draft) and between the GNSS antenna and the transducer were determined. In a MBES, the static offsets are directly measured and verified in the calibration procedure before surveying begins. However, in a CSB, this metadata isn't always directly available, and it is not uncommon to find incorrect and missing data.

Approximate adjustment of known phenomenon: There are several parameters that have been well researched, that need either to be adjusted or accounted for in the final calculation (the margin of error). These include, but are not limited to: tide, squat, dynamic draft, and speed of sound. For example, sound speed in the Ashdod Port area varies between 1,550 m/s at the height of the Israeli summer and 1,510 m/s in the winter. If a constant sound speed is entered into the echo sounder system, e.g.) the average annual speed of 1,530 m/s, this would induce a 20 m/s error in the height of the seasons resulting in a 1.3 % error in depth recordings. In a MBES, the major contributors (tide and speed of sound) are accounted for. The echo-sounder is calibrated to the correct speed of sound, and hyper-localized tide is collected and integrated. However, in a CSB, the collection of each new data stream presents its own form of challenge. Even the fundamental sensors (GNSS, echosounder) on service boats could be in need of software updates or have a hardware malfunction. With enough reliable data streams though, each of these phenomena can be accounted for, and the resulting margin of error could be minimal.

Approximate adjustment of unknown phenomenon: Beyond the traditional factors leading to uncertainty in the models, surveys can also suffer from events that are not readily identifiable, such as the impact of noise within the sensors, specifically the Echo-Sounder. In an MBES, usually the conditions of the survey boat are intentionally stable to minimize as much potential noise as possible. However, in a CSB, we have a two-fold problem. Firstly, the service boats are actively engaging in activities (berthing a large cargo ship) that generate a lot of noise. Secondly, as the service boats are collecting data while engaging in their routine activities, there is no one actively evaluating the impact on the vessel's maneuvering upon the accuracy of the sensor readings. Without being able to get into too much detail the percentage of noise within echosounders can range from approximately 0–20 % of a given service boat's data.

5. DATA AGGREGATION

In order to convert continuous measurements from each observation to a discrete evaluation measured across a larger space, we aggregate all lat/lon coordinates within their respective geohash (precision of nine characters – an area of approximately 4.77 m × 4.77 m)[4].

[4] https://michaelchirico.github.io/geohashTools/articles/geohashTools.html

The MBES data was processed using Qimera software with a shallow filter chosen for aggregation as common in safety of navigation scenarios. The filtered and cleaned data was then gridded on a 0.5 m grid.

6. RESULTS

Data was collected and processed in the Ashdod Port over a two month period -between May 15 and July 15, 2020. As we can see below (***Figure 2***), it is evident that the distribution of error is bimodal, reflecting the two service boats that were in use. We can also see in the left figure how spread out the tails are, clear signs of the impact of noise. Using just the raw data, without enrichment and processing, our median error (in meters) would be greater than 6 m, with outliers of above 20 m.

We can see (***Figure 3***) that tremendous improvements can be easily attained with enriching the data, but that it is not sufficient due to the frequency and intensity of the noise. (It is also interesting to note that each service vessel has its own distribution of noise, each Gaussian with different means and standard deviations). After removing (most) of the noise, a singular normal distribution appears.

There is a lot of room for conversation into the exact nature of the aggregation, and the impact of different cells at different resolutions, for as we see below (***Figure 4***), there are some outlier cells with a decent standard deviation, although much of it might be reduced by total noise reduction.

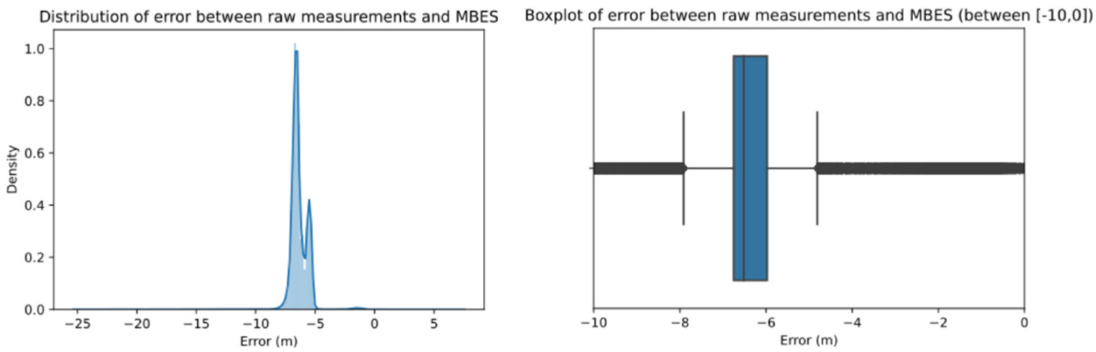

Figure 2. *In both plots, we see the distribution of error (difference between each raw measurement with the processed survey data).*

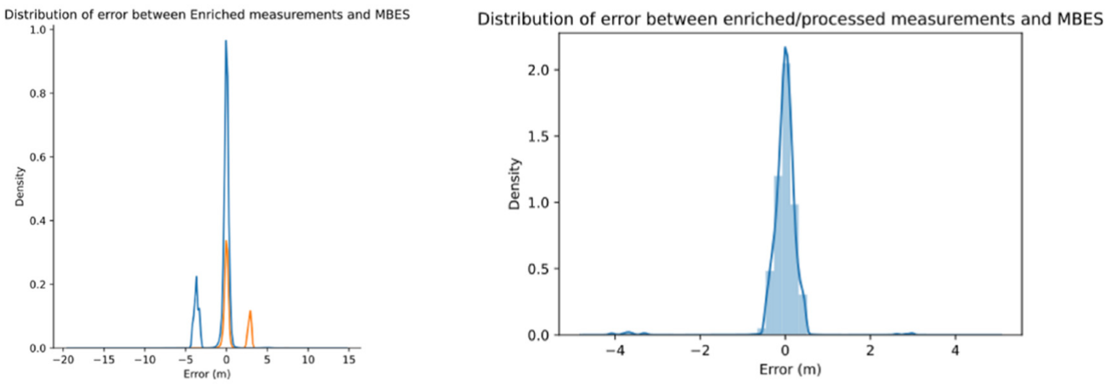

Figure 3. *On the left, we see the histogram of distribution of error (m) for the enriched data separated by the two service vessels. On the right, we see the histogram of the distribution of error (m) after both enrichment and pre-processing.*

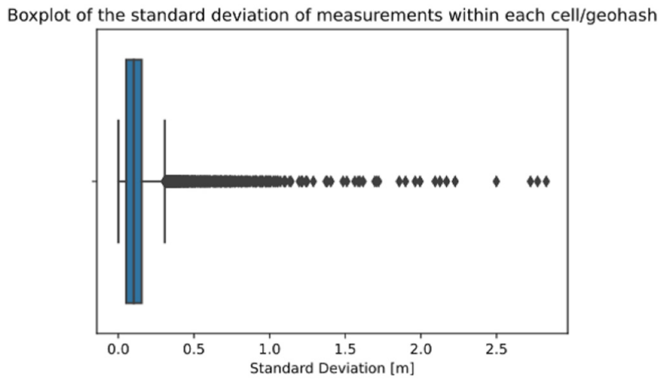

Figure 4. *Standard deviation of measurements within each geohash.*

6.1 Comparison between DEMs

A map of the area covered was produced from this data according to the data processing procedure described above, resulting in a 4.77 m × 4.77 m grid. This grid was compared to the 50 cm grid produced from the controlled hydrographic survey, using HYPACK software. The error budget for the controlled MB survey produced a TVU (Total Vertical Uncertainty) of 10 cm and THU (Total Horizontal Uncertainty) of 50 cm and 200 % coverage, complying with IHO S44 Exclusive order requirements.

When considering the entire overlapping area inside the port, 0.57 km^2 with an average depth of -14.3 m, the average depth difference between the SB and MB grids was 18 cm with a standard deviation of 14 cm. The DockTech map was generally shallower than the hydrographic survey.

However the area surveyed is not homogenous and can be divided into three sub-areas with different characteristics: a. Shallow Basin b. Deep Basin c. Slope. ***Figure 5*** below shows the three sub-areas.

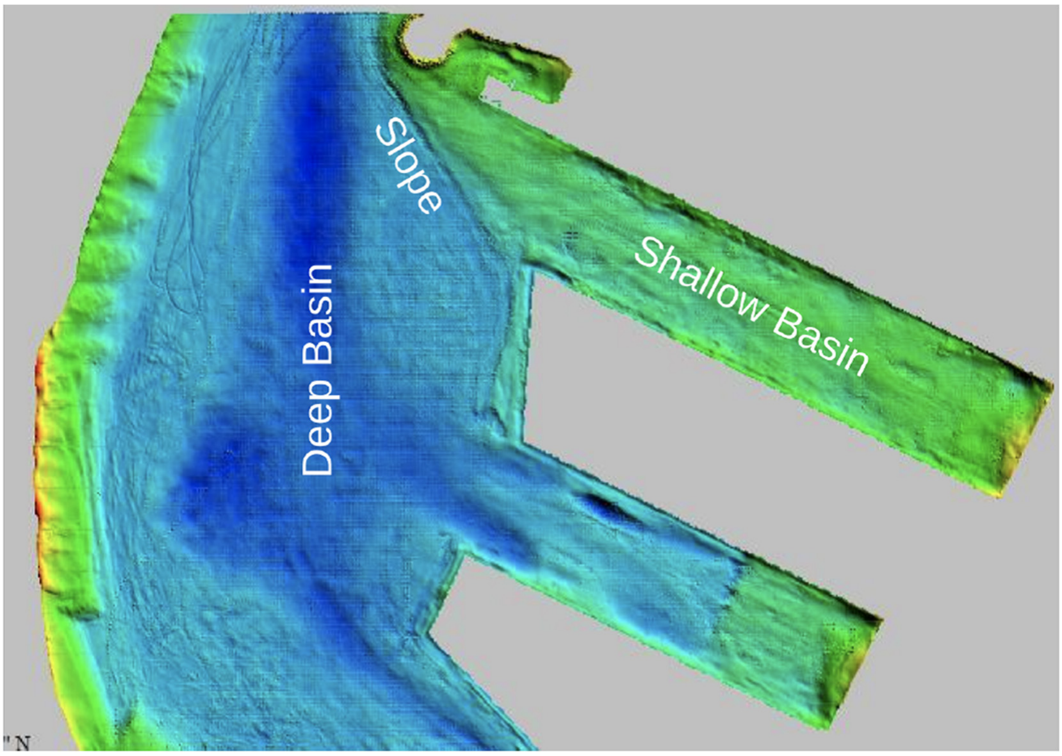

Figure 5. *Ashdod Port Sub-areas.*

When analyzing each sub-area separately, the results of the SB and MB grids comparison detailed in ***Table 1*** below were obtained.

Table 1. *Sub-area statistics.*

Sub-area	Ave. Depth	Ave. Diff.	Std. Deviation
Shallow	-11.3_{m}	1_{cm}	11_{cm}
Deep	-16.0_{m}	16_{cm}	8_{cm}
Slope	-11.5 to -14.5_{m}	15_{cm}	15_{cm}

It is evident from the table above that the shallow basin has a considerably smaller average difference than the deep basin and the slope area. One explanation for this could be sound speed. The survey was conducted during summer months with actual sound speed approximately over 20 m/s more than the one used in the echosounder. This would contribute approximately 6–7 cm to the average difference and also explain why the deeper area differs more from the hydrographic survey than the shallow area.

Another contributing factor to the difference between the shallow basin and the deep area statistics could be the number of observations in each geohash. ***Figure 6*** below depicts the color-coded representation of the number of observations used in each geohash. ***Figure 7*** shows the average error based on the number of observations. In the shallow basin, many geohashes have over 60 observations whereas in the deep area most have less than 20 observations. The direct relationship between number of observations and accuracy/variance still needs to be explored deeper, but it seems to be an important element to take into consideration. While noise still is not fully filtered, if a geohash has only a few observations, the impact of a single noisy observation (often several meters off) could greatly impact the estimated depth.

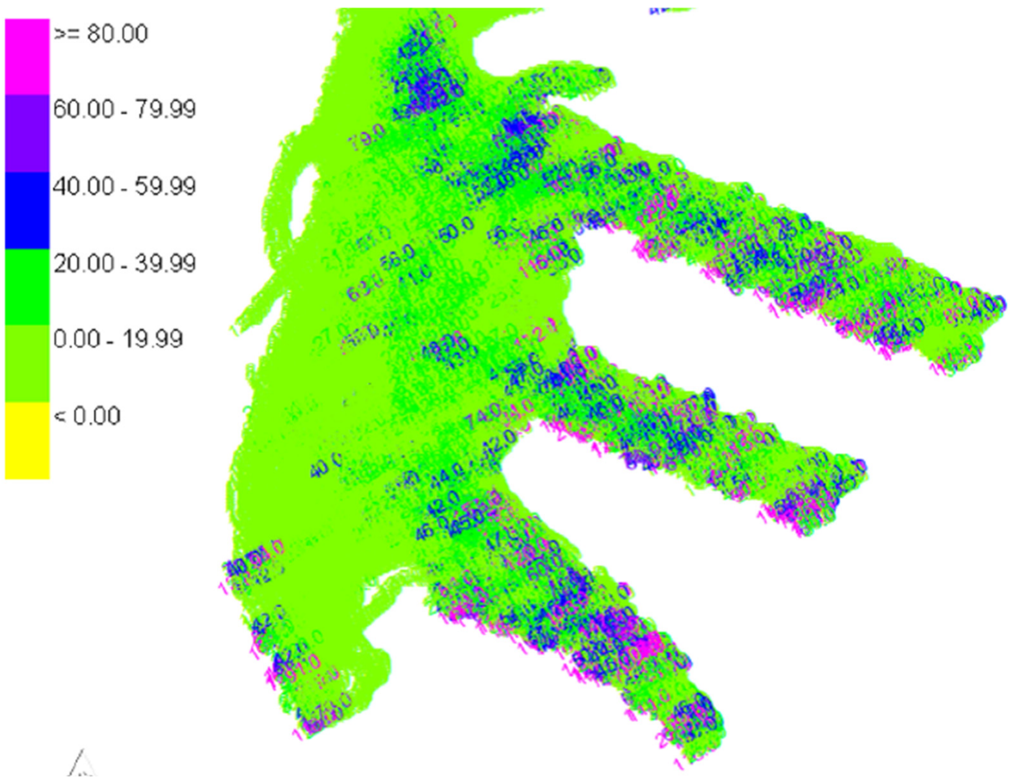

Figure 6. *Color-coded number of observations per geohash.*

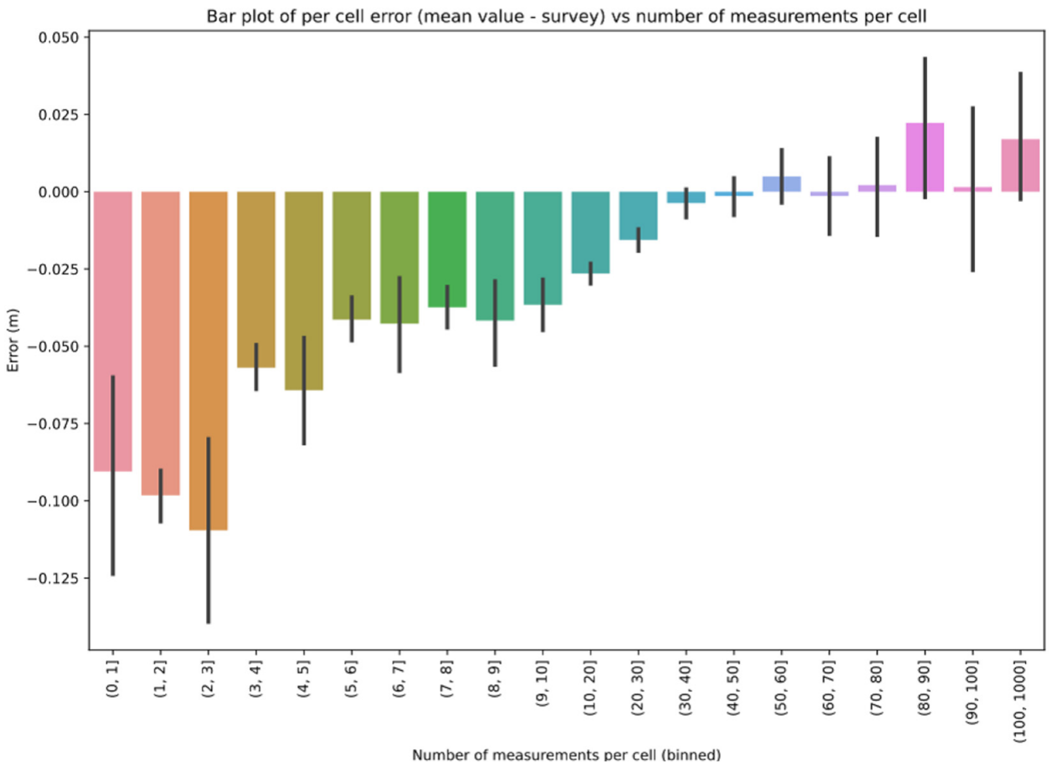

Figure 7. *Barplot of the error per cell split by the number of measurements within each cell.*

These possible contributions to the distinction between deep and shallow basins, with the constant development of processing techniques and data collection streams, can be addressed and we should expect a much greater improvement in the deep basins.

Table 1 also reveals that in the slope area both the average difference and the standard deviation are relatively large. This is to be expected, taking into consideration the size of each footprint, geohash grid size and the relatively steep slope. The Multi-Beam footprint is small, on the order of 20–30 cm, inducing a small error in the sounding on a slope whereas the Single-beam footprints are much larger, inducing considerable error. ***Figure 8*** below shows a 3-D view of the slopes.

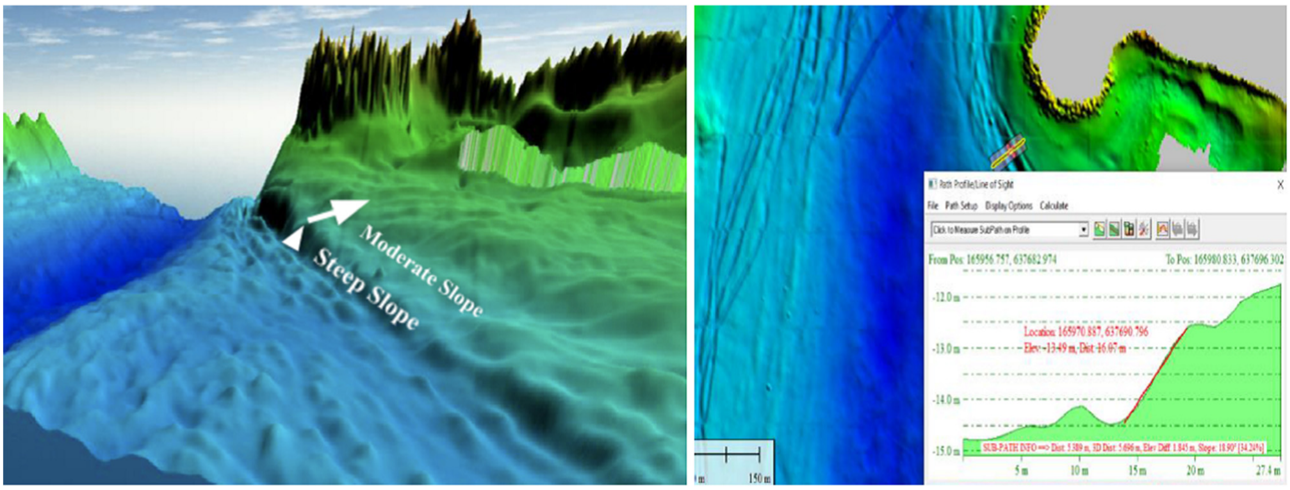

Figure 8. *Slope sub-area.*

The steep slope has an incline of about 20° and the moderate slope is on the order of 5°. On the steep slope the SB footprint would induce a 26 cm vertical error at -16 m depth and 16 cm at -10 m. The sounding would of course be shallower than the actual depth. The maximum vertical error induced by sounding at the edge of a geohash, rather than the center where the position is given, would be on the order of 90 cm. Horizontal errors related to stand-alone GNSS navigation as opposed to the controlled survey using RTK GNSS, would add to the error. This error is naturally considerably reduced as the number of samples in the geohash increases depending upon the sounding being up slope or down slope.

On the moderate slope the footprint vertical error would be 5cm at -16 m depth and 3 cm at -10 m and the maximum geohash vertical error would be 21 cm.

Further investigation of the slope sub-area differences clearly support the hypothesis detailed above, as demonstrated in ***Figures 9*** and ***10***. In ***Figure 9***, on the deeper and steeper part of the slope to the west, the differences are clearly larger than on the shallower part where the slope is moderate. In ***Figure 10***, it is clear that there were considerably more observations per geohash on the upper slope, facilitating statistical improvement of the data.

6.2 IHO S44 Requirements

S 44 edition 6 was published in September 2020. The IHO Standards for Hydrographic Surveys defines five orders of "safety of navigation surveys", detailing requirements for horizontal and vertical uncertainty, bathymetric coverage, feature detection capabilities and feature search percentage.

For safety of navigation purposes inside a harbor, the most appropriate order would be the Special Order. For other purposes, such as general port maintenance, Order 1a would suffice. The DockTech map will be analyzed according to the S44 requirements.

6.2.1 Special Order

THU – required 2 m. The data collected uses standalone GNSS navigation which in general would not fulfill this requirement. Additionally, in a confined environment with massive ships and cranes along the wharfs, multipath often contaminates the navigation data.

TVU – required a=0.25 m, b= 0.0075 in the formula $TVU_{max}(d)=\sqrt{a^2+(b\times d)^2}$. This requirement results in 26 cm at -10 m depth and almost 28 cm at -16 m. Considering the controlled hydrographic survey as "truth", the values above would be the upper limits for the 95 % confidence level, i.e. 1.96 standard deviations. The results obtained show that when considering the entire surveyed area, the DockTech map falls somewhat short of these requirements. When looking at each sub-area individually it appears that the shallow area falls within required limits whereas the slope and deeper areas do not.

Bathymetric Coverage – 100 % required. Footprint area at -10 m depth would be 2.9 m^2 and at -16 m, 7.4 m^2. The area of each geohash is 22.75 m^2 so in the shallow area at least eight non-overlapping soundings would be necessary to achieve full coverage (disregarding the fact that the sounding area is circular whereas the geohash area is square). Statistically one could assume that a geohash with at least 20 soundings would be fully covered. However, as mentioned in the Data Processing explanation, missing gaps in the data are interpolated to provide a continuous depiction of the bathymetry. When this is deemed necessary, full coverage would not be achieved.

Feature Detection – Cubic features > 1 m required. Considering the footprint sizes calculated above, this requirement is not met.

Feature Search – required 100 %. Not achieved since these are random soundings.

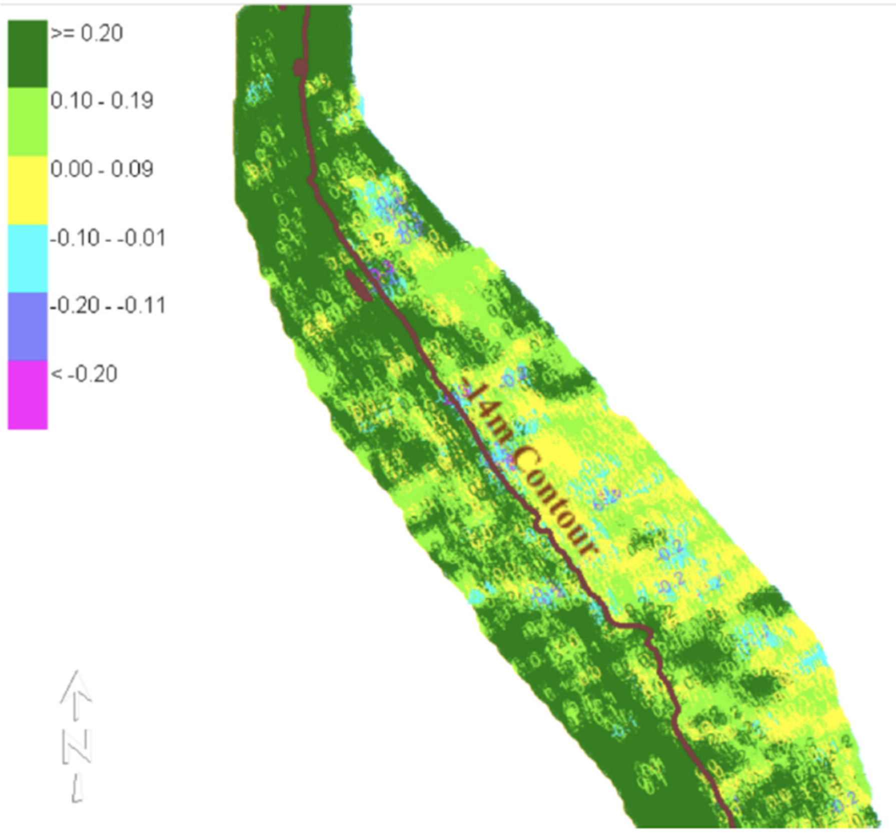

Figure 9. *Vertical differences on the slope.*

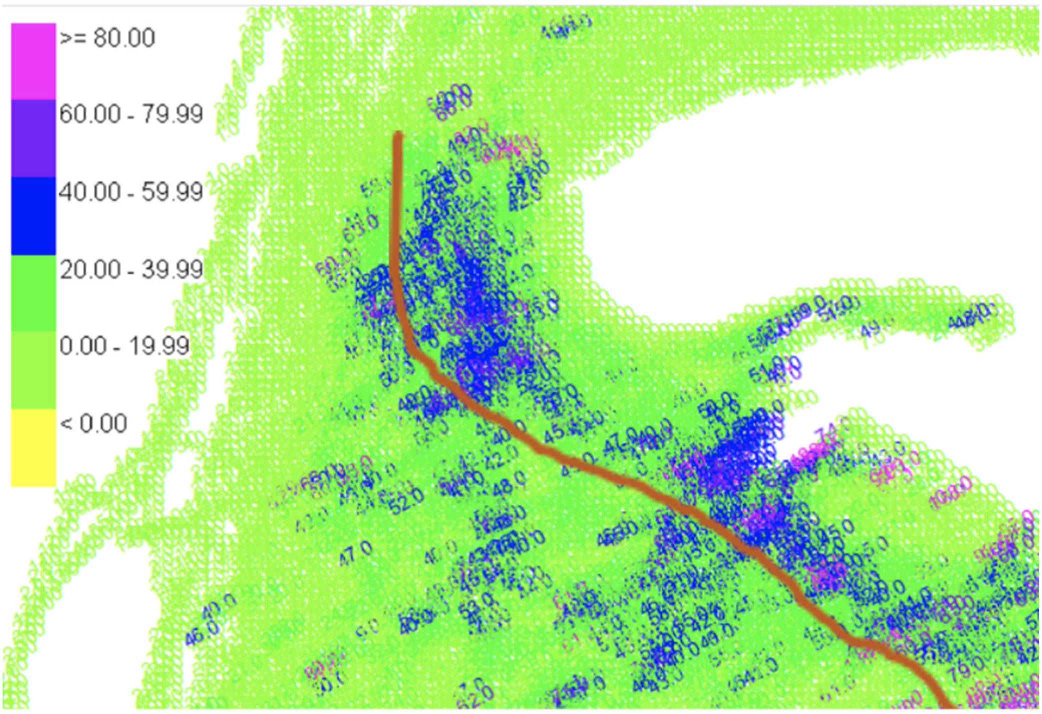

Figure 10. *Observations per Geohash on the slope .*

6.2.2 Order 1a

THU – required 5 m + 5 % of depth. In this case, standalone GNSS navigation should suffice and considering that pitch and roll are usually small on tugboats, the horizontal position of the soundings should fulfill this requirement.

TVU – required a=0.5 m, b=0.013 in the formula $TVU_{max}(d)=\sqrt{a^2+(b\times d)^2}$. This requirement translates to 51.6 cm at -10 m depth and almost 54 cm at -16 m. The results obtained throughout the entire area show that the DockTech map complies with these requirements when considering the MBES survey as "truth".

Bathymetric Coverage – ≤100 % required. Statistically full coverage would not be achieved, but the above requirement should be achieved with little less than 100 % coverage.

Feature Detection – Cubic features >2 m required. Considering the footprint sizes calculated above, once again this requirement is not entirely met.

Feature Search – required 100 %. Not achieved since these are random soundings.

6.2.3 Recommendations

In order to improve the quality of the data obtained from random soundings by a service vessel in a port and to achieve full IHO S 44 Special Order requirements, there are a number of measures that need to be taken. These measures will be detailed according to the S 44 criteria.

THU – In order to improve the horizontal accuracy of the soundings, RTK or at least DGNSS navigation should be used. In addition, static offset measurements between the GNSS antenna and the transducer should be taken with geodetic equipment when the vessel is out of the water for maintenance. Developments within Anomaly Detection in Machine Learning could also be used to filter out certain types of noise.

TVU – The major contributor to sounding error is the variation in sound speed relative to that applied in the echo sounder. Understanding that these are not survey vessels and the tugboat crews are not generally concerned with measuring sound speed and adjusting the input to the echo sounder regularly, there is a simple way to overcome this flaw. The Port Authorities or the National Hydrographic Office could take SVP measurements in the port on a regular basis, at least once a week, over a year. From these measurements a table of monthly average sound speeds could be produced and used to adjust the soundings accordingly in the data processing stage. Should the sound speed variation over the year be significant, interpolation during the month would be acceptable.

Furthermore, harbors situated in the vicinity of river estuaries or influenced by other local environmental factors, would need to be studied for their effects on sound speed and events such as flooding taken into consideration. The sound speed used in the tugboat's echo sounder must of course be known too.

A second factor influencing TVU would be the static draft. Should fuel levels change the draft significantly, a table of fuel levels vs draft should be compiled and the daily fuel level should be reported too for use in the data processing.

We saw that on the slope the relatively large geohash grid may induce significant depth error. In order to overcome this it would be preferable to reduce the geohash size to 2 m × 2 m at most.

Lastly, it is imperative that water level data be continuously available and tied correctly to the chart datum. It should be noted that using ERS (Ellipsoid Referenced Survey) techniques would make water level monitoring with a tide gauge obsolete. However, this would make RTK GNSS imperative and would also require a reliable undulation model for the port area.

Specifically in the Ashdod Port area, the small daily tidal range would induce a very small water level error on the order of 3 cm at most whereas using ILUM, the national Israel Undulation Model published by the Survey of Israel, with extrapolation to the port, would induce a vertical error on the order of 10 cm.

Bathymetric Coverage – Full coverage in the entire port area wouldn't be achieved generally by random transit soundings. In some areas, such as around the tugboat's berthing, much more than 100 % coverage would be obtained, whereas in other areas no coverage would be obtained. When considered necessary, gaps could be filled by sending the tugboats to predefined areas in their transit. In any event, to prove 100 % coverage, a map of the calculated footprint areas of each sounding would have to be produced.

Feature Detection – In order to detect features of 1 m^3 size, a transducer with a narrower Beam Width would have to be used to reduce footprint size and improve resolution. This would not usually be practical considering that tugboats are not dedicated survey vessels.

Feature Search – 100 % feature search would not usually be accomplished, according to the above arguments.

7. CONCLUSIONS

The idea to produce a bathymetric chart of a harbor area using crowd-sourced data collected from service vessels, operating daily inside the port, is both novel and interesting. Port authorities need frequent monitoring of depths within the harbor and in its approaches and entrance channel, to determine whether dredging or obstacle clearance are necessary or not. Periodical processing of data collected from service vessels can produce valuable and useful information for the port authorities.

Tugboats are most suited for this purpose since they are relatively stable and very active day and night in most ports. In our case study in the Ashdod Port, we saw that the map produced falls short of S 44 Special Order requirements. However, the map is close to the Order 1a requirements. Feature detection and feature search are the two major obstacles in achieving the standards.

With some changes and additions to the methodology, much improved results should be obtained. These have been outlined in the "Recommendations" detailed above. Once improved, finalized and checked, the procedure for producing bathymetric charts from service vessel soundings could enhance the safety of navigation in ports around the world.

8. REFERENCES

Buchanan, C., Spinoccia, M., Picard, K., Wilson, K., Sexton, M., Hodgkin, S., Parums, R., Carey, M., Siwabessy, P. J. (2013). Standard Operation Procedure for a Multibeam Survey: Acquisition & Processing.

Huang C., Bian G., Lu X., Wang M., Huang X., Wang, K.: Analysis of Error Sources and Quality Assessment for Multibeam Sounding Products. International Hydrographic Review (18), 23–37 (2017). https://ihr.iho.int/articles/the-analysis-of-error-sources-and-quality-assessment-for-multibeam-sounding-products/

Šiljeg, A., Marić I., Domazetović, F., Cukrov, N., Lovrić, M., Panđa, L. (2022). Bathymetric Survey of the St. Anthony Channel (Croatia) Using Multibeam Echosounders (MBES)—A New Methodological Semi-Automatic Approach of Point Cloud Post-Processing. Journal of Marine Science and Engineering, 10(1):101. https://doi.org/10.3390/jmse10010101

Sagawa, T., Yamashita, Y., Okumura, T., Yamanokuchi, T. (2019). Satellite Derived Bathymetry Using Machine Learning and Multi-Temporal Satellite Images. Remote Sensing, 11(10):1155. https://doi.org/10.3390/rs11101155

Costa, B. M., Battista, T.A., Pittman, S. J. (2009). Comparative evaluation of airborne LiDAR and ship-based multibeam SoNAR bathymetry and intensity for mapping coral reef ecosystems, Remote Sensing of Environment, Volume 113, Issue 5, Pages 1082-1100,ISSN 0034-4257, https://doi.org/10.1016/j.rse.2009.01.015.

Novaczek E., Devillers R., Edinger E. (2019). Generating higher resolution regional seafloor maps from crowd-sourced bathymetry. PLoS ONE 14(6): e0216792. https://doi.org/10.1371/journal.pone.0216792

Montella, R., Di Luccio, D., Marcellino, L., Galletti, A., Kosta, S., Brizius, A., Foster, I. (2017). Processing of crowd-sourced data from an internet of floating things. In Proceedings of the 12th Workshop on Workflows in Support of Large-Scale Science (WORKS '17). Association for Computing Machinery, New York, NY, USA, Article 8, 1–11. https://doi.org/10.1145/3150994.3150997

Stephens, D., Smith, A., Redfern, T., Talbot, A., Lessnoff, A., Dempsey, K. (2020). Using three dimensional convolutional neural networks for denoising echosounder point cloud data, Applied Computing and Geosciences, Volume 5, 100016, ISSN 2590-1974, https://doi.org/10.1016/j.acags.2019.100016.

Jia, S.; Liang, Z., Zhang, L., Yuan, H. (2022). Uncertainty Modeling of Crowdsourced Bathymetry Data Influenced by Marine Environment, 2022, 3rd International Conference on Geology, Mapping and Remote Sensing (ICGMRS), pp. 846-852, doi: 10.1109/ICGMRS55602.2022.9849245.

9. AUTHORS BIOGRAPHIES

Cdr. (ret) Barry Grinker lectures Marine Surveying at the Technion Mapping & Geo-Information Department in the Civil Engineering Faculty. He is the senior hydrographer at Lia Engineering & Surveying Services Ltd. Formerly Barry served as Head of the Israel Navy Hydrographic Service, representing Israel in the MBSHC and FIG Commission 4. Barry graduated from the Naval Postgraduate School USA in 1991 with a M.Sc. degree in Hydrographic Science (Cat A).

Shaul Solomon has a B.Sc. in Computer Science and pivoted into Data Science. He has spent the past few years as Lead Data Scientist at DockTech, focusing on the processing of sensor data and spatio-temporal feature engineering. Shaul is also a lecturer and speaker on the fundamentals of data science for Y-Data School of Data Science.

Assif Hassin is VP Operations at DockTech. Assif is a formal naval officer and holds a B.Sc. In Computer Science from Tel Aviv University and Business Management from Haifa University.