35th PIANC World Congress, 29 April – 23 May 2024, Cape Town, South Africa
Paper Title: Application of BIM in assessing and re-designing of wharf structure after vessel collision
Authors Names: T.P.M. Khoi, L.D. Khoa, N.H.A. Thu and N.D. Thao

Application of BIM-GIS in assessing and re-designing of wharf structure after vessel collision

Tran Phuc Minh Khoi [1,2], Ly Dang Khoa [1,2], Nguyen Hoang Anh Thu [1,2] and Nguyen Danh Thao [2]

1 Portcoast Consultant Corporation, Ho Chi Minh City, Vietnam

khoi.tpm@portcoast.com.vn

2 Ho Chi Minh City University of Technology (HCMUT), VNU-HCM, Ho Chi Minh City, Vietnam;

Abstract: In response to Vietnam's rapidly expanding economy, the country has seen a significant increase in waterway transportation, necessitating the construction of numerous river and seaports in the early decades of the 21st century. While comprehensive studies have been conducted on port system planning and hydrodynamic modeling of channels, specific research into post-vessel collision inspection processes remains underdeveloped. This paper focuses on a case study of a vessel collision at a port terminal in Southern Vietnam, exploring the use of innovative survey technologies including Unmanned Aerial Vehicles (UAVs), Terrestrial Laser Scanning (TLS), and Unmanned Surface Vehicles (USVs). The integration of Building Information Modelling (BIM), Geographic Information System (GIS) technology, and Digital Twins is examined to demonstrate their potential in enhancing port infrastructure management. This includes conducting periodic inspections and implementing redesign strategies to restore structural functionality post-collision. The paper also proposes a straightforward process for simulating vessel collisions, followed by a thorough evaluation and testing of structural components and operational equipment. Through this study, the paper aims to contribute to the advancement of port safety and maintenance practices in the face of increasing maritime traffic and associated risks.

Keywords: BIM, GIS, vessel collision, maritime, ports

Introduction

The Mekong Delta stands as the largest delta in Vietnam, boasting an intricate network of around 2,360 rivers. Waterway transportation, encompassing both inland and international routes, predominantly operates within the four key river systems: Dinh An, Soai Rap, Sai Gon-Vung Tau, and Cai Mep-Thi Vai. Approximately 41% of the nation's total inland waterway freight is transported through the Soai Rap and Cai Mep-Thi Vai rivers, originating from the Mekong Delta region and Ho Chi Minh City [1].

Figure 1 Vietnam's Southern seaport system for the period 2004, 2021, and a vision to 2050 (left to right)

Due to Vietnam's rapidly growing economy, there has been a significant increase in vessel transportation and the number of ports, leading to a heightened risk of vessel collisions with port structures (Figure 1). In the period from 2015 to July 2023, the Vung Tau Maritime Port Authority documented several collision incidents along the Cai Mep-Thi Vai channel. These incidents involved various port structures, including Phu My Port, Cai Mep International Terminal (CMIT), SP-SSA International Container Terminal (SSIT), Holcim Thi Vai Specialized Port. Notably, the Interflour Cai Mep Port experienced consecutive collision incidents between vessels and port structures in February 2023 and July 2023, highlighting the increasing challenges in maritime safety and port management in the region (Figure 2, Figure 3).

Figure 2 The Atlantic Ocean container vessel collided with Interflour Cai Mep Port's mooring dolphin. First collision of this port in February 6th, 2023; Port experienced consecutive collision incidents between vessels and port structures

35th PIANC World Congress, 29 April – 23 May 2024, Cape Town, South Africa
Paper Title: Application of BIM in assessing and re-designing of wharf structure after vessel collision
Authors Names: T.P.M. Khoi, L.D. Khoa, N.H.A. Thu and N.D. Thao

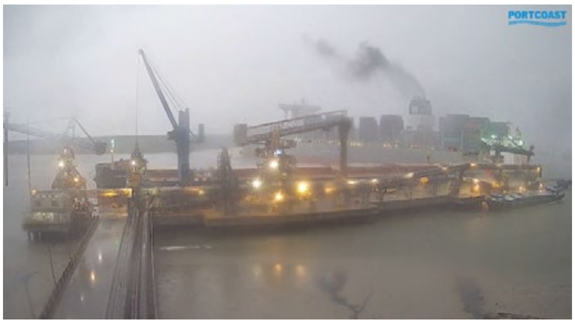

Figure 3 The WAN HAI A02 vessel collided with Interflour Cai Mep Port's moored vessel VASSOS 2. Second collision of this port in July 13th, 2023; Port experienced consecutive collision incidents between vessels and port structures

The primary purpose of this research paper is to examine the exploration of diverse, state-of-the-art surveying techniques, including Unmanned Aerial Vehicles (UAVs), Terrestrial Laser Scanning (TLS), Unmanned Surface Vehicles (USVs). By incorporating Building Information Modelling (BIM), Geographic Information System (GIS) technology, and the concept of Digital Twins, the paper seeks to demonstrate how these technologies can enhance port infrastructure management, conducting periodic inspections, and redesigning to restore the functionality of the structure when encountering vessel collision accidents. The study case of multiple vessel collisions at different time at a port site in Vietnam will be analysed.

Methodology

Application of advanced technology in port infrastructure surveying and inspection

The application of 3D laser scanning technology in construction surveying is garnering global attention, particularly for its role in creating Building Information Modelling (BIM) models from point cloud data. Research in this field, including works by Grigoras et al. (2009) [2], Shan Ji et al. (2009) [3], and Halim Setan et al. (2014) [4], has demonstrated the feasibility and effectiveness of generating plans and high-resolution models using this technology. Jingdao Chen et al. (2018) [5] further advanced this field by developing a Scan-to-BIM process for converting point cloud models into BIM models.

Utilize Terrestrial Laser Scanning (TLS) to execute detailed and extensive scans of areas affected by collisions. These scans aim to meticulously record every pertinent aspect of both the port's infrastructure and any remnants of the vessels involved. To achieve a holistic view and eliminate potential data omissions, the scanning process involves capturing the scene from a variety of angles and positions, ensuring comprehensive coverage of the entire area (Figure 4).

Figure 4 The adoption of Terrestrial Laser Scanning technology in surveying practices; A higher degree of detail and accuracy in surveying

In addition to 3D laser scanning, the use of Unmanned Aerial Vehicles (UAVs) has become a widespread trend across various sectors, including military, disaster management, weather forecasting, healthcare, photography, surveillance, agriculture, logistics, and infrastructure inspection. This wide range of applications, highlighted in studies by Bucaille et al. (2013) [6], Erdelj et al. (2017) [7], and others, underscores the versatility of UAVs when equipped with appropriate sensors.

Strategically design a detailed flight plan for UAV operations, aimed at thoroughly covering the areas affected by collisions. This plan will focus on achieving the most effective angles for capturing data with LiDAR sensor, Laser scanner, and Oblique cameras. Execute UAV flights to meticulously gather high-resolution images, along with LiDAR and laser scanning data, of both the direct collision sites and the adjacent port infrastructure. This approach is intended to ensure a comprehensive collection of detailed spatial data (Figure 5).

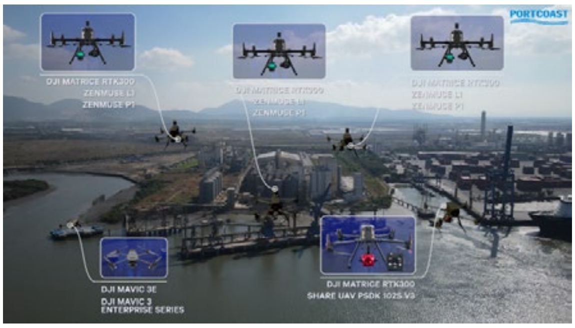

Figure 5 Unmanned Aerial Vehicles (UAVs); UAV-integrated scanning devices; New technology to produce a comprehensive survey model

Similarly, the use of Unmanned Surface Vehicles (USVs) for marine seabed and riverbed surveying is gaining momentum globally. This technology enhances survey productivity and reduces operational risks in marine and riverine environments, as evidenced in studies by Vaneck (1996) [8], M. R. Benjamin (2004) [9], and more recent research by Mariusz Specht et al. (2020) [10]

and Jacek Lubczonek et al. (2022) [11]. These studies collectively indicate a significant shift towards more accurate, efficient, and safer survey methods in various environmental conditions.

Employ Unmanned Surface Vehicles (USVs) integrated with state-of-the-art Multibeam echo sounding and LiDAR, and Side Scan Sonar technologies to gather comprehensive high-resolution data for both underwater and above-water regions at collision sites. This includes capturing accurate depth measurements, delineating structural contours, and identifying possible debris fields. Subsequently, process this extensive data collection to construct accurate bathymetric maps and detailed 3D models, effectively mapping the impacted areas of the port infrastructure (Figure 6).

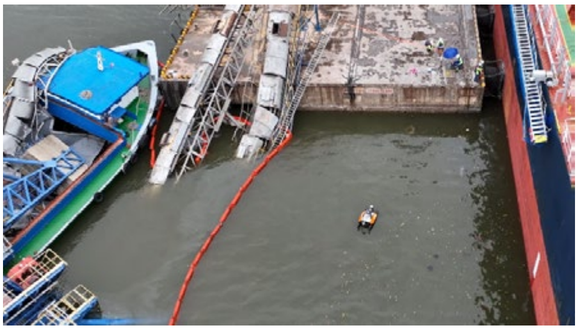

Figure 6 Terrestrial Laser Scanning; The adoption of Terrestrial Laser Scanning technology in surveying practices; A higher degree of detail and accuracy in surveying

Integrating various data sources or comprehensive damage assessment and reporting port infrastructure affected by vessel collisions
By integrating data from multiple sources, the damage assessment becomes more robust, accurate, and insightful, providing a solid foundation for informed decision-making in post-collision recovery and future preventive strategies.

Transform the raw Terrestrial Laser Scanning (TLS) data into precise 3D models that accurately represent the sites of vessel collisions. Utilize these models to conduct an in-depth analysis of the damage, pinpointing the exact locations of impact and deciphering the dynamics of each collision incident. To gauge the full extent of structural changes and damages, compare the pre-collision TLS data, such as earlier scans or existing 3D Building Information Modelling (BIM) as-built models, with the data collected post-collision (Figure 7, Figure 8).

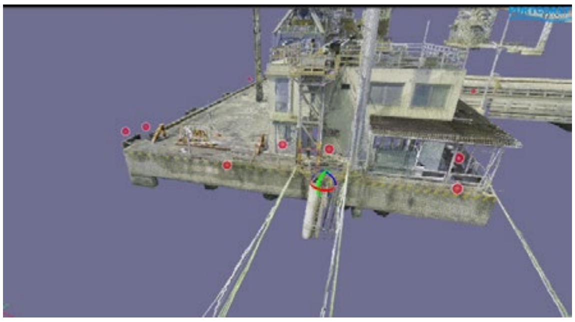

Figure 7 Terrestrial Laser Scanning; Location of scanning stations around the accident area

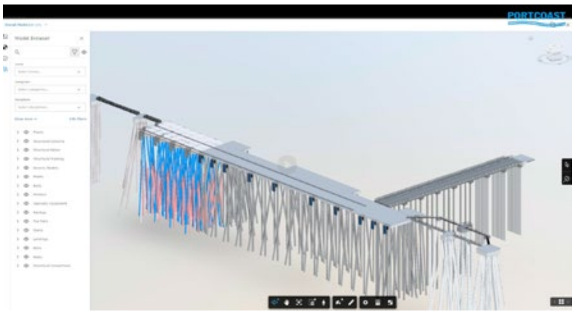

Figure 8 Autodesk Construction Cloud (ACC); Integrate existing structures and new design structures into one BIM model

The LiDAR data is processed in DJI Terra into a point cloud model, typically *.las files. This data is then directly imported into software such as Cyclone 3DR, Autodesk Civil 3D, and ArcGIS Pro to create a triangulated mesh surface, contour lines, and develop topographic maps from the point cloud data in a 3D environment. Whilst, The Photogrammetry data is processed in DJI Terra into texture mesh, typically in *.B3DM, *.OBJ, *.I3S formats. Both data are calibrated using Ground Control Points (GCPs) to enhance accuracy and are further verified with check points (CPs) (Figure 9).

Figure 9 A view of the existing structure of the jetty from ArcGIS Pro

Survey data from Unmanned Surface Vehicles (USVs) integrated with state-of-the-art Multibeam echo sounding and LiDAR devices will be processed using Hypack software, creating a raw point cloud model for underwater terrain and riverbanks, which are assigned coordinates and

35th PIANC World Congress, 29 April – 23 May 2024, Cape Town, South Africa
Paper Title: Application of BIM in assessing and re-designing of wharf structure after vessel collision
Authors Names: T.P.M. Khoi, L.D. Khoa, N.H.A. Thu and N.D. Thao

elevations according to the national elevation system, followed by exporting the Point Cloud data files in formats (*.E57, *Las...). The point cloud data from both onshore and underwater will then be integrated using software such as Cyclone 3DR, Autodesk Civil 3D, or ArcGIS Pro for noise reduction, data merging, error checking, and exporting the final data result as a combined point cloud dataset (Figure 10).

Figure 10 Broken pile segments at sea bed, scanned from USVs devices and integrated into ArcGIS Pro

Collect data from a wide array of sources, including USVs, UAVs surveys, LiDAR and Multibeam echo sounding data, CCTV footage, vessel tracking systems, eyewitness accounts, port operation logs, and historical data. The collection process requires effective coordination with various agencies, local authorities, and data storage systems to ensure a thorough and complete data set. Once collected, all data is aggregated into a single data centre environment such as GIS for spatial analysis and BIM software for structural assessments.

Simulation of Vessel collisions to analyse impact on port infrastructure

The collaboration between Autodesk and Esri, known as GeoBIM, represents a significant advancement in integrating geographic information systems (GIS) with Building Information Modelling (BIM), enables a seamless flow of data and insights across the project lifecycle. For effective integration into a GeoBIM environment, a BIM model must first be georeferenced within a GIS platform like ArcGIS Pro. Georeferencing involves aligning the BIM model to a specific coordinate system used in GIS to ensure that the model accurately represents its real-world geographical location. This integration facilitates improved planning, design, construction, and management of buildings and infrastructure by allowing users to visualize, analyse, and simulate real-world contexts alongside detailed building or infrastructure models (Figure 11).

The process of simulating vessel collisions utilizes 3D digital models of both the vessel and the wharf. Initial estimates of the vessel's speed and collision trajectory are derived from historical navigation data. The interaction between the laceration surface on the vessel and the damaged area on the wharf is modelled using point cloud and photogrammetry data. This data, along with other relevant information, is then integrated into a BIM-GIS framework and further enhanced through a Game Engine, creating a comprehensive and immersive simulation environment for detailed analysis of the collision.

Autodesk's acknowledgment of Unreal Engine underscores the vital role of real-time 3D visualization and interactive media in the design and construction industry, enhancing tools and capabilities for professionals globally. Esri's ArcGIS Maps SDK for Unreal Engine bridges GIS and 3D visualization, fostering applications that combine spatial analytics with dynamic graphics. Utilize visualization tools to create compelling visual representations of the collision impact, helping stakeholders to fully comprehend the extent and nature of the damage. By integrating various data sources, generate detailed 3D models, maps, and simulations that vividly illustrate the consequences of the collision, providing a clearer, more accessible understanding of the incident's impact.

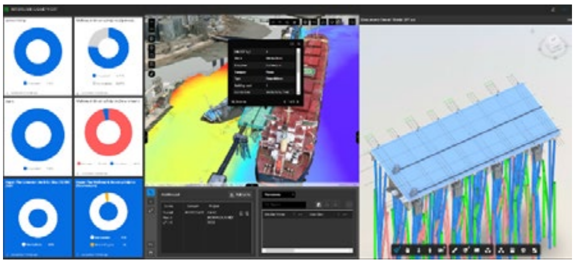

Figure 11 Manage re-construction progress on the ArcGIS platform with integrated BIM (design) model

RESULTS

Checking of the structural changes and damages of the port

The study utilized pre-collision data, including Terrestrial Laser Scanning (TLS) and Unmanned Aerial Vehicles (UAVs) surveys, along with as-built drawings of the port, to establish a baseline for comparison with post-collision TLS data. This comparative analysis was instrumental in identifying and documenting the structural changes and damages sustained by the port during the collision. The juxtaposition of pre- and post-collision datasets provided a clear view of the extent of the impact, highlighting areas that suffered the most damage and requiring immediate attention (Figure 12, Figure 13, Figure 14).

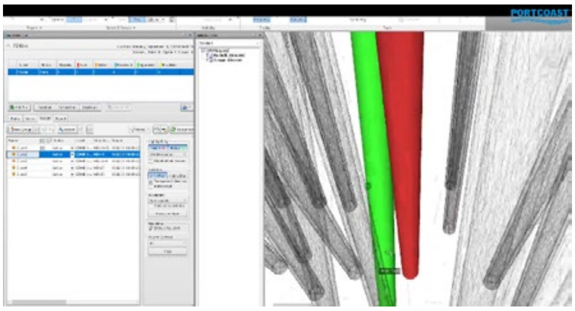

Figure 12 Clash analysis during the design process between the existing structures remaining after the collision and the newly designed structures

Figure 13 Integrate detailed design model (reinforcement) into the same platform as existing structures

The data gathered using Unmanned Surface Vehicles (USVs) equipped with Side Scan Sonar offered invaluable insights into the underwater impact of the collision, contributing significantly to the planning and execution of salvaging operations. The precise nature of this underwater survey data ensured that the most affected areas were accurately identified, aiding in the formulation of effective response strategies.

Post-collision data was employed to update the existing as-built 3D Building Information Modeling (BIM) models of the port. These updated models are now integral to conducting periodic inspections and formulating redesign strategies to restore and enhance the port's functionality. The revised BIM models reflect the current state of the port infrastructure, providing a reliable foundation for future planning and decision-making processes. This proactive approach in updating the BIM models ensures that the port management has the most current and accurate information at their disposal, which is essential for maintaining operational efficiency and safety standards.

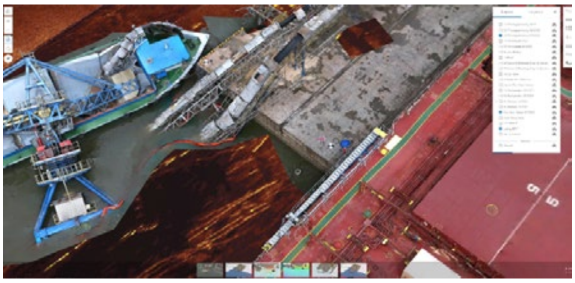

Figure 14 Pre-collision data, post-collision data and re-construction data are integrated into one platform

Vessel Collision Scenarios

Utilizing the combined strengths of Autodesk's BIM, Unreal Engine, and Esri's GIS capabilities, the study produced detailed visual representations of the vessel collision's impact. These visualizations included intricately detailed 3D models, maps, and simulations that not only illuminated the extent of the damage but also provided stakeholders with a clear and comprehensive view of the collision's aftermath. The integration of various data sources, such as BIM models, point cloud data, and historical navigation data, into these visualizations ensured a holistic and nuanced understanding of the incident's impact on the port infrastructure.

The resulting 3D models, maps, and simulations went beyond merely highlighting damage extents; they offered stakeholders a lucid and thorough perspective of the collision's consequences. The incorporation of a diverse range of data sources, including BIM models, point cloud data, and historical records, into these visual outputs guaranteed an all-encompassing and insightful portrayal of the incident's ramifications on the port's infrastructure (Figure 16).

A significant outcome of this integration was the ability to analyse the collisions from various viewpoints, transcending traditional methods like vessel tracking or CCTV footage (Figure 15). This multi-perspective approach allowed for a more comprehensive review of the incident, unveiling aspects that might be overlooked in conventional analyses. Stakeholders could virtually navigate through the collision scene, examining the impact from different angles and perspectives, which provided a deeper understanding of the event's complexity and guided more informed decisions for future infrastructure management and safety improvements.

35th PIANC World Congress, 29 April – 23 May 2024, Cape Town, South Africa
Paper Title: Application of BIM in assessing and re-designing of wharf structure after vessel collision
Authors Names: T.P.M. Khoi, L.D. Khoa, N.H.A. Thu and N.D. Thao

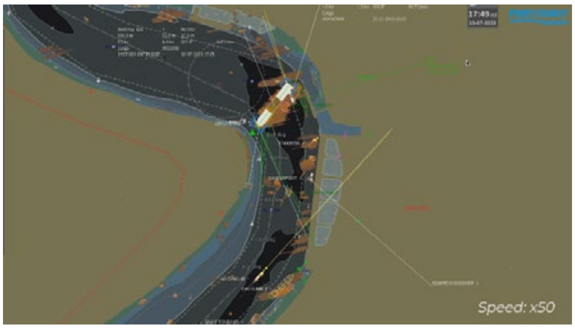

Figure 15 Vessel tracking data extracted from the vessel is an important information in collision investigation and simulation

The combination of advanced visualization, simulation technologies, and spatial analysis in this study not only enhanced the understanding of the vessel collision but also demonstrated the potential of these technologies in broader infrastructure management and safety applications. The ability to examine incidents from multiple perspectives opens up new possibilities for risk assessment, disaster response, and strategic planning in maritime infrastructure.

Figure 16 A product from Unreal Engine that simulates collisions with all pre-collision and post-collision data integrated

Discussion and Conclusions

This paper, set against the backdrop of Vietnam's burgeoning economy and the corresponding surge in waterway transportation, addresses the critical need for advanced post-collision inspection processes in the burgeoning network of river and seaports. The case study of a vessel collision at a Southern Vietnamese port terminal sheds light on the efficacy of innovative survey technologies such as Unmanned Aerial Vehicles (UAVs), Terrestrial Laser Scanning (TLS), and Unmanned Surface Vehicles (USVs). The integration of Building Information Modelling (BIM), Geographic Information System (GIS) technology, and Digital Twins has proven instrumental in enhancing the management of port infrastructure. These technologies not only facilitate regular inspections but also play a vital role in devising strategies for the restoration of structural integrity following collisions. Furthermore, the paper introduces a streamlined process for simulating vessel collisions, enabling a comprehensive assessment and testing of structural and operational components within the port environment. This research contributes significantly to the ongoing efforts to elevate port safety standards and maintenance practices, particularly in the context of the increasing maritime traffic and the risks associated with it.

The findings of this study underscore the importance of adopting a multifaceted approach to port infrastructure management and safety in the face of evolving challenges. The application of advanced technologies in surveying and inspecting port infrastructure post-collision provides a more comprehensive understanding of the impacts and aids in effective decision-making for repairs and future preventive strategies. Integrating various data sources for damage assessment ensures a holistic view of the collision's aftermath, thereby facilitating more accurate and informed reporting.

The simulations of vessel collisions offer a unique insight into the dynamics of such incidents, allowing for a detailed analysis of the impact on port infrastructure. This approach not only aids in understanding the structural changes and damages incurred but also serves as a proactive tool in preparing for and mitigating potential future incidents. By simulating various collision scenarios, port authorities and stakeholders can better anticipate potential risks and develop more robust safety protocols and infrastructure designs.

This study's methodology and findings highlight the potential of cutting-edge survey and modeling technologies in enhancing the resilience and safety of port infrastructure. As maritime traffic continues to grow in line with Vietnam's economic expansion, the need for such advanced approaches becomes increasingly critical. This research paves the way for further studies and the adoption of similar strategies in other maritime contexts, potentially contributing to a global improvement in maritime safety and infrastructure management.

References

[1] Do, S.T., Hoang, H., Truong, N.N.T., Che, D.H.Q. (2023). Simulation of Vessel Collision Scenario Using Photogrammetry and 3D Laser Scanning-A Case Study at the Container Terminal. In: Reddy, J.N., Wang, C.M., Luong, V.H., Le, A.T. (eds) ICSCEA 2021. Lecture Notes in Civil Engineering, vol 268. Springer, Singapore. https://doi.org/10.1007/978-981-19-3303-5_28

[2] Grigoras, I.-R & Covăsnianu, Adrian & Gheorghe, Plesu & Benedict, B.. (2009). Topographical surveys: Classical method versus 3D laser scanning. Case study - An application in civil engineering. Geographia Technical.

[3] Shan, J., Charless, K., "Topographic Laser Ranging and Scanning: Principles and Processing" (2009). Book. USA: CRC Press.

[4] Luh, L., Setan, H., Majid, Z., Chong, A., Tan, Z., “High resolution survey for topographic surveying” (2014). OP Conference Series: Earth and Environmental Science. 18. 10.1088/1755-1315/18/1/012067

[5] Chen, Jingdao & Cho, Yong. (2018). Point-to-point Comparison Method for Automated Scan-vs-BIM Deviation Detection.

[6] Bucaille, I., Héthuin, S., Munari, A., Hermenier, R., Rasheed, T., & Allsopp, S. (2013). Rapidly Deployable Network for Tactical Applications: Aerial Base Station with Opportunistic Links for Unattended and Temporary Events ABSOLUTE Example. MILCOM 2013-2013 IEEE Military Communications Conference, 1116-1120.

[7] Erdelj, M., Natalizio, E., Chowdhury, K. R., & Akyildiz, I. F. (2017). Help from the Sky: Leveraging UAVs for Disaster Management. IEEE Pervasive Computing, 16(1), 24-32

[8] Thomas w. vaneck., Claudia d. rodriguez-ortiz., Mads c. schmidt, Justin e. manley.,“Automated Bathymetry Using an Autonomous Surface Craft“, Journal of the Institute of Navigation; Volume43, Issue4, 1996.

[9] Benjamin, M.R. and Curcio, J. 2004. COLREGS-Based Navigation in Unmanned Marine Vehicles. In: IEEE Proceedings of AUV-2004, Sebasco Harbor, USA.

[10 Mariusz Specht, Cezary Specht, Maciej Szafran, Artur Makar, Paweł Da̧browski, Henryk Lasota and Piotr Cywi´ nski., “The Use of USV to Develop Navigational and Bathymetric Charts of Yacht Ports on the Example of National Sailing Centre in Gda´ nsk “, Remote Sens. 2020, 12, 2585.

[11] Jacek Lubczonek * , Witold Kazimierski , Grzegorz Zaniewicz and Malgorzata Lacka., “Methodology for Combining Data Acquired by Unmanned Surface and Aerial Vehicles to Create Digital Bathymetric Models in Shallow and Ultra-ShallowWaters“. Remote Sens. 2022, 14, 105.