TRANSNAV
http://www.transnav.eu
the International Journal on Marine Navigation and Safety of Sea Transportation
Volume 18
Number 1
March 2024
DOI: 10.12716/1001.18.01.11

The Application of Mixed Reality and UAS Technology in Port Decision-Making Process Based on PASSport Project

L. Gucma[1], B. Muczyński[1], M. Bilewski[1], M. Gucma[1] & M. Nisi[2]
[1] *Maritime University of Szczecin, Szczecin, Poland*
[2] *Sistematica S.p.A,Terni, Italy*

ABSTRACT: It is becoming increasingly important to provide a solution for managing the present mission and status of autonomous and semi-autonomous vehicles operating on site in large and complex port locations. More ports are implementing digital twin systems, which provide a complete 3D reconstruction of the port as well as real-time data on all objects and actions in progress. It is challenging to provide all relevant data in a way that improves situational awareness and decision-making, resulting in improved management and a faster, more effective response during an emergency. This is due to greater port areas and drones operating in the air, on the water's surface, and underneath. To solve this issue, the PASSport initiative, a project financed by the European Space Agency (EUSPA), is developing an innovative solution based on Mixed Reality (MR) technology. The solution combines real-time geo-tagged and Earth Observation data to provide end users with enhanced 3D representation of the port area via a dedicated Head Mounted Display (HMD) that records user location and movement.

1 INTRODUCTION

Ships have a significant environmental impact on seaport areas.

Ports serve as entrance points for worldwide maritime trade, however despite the sector's significant economic and social benefits, there are a number of cases where it severely impacts the environment and the health of EU inhabitants [Passerini et al 2019]:

- Ports and shipping can contribute to global warming by emitting greenhouse gases.
- Because 40% of Europeans live within 50 kilometers of the sea, air pollution from ships can harm both the marine ecosystem and human health.
- Pollution incidents, such as oil spills, can have serious consequences for the marine life and inhabitants of the affected areas.
- According to study, underwater noise from ships sailing over the ocean can cause hearing loss, increased stress, and behavioral changes in marine creatures.
- Untreated ballast water aids in the spread of species from one maritime area to another, altering ecosystems and threatening native marine life.

Ballast water is necessary for ships to operate correctly. The International Maritime Organization (IMO) has worked hard to eliminate both accidental and purposeful ship pollution. MARPOL, one of the most important international agreements for the maritime environment (International Convention for the Prevention of Pollution from Ships, 1973, as revised by the Protocol of 1978), has been one of the fundamental endeavors in this area. It was established by the International Maritime Organization (IMO) to reduce pollution of the seas and oceans, including the marine environment and adjacent air pollutants included in Annex I, II, III, IV, V, and VI. Pollution from ships in ports is classified as follows:

– Particulate matter (PM), SOx (sulphur oxides), NOx (nitrogen oxides), and greenhouse gases (particulate matter) are examples of air pollutants.
– Spills caused by ships, such as (accidental and intentional) oil, chemical, and dry-bulk leaks during loading and unloading procedures.
– Waste-related water contamination.
– Gray and black water bilge water contamination (e.g., sanitary facilities) (sinks, showers, kitchens, and laundries).
– Contamination from water used for cargo hold cleaning.
– Pollution caused by solid waste (litter).
– Invasive species, as well as other biological matter, such as bacteria or viruses, contaminating ballast water.
– Noise in the air and beneath the water.

Several studies have shown that more international legislation are needed to review vessel-related air pollution caused by ship traffic emissions [Lindgren, 2021].

2 STATE OF THE ART

Both MR and UAV technologies have been used in various scenarios in port environments. Drones, including UAS, are being include as a part of so-called Industry 4.0 in ports and maritime industry bringing improvements in areas like ship-shore packages delivery, pollution monitoring and surveillance [Zarzuelo, et al. 2020]. MR has been used mostly as a simulation technology that can improve immersion and lower cost during trainings and also as a design tool for shipbuilding [Sanchez-Gonzalez, et al. 2019]. Directly in port areas MR has been implemented as an information sharing platform [Shu et al. 2007] and for visualization of a port’s digital twin [Yao et al. 2021].

While there are notable examples of ports that implement both of those technologies, like Hamburg, Rotterdam, or Shanghai, not much can be found in scientific literature that would present a comprehensive system utilizing UAS and MR for port operations, including air pollution monitoring.

3 PASSPORT SOLUTION

The PASSport program's goal is to develop and validate a method for expanding situational awareness using fixed-wing, rotary-wing, and underwater drones in port environments.

The EU Directive 2005/65/CE on Enhancing Port Security calls for the establishment of surveillance systems across the port area to considerably boost security and safety for daily operations engaged in the port region. The directive applies to approximately 1000 European ports. The proposed method intends to enhance presently in use platforms by extending the surveillance perimeter with a fleet of drones. It provides innovation and operational assistance for identifying, managing, and analyzing safety and security aspects of daily operations, with a focus on:

– Pollution monitoring (environmental protection).
– Support to e-navigation (safety).
– Critical buildings/ Infrastructures protection (security).
– Protection against non-cooperative small craft approaching the port areas (security).
– Underwater threats monitoring (security).

The unique aspect of the project is the use of a fleet of partially automated drones that integrates Galileo services (and other sensors) for safe and effective guidance, navigation, and control (GNC) even in the presence of obstacles like buildings and other ground assets as well as potentially unfavourable weather conditions. The PASSport system design is shown in Figure 1, which lists the segments shown below:

– PASSport Aerial Segment (PAS),
– PASSport Ground Segment (PGS), composed by mission (PMS) and Control (PCS) elements.

The purpose of PASSport is to ensure the following key features:

– Measuring player awareness of dangers and increasing player awareness (security). The PASSport platform suggests the design and implementation of suitable procedures that can be used to fight threats after the assets and infrastructure which need to be secured against the threats and risks of purposeful illegal activity facing port activities are recognized. This is accomplished after determining the risk level (normal, increased, or high), and it is done so by following specified methods and utilizing technical tools designed with ports in mind. This enables the proper response to be given to infrastructure's potential vulnerability.
– Control and oversight of port areas (security and safety). The PASSport platform offers a suitable Human-Machine Interface (HMI) to apply pertinent procedures and monitor port security and safety on a regular basis.

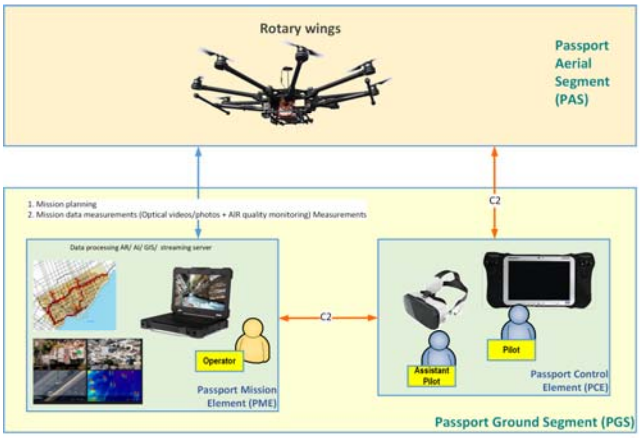

Figure 1. PASSport architecture for the pollution monitoring (source: own work)

Data possessed by the Remotely Piloted Aircraft Systems (RPAS) are analysed at the PGS level in real time by a local computer. In order to provide proper positioning, RPASs are outfitted with high accuracy

GNSS receivers that leverage Galileo differentiators such as OSNMA (for position reliability and security), HAS/PPP (for positioning accuracy), and multi-frequency (for robustness and accuracy). These technologies are combined with contemporary robotics (vision-based navigation, AI, and Deep Learning algorithms) to ensure automated, secure, and continuous operations.

4 THE VALIDATION CAMPAIGN IN KOLOBRZEG

Maintaining air and water quality is a difficulty for all ports and harbors. Mitigating difficulties entails caring for the entire marine ecology as well as the surrounding land. Ports and harbors are densely populated industrial locations near the water. Many activities, including boat repair, transportation, terminal operations, cargo handling, and storage, have the potential to harm air/water quality, especially if an incident occurs. In order to validate the water and air pollution monitoring system, as well as the augmented reality system interface as a situational awareness solution, the PASSPort team conducted testing in the Port of Kołobrzeg (Figure 2). The Kołobrzeg Port is located on the Baltic Sea, at the mouth of the Parsęta River. It performs a merchant ship loading/discharging, fishing and passenger function. The port has a several loading quay, two shipyards, fishing harbour and two marinas. As a result, the port of Kołobrzeg recognized a pollution monitoring concern and views PASSport as a suitable solution for:

– Air quality surveillance mission.
– Water pollution surveillance mission

A 3D point map is generated with each data point describing air and water quality as measured with all installed sensors. Colour coding and simple alert system should be implemented. The mission assumes the surveillance flight aerial and marine complemented with additional EO data from satellite.

Figure 2. Port of Kołobrzeg. Layout. (1) – cargo handling and administration area, (2) – fishing port and shipyard area, (3) – yacht marina

The aim of the validation is to show the solution to the end user - in this case the Kolobrzeg Sea Port Authority. The system consists of the following modules (Figure 3):

– A drone module consisting of flying drones (UAVs) and floating drones (USVs) with operators controlling their operation.
– Communication system based on the Internet and GSM communication (4G/5G).
– A server responsible for processing data including also data from Copernicus and presenting it to end users and decision-makers.
– A mixed reality system, which is an operator decision support system enabling two-way communication between decision makers and drone operators.

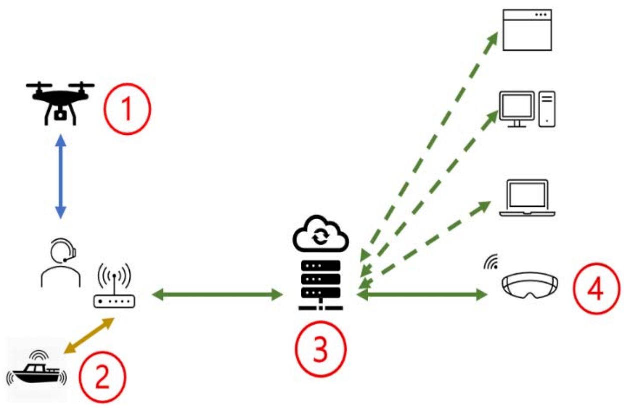

Figure 3. Architecture of the PASSport solution (1- flying drone with operator, 2 - floating drone with operator, 3 - server, 4 - decision-making part with interface in mixed reality technology)

5 PASSPORT PLATFORM VALIDATION RESULTS IN KOOBRZEG PORT

The following equipment and services were used during the validation campaign:

1. A rotary wings drone, i.e. DJI Matrice 300 RTK (Figure 4). It provides a 30-minute flight with a maximum load of 3kg and the ability to operate three sensors. Hot-swapping the battery, i.e. without turning the drone off, allows all intended tasks to be practically accomplished. The drone is able to defy wind speeds of up to 15 m/s. Its speed during flight is approximately 20 m/s. The drone is equipped with an Real-time kinematic positioning system (RTK) to achieve in-flight positioning accuracy of up to 10 cm. A Sniffer 4D was used [Kim et al. 2021] as the main air pollution sensor on the drone, allowing the detection of particulate matter with different particle diameters, sulphur oxides, nitrogen oxides and ozone (Figure 6):
   – Particulate matter:
     – PM1 (0.3 - 10 μm),
     – PM2.5 (0.3 - 10 μm),
     – PM10 (0.3 - 10 μm),
   – O_3 + NO_2 (0-10 ppm),
   – SO_2 (0- 10 ppm).

   The drone was additionally equipped with a specialised Zenmuse H20t camera, which is an integrated vision and thermal imaging camera that also has a laser rangefinder. No UV cameras (PCO-

UV in the 190nm - 1100nm band) or the Mica Sense multispectral camera (supporting as many as 10 bands) were used in the study due to the inability to simulate spillage.

2. A double-hulled USV 'Sharky' (Figure 5) designed for hydrographic surveys in sheltered waters (rivers, lakes, harbour basins, lagoons) was used during the validation. The 1 m x 0.85 m vehicle has a laminated hull design allowing it to operate in water temperatures in the full encountered range of 1-30 deg C. The freeboard height is 0.6 m and the minimum draught of 0.3 m allows it to be used in the shallowest areas. The displacement of max. 25 kg allows up to 10 kg of apparatus to be fitted. The electric propulsion motor (brushless direct-current motor - BLDC) allows infinitely variable speed control from 0 to 6 knots. The drone is supplied with a single-beam probe and water sampling kit.

Figure 4. DJI Matrice 300 RTK drone with Sniffer 4D air pollution sensor and thermal imaging camera installed

Figure 5. The USV "Sharky" floating drone in preparation for testing during the validation campaign

3. EO data from Copernicus. The scope of the activities carried out within the PASSport project was to evaluate and assess the usability and applicability of Copernicus services to the PASSport scenarios and to deduce attainable performances applicable to PASSport-related applications. The great advantage of the Copernicus program is represented by the synergic use of different satellite platforms (ESA's families of dedicated Sentinel and Contributing Missions), hosting either active or passive sensors, and observing different portions of the electromagnetic spectrum. Each region of the electromagnetic spectrum has its unique applicability for observations. In particular, quality parameters assessment and monitoring using Sentinel-5P have been analysed for the campaign n Kolobrzeg.

4. A dedicated application was created for the first-generation Microsoft HoloLens device, which is one of the most advanced mixed reality technology devices available on the market, allowing for full 3D holographic projection. Through its use, it is possible to present a three-dimensional map of the area with clean air measurement points, the current position of the drone along with its parameters. Configurable values for standards and alerts allow quick and accurate identification of areas where there is a risk of increased emissions.

Finally, a Mixed Reality solution [Radanovic et al. 2022] has been proposed as an experimental solution where data from multiple drones as well as any external data source like Automatic identification system (AIS) or Copernicus, can be integrated and visualized together. For the purpose of the campaign, a Microsoft HoloLens gen. 1 device has been used. The application has been developed using following software and SDK:

– Unity Engine 2019.4,
– Microsoft Mixed Reality Toolkit,
– Microsoft Maps SDK for Unity.

This particular set of tools makes it possible to develop a solution that can be build for range of hardware platforms in both AR and VR technology, including Microsoft Hololens gen. 1 and 2, Meta Quest and SteamVR devices. Since the data is taken directly from the server it is possible to feed processed and historical data in real-time (Figure 7).

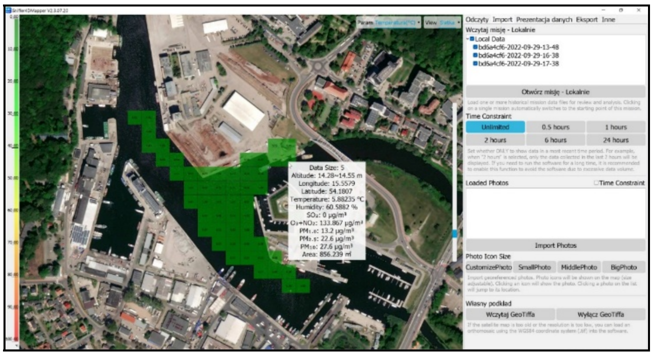

Figure 6. Visualization of data from Kołobrzeg campaign using Sniffer4D Mapper™ Analytic Software

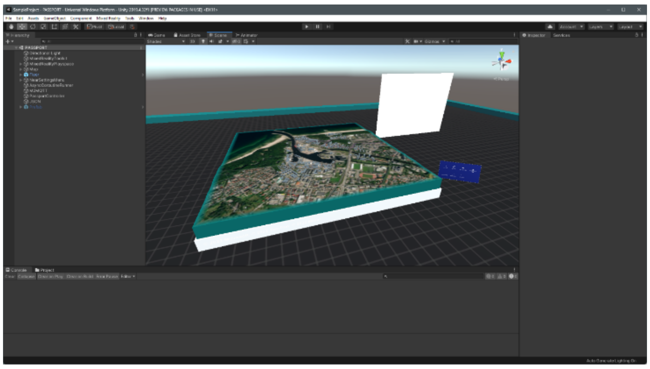

Figure 7. Dedicated MR application. View from the Unity Engine Editor

The presented architecture makes it possible to present the data with a 1Hz sampling rate in real time, in 3D environment to any end-used with an authenticated access to the server (Figure 8).

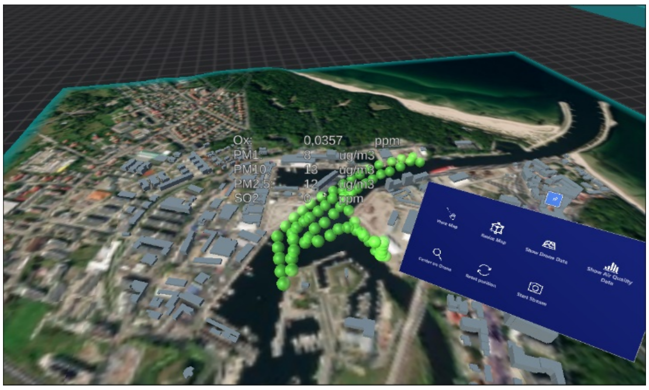

Figure 8. Data as presented in the MR app. Screenshot taked from desktop version of the app (source: own work)

Due to the massive traffic involving the coastal area of Kołobrzeg, the monitoring of air pollution is a paramount task in order to reduce the risk of environmental health problems. Data has been acquired locally using the drones fleet equipped with the Sniffer 4D sensors (Figure 9).

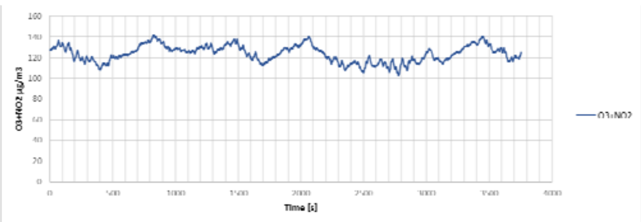

Figure 9. In situ data using the fleet of drones equipped with Sniffer 4D sensors.

6 CONCLUSIONS AND FUTURE WORK

This article presents PASSport's validation campaign in the port of Kolobrzeg in order to evaluate the water and air pollution monitoring system and the augmented reality system interface as a situational awareness solution. This was the first in a series of validation initiatives for the PASSport project. The following validation campaigns will take place in Hamburg (for critical infrastructure), Valencia (for e-Navigation), Le Havre (for small, recalcitrant vessels), and Ravenna (for underwater risks).

In-situ data from several GPS-referenced drones, as well as any external data sources, such as AIS or Copernicus, are merged and presented in a Mixed Reality application, which has been made available as an experimental solution.

Future work will address a variety of other research, operational, and engineering issues in order to fully utilize and implement the developed system and drones for port surveillance and pollution management. Among these issues are:

– Automated monitoring - Drones can perform monitoring tasks autonomously, but safety is crucial in this circumstance, thus drones must fly over water while keeping a safe distance from ships and other objects to avoid endangering people of surrounding structures.
– Development of a multi-sensor head for scanning port environmental contaminants (combination of optics and other sensor heads).
– Such a multisensor platform can be built using OEM components.
– A proposed oil spill tracking and forecast initiative includes the development of a multisensor platform with integrated optics, laser fluorescence, and a thermal imaging camera for tracking already-spilled oil.
– Monitoring triggered by the operator. Performing certain tasks as directed by the operator. Circumnavigating an object, stationary suspension, etc.
– Physical sampling of water. Landing and taking off from water.
– Assisting in firefighting operations and dealing with chemical and oil accidents. Information on an oil spill is provided. Monitoring of oil spots or fires online.
– Giving testimony in court about air and water pollution.
– Drone approach to a moving vessel collecting exhaust samples utilizing AIS data and visual observation by the operator. It is also in great demand in terms of safety.
  Keep an eye on the yacht as it approaches the quay for signs of excessive mooring energy and damage to the fenders and quay.

ACKNOWLEDGEMENTS

The PASSport project, Operational Platform managing a fleet of semi-autonomous drones exploiting GNSS high Accuracy and Authentication to improve Security & Safety in port areas, has received funding from the European Union Agency for the Space Programme (EUSPA) under the European Union's Horizon 2020 research and innovation programme under grant agreement No 101004234.

REFERENCES

Kim M., Jang Y., Heo J and Park D. 2021, A UAV-BASED AIR QUALITY EVALUATION METHOD FOR DETERMINING FUGITIVE EMISSIONS FROM A

QUARRY DURING THE RAILROAD LIFE CYCLE. Sensors, https://doi.org/10.3390/s21093206

Lindgren S. 2021, THE COAST IS CLEAR: SHIPPING EMISSION STANDARDS, AIR QUALITY AND INFANT HEALTH, Transportation Research Part D: Transport and Environment, https://doi.org/10.1016/j.trd.2021.103067

Radanovic M., Khoshelham K. and Fraser C. 2022, VIRTUAL ELEMENT RETRIEVAL IN MIXED REALITY ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences,

Passerini, G., Rodriguez G. and Ricci, S. 2019, Maritime Transport, Wit Press. Southampton - Boston.

Sanchez-Gonzalez, P-L, Díaz-Gutiérrez, D., Leo T.J., Núñez-Rivas L.R. 2019, TOWARD DIGITALIZATION OF MARITIME TRANSPORT? Sensors 19, no. 4: 926. https://doi.org/10.3390/s19040926

Shu, F., Mi, W., Xu, Z. 2007 THE INFORMATION SHARING PLATFORM FOR PORT CONTAINER TERMINAL LOGISTICS USING VIRTUAL REALITY, IEEE International Conference on Automation and Logistics, Jinan, China, pp. 2570-2575, doi: 10.1109/ICAL.2007.4339013

Yao, H., Dachuan W., Mengchao S., Yue Q. 2021, APPLICATION OF DIGITAL TWINS IN PORT SYSTEM, Journal of Physics: Conference Series 1846 (1): 012008. https://doi.org/10.1088/1742-6596/1846/1/012008.

Zarzuelo, I. de la Peña, Soeane, M. J. F., Bermúdez, B. L. 2020, INDUSTRY 4.0 IN THE PORT AND MARITIME INDUSTRY: A LITERATURE REVIEW, Journal of Industrial Information Integration, Volume 20, 100173, ISSN 2452-414X, https://doi.org/10.1016/j.jii.2020.100173