PASSport
Executive Summary
PASSport – D1.4

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1 INTRODUCTION

1.1 SCOPE

This document is the project executive summary and reports the evidence and the outcomes reached along with the project.

1.2 APPLICABLE DOCUMENTS

ID	Description
[AD 1]	GRANT AGREEMENT NUMBER - 101004234

Table 1-1 Applicable Documents

1.3 REFERENCE DOCUMENTS

The following table includes all the deliverables prepared along with the project.

ID	Description
[RD 1]	PASSport D1.1 Quarterly Progress Report
[RD 2]	PASSport D1.2 Data Management Plan
[RD 3]	PASSport D1.3 Risk Register and Treatments
[RD 4]	PASSport D1.4 Executive Summary (this document)
[RD 5]	PASSport D2.1 User Requirements analysis
[RD 6]	PASSport D2.2 Use cases definition
[RD 7]	PASSport D2.3 Regulation for RPA usage in port areas (issue 1.0)
[RD 8]	PASSport D2.4 PASSport Specifications and Design
[RD 9]	PASSport D3.1 PASSport Ground Segment
[RD 10]	PASSport D3.2 PASSport Ground Segment User Manual
[RD 11]	PASSport D3.3 RPA complete units
[RD 12]	PASSport D3.4 Aerial Rotary wings drones Operational User Manual
[RD 13]	PASSport D3.5 Aerial Fixed wings drones Operational User Manual
[RD 14]	PASSport D3.6 Underwater drones Operational User Manual
[RD 15]	PASSport D3.7 TN: Usage of EO to monitor activity in port area
[RD 16]	PASSport D3.8 TN: GNSS solutions to support port safety and security
[RD 17]	PASSport D3.9 TN: Augmented Reality to support port safety and security
[RD 18]	PASSport D3.10 TN: AI &DL for GNC to support port safety and security
[RD 19]	PASSport D3.11 TN: Rotary wings drones to support port safety and security
[RD 20]	PASSport D3.12 TN: Underwater drones to support port safety and security
[RD 21]	PASSport D3.13 TN: Fixed wings drones to support port safety and security
[RD 22]	PASSport D3.14 System Verification Plan
[RD 23]	PASSport D3.15 Verification Report (On factory Test results)
[RD 24]	PASSport D4.1 Regulation for RPA usage in port areas (issue 2.0)

ID	Description
[RD 25]	PASSport D4.2 Validation Plan
[RD 26]	PASSport D4.3 Validation Campaigns Report
[RD 27]	PASSport D5.1 Stakeholder Data base
[RD 28]	PASSport D5.2 Dissemination Plan
[RD 29]	PASSport D5.3 Project Web site
[RD 30]	PASSport D5.4 Social media
[RD 31]	PASSport D5.5 Press Releases and publications
[RD 32]	PASSport D5.6 Newsletters (at least 3)
[RD 33]	PASSport D5.7 Poland (Szczecin) Workshops materiel
[RD 34]	PASSport D5.8 Italian (Crotone) Workshops materiel
[RD 35]	PASSport D5.9 Spanish (Valencia) Workshops materiel
[RD 36]	PASSport D5.10 German (Hamburg) Workshops materiel
[RD 37]	PASSport D5.11 French (Le Havre) Workshops materiel
[RD 38]	PASSport D5.12 Papers to attend conferences
[RD 39]	PASSport D5.13 Final Workshops materiel
[RD 40]	PASSport D5.14 Professional User training material (incl planning and report)
[RD 41]	PASSport D5.15 Advisory boards minutes
[RD 42]	PASSport D6.1 Business Model
[RD 43]	PASSport D6.2 Cost Benefit Analysis
[RD 44]	PASSport D6.3 RoadMap
[RD 45]	PASSport D6.4 Business Plan
[RD 46]	PASSport D6.5 Sales Strategy Report
[RD 47]	PASSport D7.1 H - Requirement No. 1
[RD 48]	PASSport D7.2 POPD - Requirement No. 2
[RD 49]	PASSport D7.3 EPQ - Requirement No. 3
[RD 50]	PASSport D7.4 M - Requirement No. 4
[RD 51]	PASSport D7.5 OEI - Requirement No. 5
[RD 52]	PASSport D7.6 GEN - Requirement No. 6
[RD 53]	PASSport D1.1 Quarterly Progress Report

Table 1-2 Reference Documents

1.4 ACRONYMS

Acronym	Description
AI	Artificial Intelligence
AIS	Automatic Identification System
AUV	Autonomous Underwater Vehicle
BVLOS	Beyond Visual Line of Sight
C2	Command and Control
CCTV	Closed-circuit television
ENV	Environmental
EO	Earth Observation
GNC	Guide Navigation Control
HAS	High Accuracy service
HMI	Human Machine Interface
IMU	Inertial Measurement Unit
MI	Monitoring and Inspection
MR	Mixed Reality
MTD	Master Tethered Drone
OL	Operations and Logistics
OSNMA	Open Service Navigation Message Authentication
PAS	PASSport Aerial Segment
PASSPORT	Operational Platform managing a fleet of semi-autonomous drones exploiting GNSS high Accuracy and Authentication to improve Security & Safety in port areas
PGS	PASSport Ground Segment
PL	Protection Level
PPP	Point Precise Positioning
PUS	PASSport Underwater Segment
RFI	Radio Frequency Interference
RGCS	RPAS Ground Control Segment
RGMS	RPAS Ground Mission Segment
UD	Underwater Drone
VLOS	Visual Line of Sight

Table 1-3 Acronym List

2 SUMMARY

The purpose of the PASSport (Operational Platform managing a fleet of semi-autonomous drones exploiting GNSS high Accuracy and Authentication to improve Security & Safety in port areas) is to engineer and qualify a solution extending situational awareness based on aerial fixed/ rotary wing and underwater drones to **improve safety and security in port areas.** The need stems from the directive 2005/65/CE asking to **complement surveillance systems for the whole port area**, to significantly improve security and safety for daily operations implanted in port area. This result also in saving citizen lives ensuring a high and equal level of safety and security for all European ports. Around one thousand European ports fall within the scope of the directive. As a consequence, PASSport responds to the needs expressed by port authorities, harbour master and border control authorities which are active parties in the consortium and will be directly involved in the definition of the proposed solutions.

The PASSport solution of the project combines both aerial and underwater unmanned vehicles with a network of RFI monitoring stations. **The use of this fleet of drones** is intended to provide innovation and operational support to the recognition, management and analysis of safety and security aspects of daily operations, with particular attention to pollution monitoring, support to e-navigation, protection of critical infrastructures and against non-cooperative small craft approaching port areas, and underwater threats monitoring. Particularly, the drones will combine state of the art technologies to collect on field data in real time, which allows surveillance with an extended situational awareness by covering larger areas. So far, operational activities to guarantee security and safety are dealing with static sensors, and the data collected cannot automatically trigger dedicated operational procedures. With PASSport vision, this limitation is overcome by proposing a holistic surveillance solution. The solution is planned to be connected with already deployed operational platforms and exploit the innovation brought by drone assisted with E-GNSS technology. The above-mentioned drone fleet integrates, among other sensors, the use of GNSS receivers for a secure, safe and accurate guidance, navigation, and control (GNC). GNSS technologies are widely used for many purposes in drone navigation systems, as they are integrated in most, if not all, conventional autopilots. However, accuracy and security of this technology can be compromised in certain demanding areas, such as port infrastructures due to multipath, or if subjected to certain interferences, either intentional or not, and this is the reason why hybridisation with other sensors is usually contemplated. In any case, even with hybridised configurations, a diminished GNSS performance may lead to a potential degradation of the drone navigation system. Taking this into consideration, the integration and exploitation of new GNSS services oriented to improving accuracy and security is not only justified but also necessary. In terms of accuracy, a **PPP algorithm in post-processing** is considered, as it is a widely mature positioning technique. This positioning method uses single or dual-frequency code and carrier phase measurements for centimetric accuracy applications. On the other hand, in terms of security, navigation with Galileo's newcomer **Open Service – Navigation Message Authentication (OSNMA) is used.** OSNMA is a data authentication function for Galileo that provides receivers with the assurance that the received Galileo navigation message is coming from the system itself and has not been modified[1]. The use of this service in the PASSport solution helps in the avoidance of some of the aforementioned threats in port context. In terms of safety an integrity approach is considered to provide protection levels (PLs). The described capabilities in terms of accuracy, integrity, and security will be introduced in an evolution of GNSS receiver MAGIC User Terminal, which will be embarked onboard the aerial drones. For the monitoring backbone, srx-10i (also known as DINTEL) will provide a cost-effective, dual-band, simultaneous monitoring of GNSS bands. Within the PASSport project, also Copernicus data are considered, whose objective is to deliver data, information, services and knowledge at global level and within a variety of applications and within several domains. The scope of the activities was to evaluate and assess the usability and applicability of Copernicus services to the PASSport scenarios and to deduce attainable performances applicable for PASSport related applications. The proposed solution is intended to complement already operational platforms by extending the surveillance perimeter using a fleet of drones to provide innovation and operational support to the recognition, management and analysis of safety and security aspects of daily operations with particular attention to:

- ✓ Pollution monitoring (safety)
- ✓ 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)

[1] Galileo Open Service Navigation Message Authentication (OSNMA) | European GNSS Service Centre (gsc-europa.eu)

3 THE NEED FOR SAFETY AND SECURITY IN PORT AREAS

3.1 THE CONTEXT

The target operational environment of PASSport is represented by the port areas. Ports are located usually to very crowded areas therefore expose millions of its inhabitants on threats.

Figure 3-1 Sea-side and ground-side port areas scenarios

The major mission requirement of PASSport is to increase situation awareness in ports by delivering set of airborne and underwater robotics to collect information on the field. The following categories are envisaged:

- ✓ **Monitoring and Inspection (MI).** MI includes everyday monitoring of ships, goods, passengers, vehicles rail, with special attention of critical infrastructure, walls, fences, and general safety monitoring mostly to avoid dangerous and critical situations. This category includes both daily operations and urgent dedicated safety inspections, firefighting operations and accidents management.
- ✓ **Environmental (ENV).** ENV is focused on detecting environmental pollution, identifying sources of detected pollution, monitoring its spread and assisting during clean-up operations, in case of oil spill or other serious water pollution emergencies.
- ✓ **Operation and Logistics (OL**). OL is related with strict port operations like ships traffic monitoring, ship at the quay monitoring, cargo monitoring, stock piles volume, containers and E-Navigation in aspect of efficiency. One of the most critical aspects of port operations is vessel traffic management. Harbours generally have narrow channelled entry/exit and need to cater to the movement of a large number of ships daily. This process can get extremely complicated and safety-critical, as a tiny error can have catastrophic consequences, including loss of life and incapacitation of the port.

3.2 PASSPORT CAMPAIGNS

With reference to the scenarios envisaged in chapter 3.1, the following campaigns have been envisaged.

PASSPORT use case	Mission type	Campaign site
Pollution monitoring	ENV	Kolobrzeg port
Support to e-navigation	OL	Valencia port
Critical buildings and infrastructures protection	MI	Hamburg port
Protection against non-cooperative small craft approaching the port areas	MI	Le Havre port
Underwater threats monitoring	MI	Ravenna port

Table 3-1 PASSport use cases and campaigns

3.2.1 POLLUTION MONITORING IN KOLOBRZEG PORT

The Kołobrzeg Port is located on the Baltic Sea (130km from Szczecin, and 270km from Berlin by road), at the mouth of the Parsęta River. It performs a merchant ship loading/discharging, fishing and passenger function, it also has a 2 yacht marina. The port has a several loading quay, two shipyards, fishing harbour and two marinas. In the area where the commercial function is performed, ships with a length of up to 100 meters, width of up to 15 meters and a draft of up to 5.0 meters are operated. Yearly traffic of commentarial ships is around 100 per year. There is passenger ship traffic in the summer (several moves daily) and fishing (several moves daily).

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

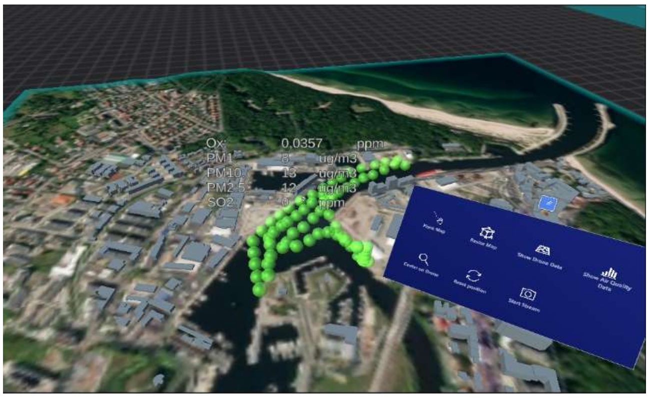


Figure 3-3 Data as presented in the MR app. Screenshot taken from desktop version of the app

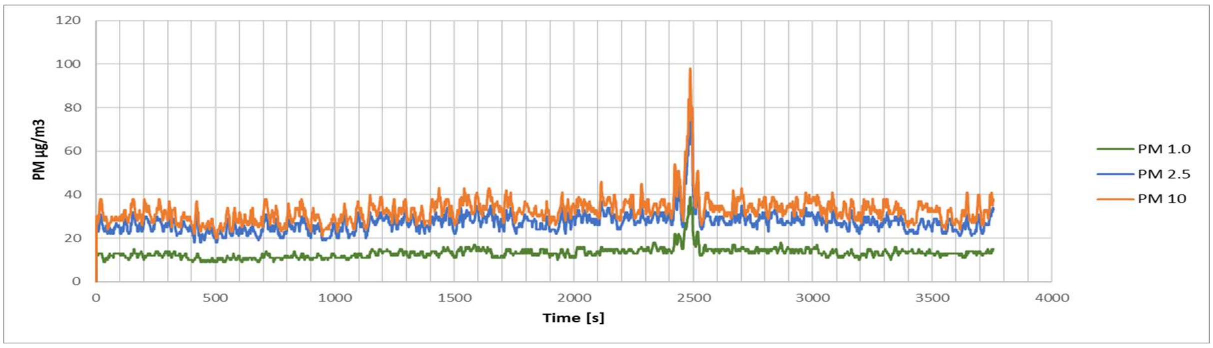


Figure 3-4 Recording of a PM measurements during artificial air pollution exposition

Port of Kołobrzeg is one of invited interested parties and, as per questionnaire used for defining user requirements, is planning to use drones for specific mission. After collecting data via the questionnaire, the port board has been invited for discussion and pointed out that the city of Kołobrzeg, being a health resort, is very aggressive towards any possible source of pollution. The port would like to position itself as one of leading examples of air and water pollution monitoring. Hence the port of Kołobrzeg identified problem of pollution monitoring and is convinced that it could be solved using drones and is interested in PASSport as a possible solution.

3.2.2 SUPPORT TO E-NAVIGATION USING TARGET DETECTION AND LOCALISATION IN VALENCIA PORT

The Port Authority of Valencia, locally recognized as 'Autoridad Portuaria de Valencia,' plays a pivotal role in the effective administration and operation of three distinct ports situated in the Valencia region of Spain (Valencia, Sagunto and Gandía). Tasked with the responsibility of ensuring smooth and efficient maritime activities, this authoritative body acts as the driving force behind the region's maritime trade and connectivity. Moreover, the Port Authority of Valencia plays a crucial role in promoting safety and security within the maritime domain. Through stringent regulations, advanced surveillance systems, and effective emergency response mechanisms, the authority strives to guarantee the well-being of both personnel and assets within the port facilities.

Figure 3-5 *Valencia Port (West)*

Figure 3-6 shows a frame during one of the flight experiments during the campaign. In this flight different container vessels, tugboats, a pilot boat and a port buoy were detected and geolocalized. In the left side of the figure, it is shown an image of the visual camera including the bounding boxes of the objects detected by YOLO; two container vessels (one small on the top-right) and a buoy. The right side of the figure shows the real-time position of the geolocalized objects (container vessel and buoy) over a map plus the position of the drone given by the localization system.

Figure 3-6 Real-time vessel geolocalization. Left: AI-based object detection. Right: positioning of drone and geolocalization of container vessel and port buoy.

Figure 3-7 Trajectory of a container vessel estimated by the geolocalization system.

In the map presented in Figure 3-6 it can be seen a real image of the buoy captured by the satellite systems (very small object on the left side of the circle that highlights the geolocalized buoy). Even its position may not match with the real position of the bouy since they usually fluctuate depending on the direction of water currents, it can be used to compare with the buoy position estimated by our geolocalization system (pink dot on the map). Considering the bouy satellite image as the ground truth position it has observed that the average position error of the geolocalized buoy is less 5 meters.

Figure 3-7 presents the trajectory followed by the MSC container vessel during a part of the flight experiment. This trajectory corresponds to the one estimated by the geolocalization system post-processed to eliminate certain outlier values. These outliers only appear when a fast and major change in orientation is applied on the drone. That is because there exists a small delay between the orientation estimated by the localization system and the real one (typical when using Kalman filters). Nevertheless, these outliers are not so common, and were mostly caused due to the windy conditions and sudden wind gusts during the experiment days.

3.2.3 CRITICAL BUILDINGS AND INFRASTRUCTURES PROTECTION IN HAMBURG PORT

The Port of Hamburg (German: Hamburger Hafen) is a seaport on the river Elbe in Hamburg, Germany, 110 kilometres (68 mi) from its mouth on the North Sea. Known as Germany's "Gateway to the World" (Tor zur Welt), it is the country's largest seaport by volume. In terms of TEU throughput, Hamburg is the third-busiest port in Europe (after Rotterdam and Antwerp) and 15th-largest worldwide. In 2014, 9.73 million TEUs (20-foot standard container equivalents) were handled in Hamburg. The port covers an area of 73.99 square kilometres (28.57 sq mi) (64.80 km² usable), of which 43.31 km² (34.12 km²) are land areas. The branching Elbe creates an ideal place for a port complex with warehousing and transhipment facilities. The extensive free port was established when Hamburg joined the German Customs Union.

Figure 3-8 Port of Hamburg

In this campaign the usage of Galileo and Copernicus (see section 5.2) has been experienced. Hamburg was the first GNSS testing campaign of the project. As such, the goal was to conduct an initial verification of the functionality of the receivers in a port environment, but off-board drones. Specifically, the focus was put on the evaluation of PPP as a high accuracy reference source for future tests, and also on analysing how the GNSS environment affects the performance of the OSNMA implementation at ground level. The OSNMA-enabled receiver was configured for “GAL OSNMA + GPS”

Figure 3-9 (a) Vessel used for the dynamic test in Hamburg. (b) Antenna installation on the vessel.

This section includes the most relevant OSNMA and PPP results from the campaign performed in Hamburg. Starting with PPP, Table 3-2 includes the KPIs from both the static and the dynamic tests. In all points, the 2σ deviation is higher for the longitude compared to the latitude. For the open sky points, the 2σ latitude deviation remains below 0.1m, while the 2σ longitude reaches up to 0.20m. Comparing these points with those in degraded environment, although HAM-P3 shows a low latitude deviation, generally the results are worse, especially in HAM-P4, which is a reasonable output given that in this point the antenna was surrounded by not two, but three containers. Moving on to the last line of the table, PPP deviations were also obtained for the dynamic test on the vessel. With a recording that lasted over 4 hours, and oppositely to the static results, the latitude 2σ is higher than the longitude deviation. In any case, they remain below the values obtained in HAM-P4. These results confirmed that the use of PPP as a reference is suitable for open sky applications, and in those cases where the GNSS environment is considered degraded, the output of the algorithm should be carefully analysed before its consideration as a reference to assess the performance of other GNSS solutions.

Recording ID	Test type	Location	GNSS Environment	Recording duration [min]	Latitude	Longitude	Latitude Error 2σ [m]	Longitude Error 2σ [m]
HAM-P1	Static	Building rooftop 1	Open sky	47	57° 32' 27.93"	9° 57' 55.87"	0.09	0.12
HAM-P2	Static	Building rooftop 2	Open sky	59	53° 32' 27.91"	9° 57' 56.69"	0.07	0.08
HAM-P3	Static	Between 2 port containers	Degraded	95.5	53° 32' 27.45"	9° 57' 55.43"	0.06	0.20
HAM-P4	Static	Between 3 port containers	Degraded	43.30	53° 32' 28.09"	9° 57' 56.88"	0.43	0.67
HAM-V	Dynamic	Elbe river trajectory	Open sky	278.77	-	-	0.38	0.10

Table 3-2 PPP performance assessment from Hamburg

3.2.4 PROTECTION AGAINST NON-COOPERATIVE SMALL CRAFT APPROACHING THE PORT AREAS IN LE HAVRE PORT

The port of Le Havre is part of HAROPA port and its activity is mainly specialized in the transport of containers, motor vehicles, chemical materials, passengers, building materials, energy and agro-food materials and bulk. With nearly 4,400 ships to be received in 2020, including 1,835 container ships, the port's traffic amounts to 55 MT. The port area covers 77,700 hectares and 35 km of quays dedicated to specific uses. The port has an oil terminal in Antifer, about 20 km from the port. Since June 1st 2021, the ports of Le Havre, Rouen and Paris, have now merged to form a single port: HAROPA PORT, the Seine axis Major River & Sea Port. HAROPA is the 1st port in France. The leading port complex in France, HAROPA PORT is the 5th largest in northern Europe with more than 120 million tonnes of maritime and river traffic.

Figure 3-10 Port of Le Havre

The primary objective of Le Havre campaign is to show and demonstrate the added value of drones in the surveillance of the port facilities and vicinity. GNSS positioning service is central in this mission for the operation and tracking of drones, for the coordination between actors and for the identification of targets (georeferencing images and videos). The demonstration campaign in le Havre port has been planned and designed to showcase the main benefits and usage of a multi sensor system of systems deployed in the port area (fixed wing drone, rotary wing drone, fixed camera) providing valuable information to a single ground station. The raw information transmitted by the various 'sensors' to the platform is analysed and enriched with Artificial Intelligence functions to deliver the end user with an additional tool to ensure port security and safety.

Figure 3-11 Boreal (fixed wings) planned trajectory

Figure 3-12 Boreal (fixed wings) Flown trajectory

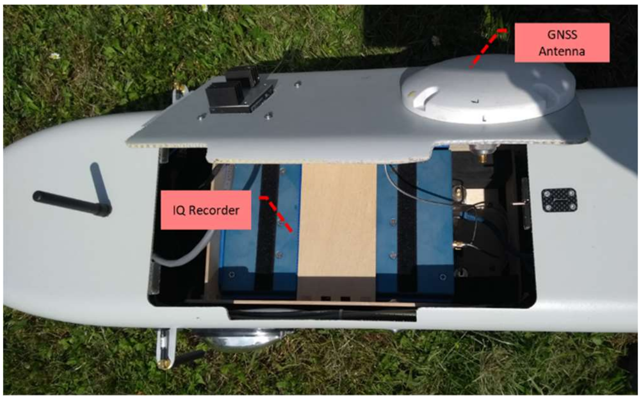


Figure 3-13 Recorder installed on Boreal drone

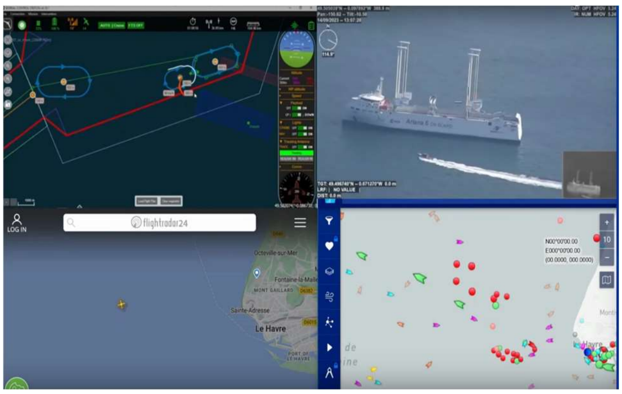


Figure 3-14 Sample of gathered images

3.2.5 UNDERWATER THREATS MONITORING IN RAVENNA PORT

The Port of Ravenna is a canal port with 27 private terminal operators; the overall length of quays is almost 24 km, 14,5 km of which are in operation. Current capacity comprises 603.000 square meters of warehousing, 1.350.000 square meters of yards and 1.256.000 cubic meters of tank storage. The Port manages mainly dry bulk cargo, general cargo, agricultural products, liquid bulk cargo (oil and others) and, to a lesser extent, containers and Ro-Ro traffic. The port of Ravenna is an "A" Category port as indicated in Decision N. 661/2010/EU of the European Parliament and of the Council of 7 July 2010 on "Union guidelines for the development of the trans-European transport network". With the approval of the new TEN-T guidelines (Annex II of Regulation (CE) 1315/2013 of the European Parliament and of the Council of 11 December 2013 on Union guidelines for the development of the trans-European transport network), the Port of Ravenna is included within the TEN-T list of core ports and core inland ports.

Figure 3-15 Port of Ravenna

Activities have been done in a dock area. The area is a dock dedicated to host fishing boats and the patrol boats of Coast Guard and Customs Police (Guardia di Finanza). Moreover is an area where are moored the pilot boats. The dock is on the Candiano Canal near to the beginning of the guardian piers the absence of a concessioner responsible for the security of the area, the presence of patrol boats make this dock a perfect site for the campaign related with the inspection and acquiring of data about the status of the seabed. Another area is the city dock, close to the Port Authority premises. The area is part of a dock with specific restrictions to the navigation. Can be used for the realization of the demonstrator mainly for the possibility to use drones without dangerous interactions with other vessels or port operations.

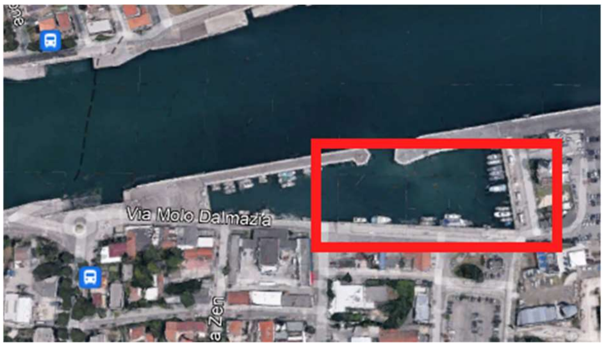


Figure 3-16 Area#1 of intervention

Figure 3-17 Area#2 of intervention

A bathymetry algorithm has been tested during the activities carried out at the Ravenna Port both in May 2022 and October 2023. In both the cases, the UD was equipped with the Nortek DVL1000, generally employed in the navigation filter framework but has also used for mapping purposes. The UD vehicle performed two autonomous missions at the Ravenna Port (in two distinct locations) and acquired data to compute an approximated bathymetry of the basin seabed, as reported in
Figure 3-18

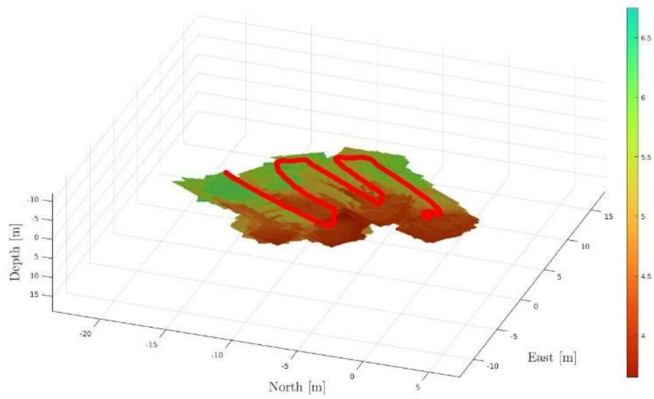


Figure 3-18 Bathymetry of the Ravenna Port seabed performed during the experimental campaigns

4 PASSPORT SOLUTION

The vision of PASSport is based on the introduction of a **fleet of automated aerial (rotary wings and fixed wings) and underwater drones** concept to provide a tangible contribution on operational procedures to mitigate the risks in port areas. Whereas in the last month a lot of activities are initiated in port areas involving drones, the **concept of a fleet represents a complete novelty making the solution more resilient against external attacks or accidental events** (e.g. bad weather conditions). In particular, the drones combine state of the art technologies to collect on field data in real time. This allows **surveillance with an extended situational awareness (by covering larger areas)**. Indeed, to date, operational activities to guarantee security and safety are dealing with static sensors (radar, CCTV, cooperative systems as AIS, e-navigation), whereas collected data **cannot automatically trigger dedicated operational procedures**. This approach represents a key limitation of current practices which PASSport vision aims to overcome by proposing **a holistic surveillance solution**.

The solution is thought to be connected with **already deployed (installed in port facilities) operational platforms** and exploits the innovation brought by **drones assisted with GNSS technology,** in particular as an input for the Guidance, Navigation and Control system allowing the planning and execution of **safe and accurate trajectories**.
PASSport system architecture is reported in Figure *4-1*, where the following segments are identified.

- ✓ PASSport Ground Segment (PGS)
- ✓ PASSport Aerial Segment (PAS).
- ✓ PASSport Underwater Segment (PUS).

The interface for the end-user the PGS gathering from both the aerial/ underwater segments (PAS/ PUS) and from External Operational Entities, i.e.

- ✓ *Shiplocus*
- ✓ Srx-10i/ DINTEL

Images captured by the RPAS are processed in real time by a local computer at RGMS level. RPAS is equipped with high accuracy GNSS receivers leveraging on Galileo differentiators that are OSNMA (for the reliability and security of the position), PPP (for the positioning accuracy), and multi-frequency (for robustness and accuracy) in order to provide a proper positioning and combined with modern robotics technologies (vision-based navigation, AI and Deep Learning algorithms) to guarantee automated, secure and continuous operations. Finally, the RPAS Ground Control Segment (RGCS) offers the possibility to command and control the RPAS in case of any emergency, as a possibility to recover contingent malfunctioning on the RGMS to RPAS link (Command and Control link loss).

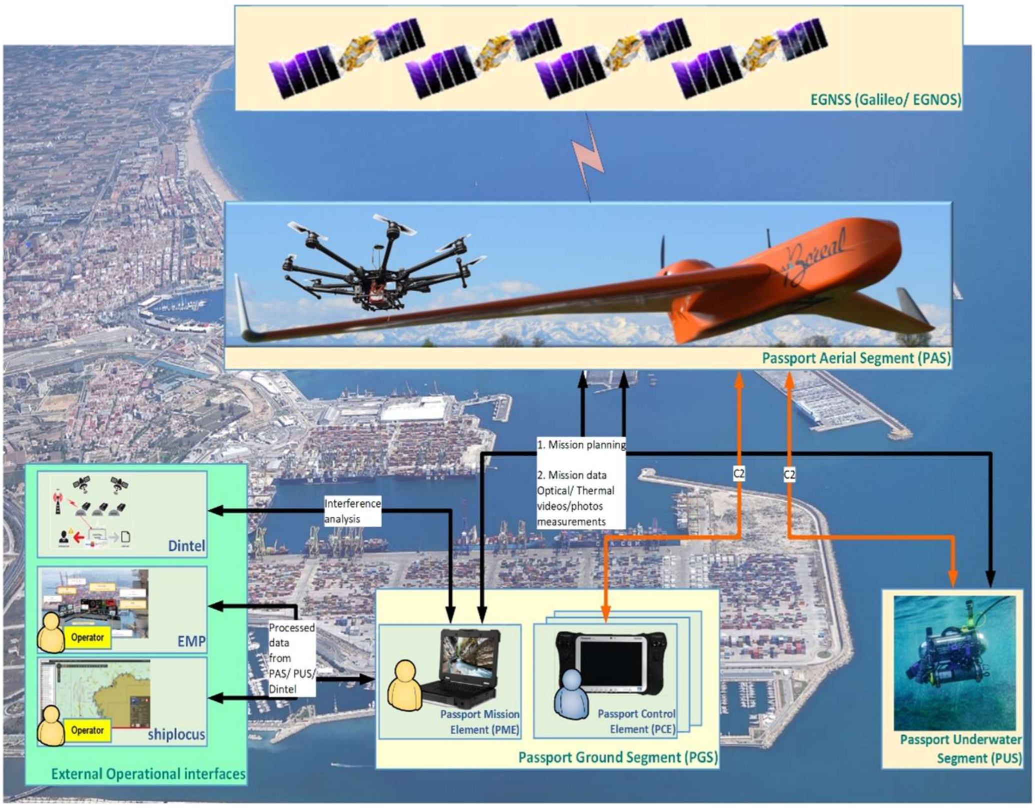


Figure 4-1 PASSport solution

4.1 THE MISSION AND CONTROL PLATFORM

PASSport is thought to guarantee the following main functionalities:

- ✓ **Measurement of threats awareness and awareness-raising among players (security).** Once the assets and infrastructure which need to be protected are identified against the threats and risks of intentional illegal action facing port activities, the PASSport platform proposes the design and implementation of appropriate measures which can be used to counteract threats. This follows the identification of a risk level i (normal, increased, high), and is achieved by means of specific procedures and by using technical equipment tailored to the needs of ports. This makes possible to provide the right response to the potential vulnerability of infrastructure.
- ✓ **Inspection and supervision of port areas (security and safety)**. The PASSport platform provides a suitable HMI to monitor, in an appropriate and regular manner, port security&safety and to implement relevant procedures.

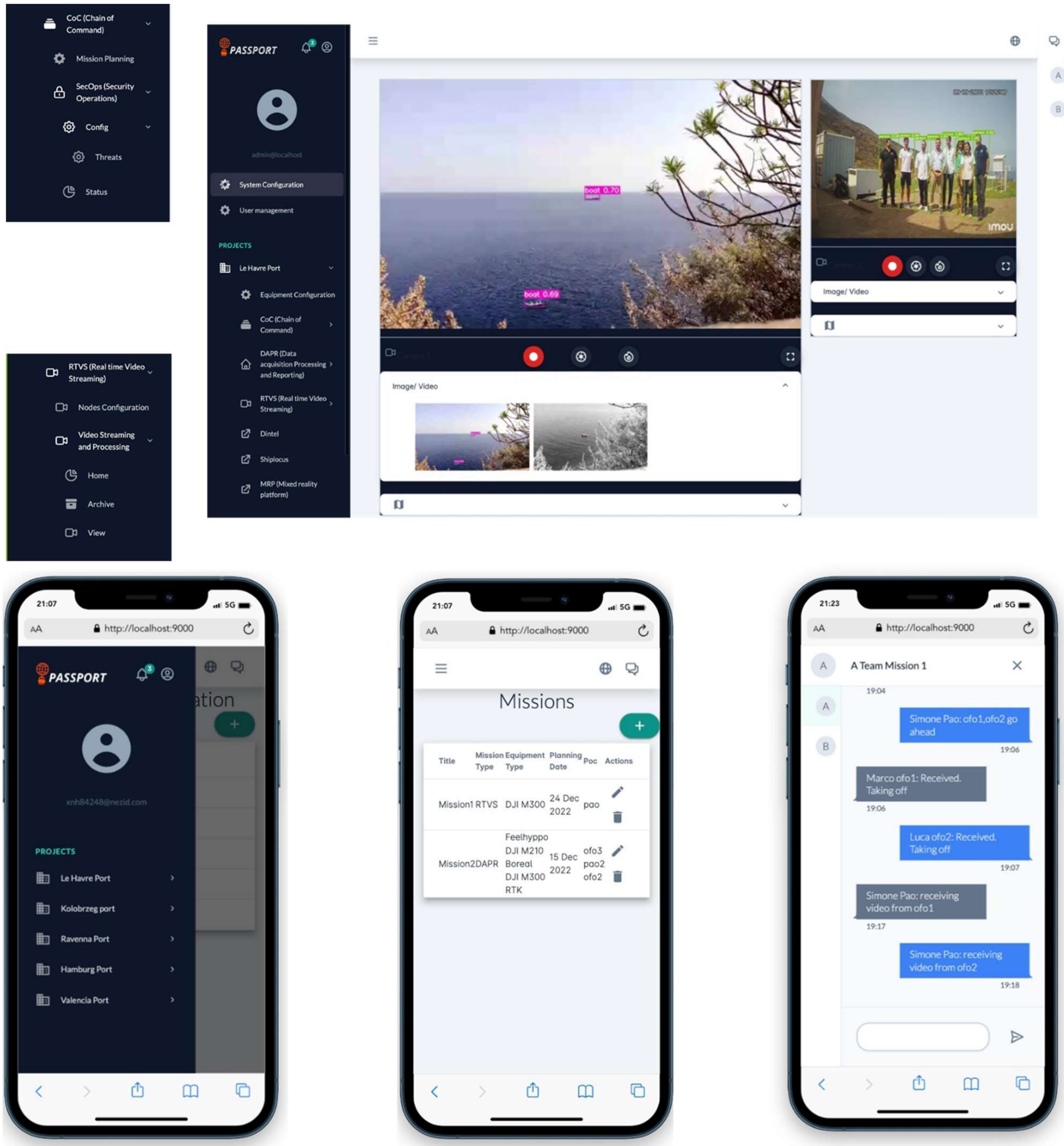


Figure 4-2 PASSport Mission and control platform (a) desktop and (b) mobile visualisation

4.2 THE FLEET OF DRONES

4.2.1 THE FIXED WING FOR LONG ENDURANCE SURVEILLANCE OPERATIONS

The surveillance and security of a major port is not limited to the nearby infrastructure. Like any operating platform for transportation means, it needs to manage ingoing and outgoing flows to guarantee a smooth operation in the port itself. To organize efficiently the traffic in the port vicinity, the port authorities start monitoring and controlling incoming flows in a 50km radius. Dedicated waiting areas are used to regulate the traffic. These waiting areas are located strategically near the port channels with a high density of ships mooring, entering the channel, or leaving. The port is equipped with control tower, communication and tracking systems and operates according to a pre-established plan and strict procedures. However, the control and monitoring of the situation on the water body between the port and the waiting areas is not always easy.

The possibility to introduce a new element providing up-close and live visuals on over sea situations within a range of 50NM was seen by port a clear opportunity to improve the management of security and surveillance around the port. Boreal drone was a perfect fit to test this new solution in the context of the PASSport demonstration at Le Havre port HAROPA.

Figure 4-3 Boreal fixed wings drone

The Boreal Drone is known for long range autonomous flights over long stretch of unpopulated areas for distance up to 50NM (without satellite com) and during up to 8 hours. It performs surveillance missions equipped with a gyrostabilized camera that can transmit the videos and image to its ground station and even broadcast them to streaming channels as demonstrated in the PASSport project. The video and images are geo referenced and transmitted live to the end user who can react and take decisions based on the information received. In the context of the Le Havre demonstration, request to zoom, follow a ship or detect fast moving ships are examples of requests that Boreal executed to support Surveillance and security scenarios defined by the port. Demonstration of the full setup was prepared carefully with the Le Havre Port along with the French safety agency DSAC for the authorization and the restricted area creation.

Figure 4-4 Boreal under test during the campaign in Le Havre

Boreal drone flew for straight 2 hours over the sea and provided live video of Le Havre waiting areas and performed specific ship surveillance on request of the Port Tower.

4.2.2 THE RECHARGING DRONE FOR AUTONOMOUS OPERATIONS

"Drone-in-a-box" devices are an emerging form of autonomous unmanned aerial vehicle technology that uses drones that deploy autonomously from a box that serves as a landing platform and charging base at the same time. Autonomous drone System used in the Passport project is composed of 5 main elements:

- Hangar, which protects and charges the drone:
  - Landing, take-off and charging pad;
  - External covering structure;
  - "K100" control module;
  - Nvidia Jetson card;
  - 4G LTE modem;
  - Full HD webcam;
  - Air conditioning
- Unmanned aerial vehicle;
- Ground Control Station system that allows remote control of the drone;
- Independent weather station;

Figure 4-5 Hangar closed and standby

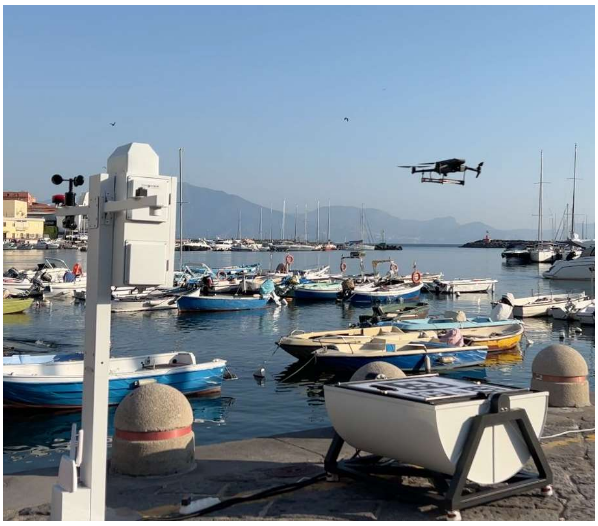


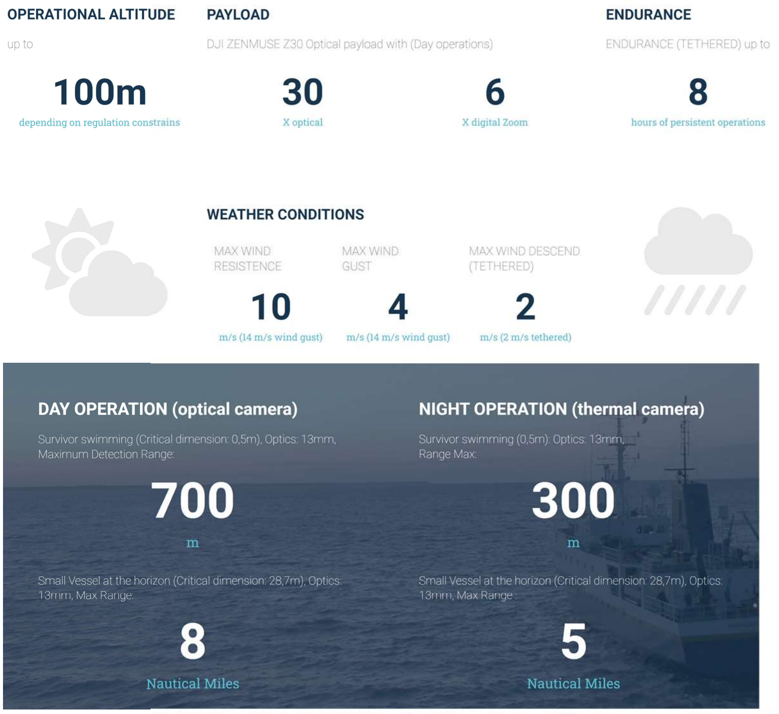
Figure 4-6 Drone during takeoff from the hangar

The ground station has a mobile dome cover that completely covers the drone during the charging phase, protecting it from bad weather and atmospheric agents and which, at the time of the mission, opens allowing the drone to take off autonomously. Once the mission is over, the drone returns to the charging base on its own. Once recharged, it is ready for the next mission. The hangar has an air conditioning system, which ensures correct maintenance of the temperature, both during standby time and during the drone battery charging time. The hangar is designed to contain the drone and its charging station, as well as an antenna with GNSS receiver for the operation of the RTK/PPK precision positioning system; it is designed to be positioned near the area to be monitored and also be able to communicate with the technical room and provide the artificial intelligence with the data collected during the survey. The drone inside the hangar is equipped with the sensors considered most useful for surveying activities, and is equipped with a charging station, so as to be always available for take-off and to fly on a pre-set route. Missions can be planned from a command station via remote piloting software that allows real-time transmission of optical and thermal images and it allows to control the mission from any distance with a simple click.

4.2.3 THE TETHERED DRONE FOR TIME EXTENDED OPERATIONS

This solution implements a tethered drone solution which main function is to provide persistent surveillance to port operations. In fact, this drone placed in a suitable and strategic position of the harbour, will be capable of many hours of operations without the need of recharging the batteries, since its main power is fed directly by the tether. Furthermore, the tether provides a physical limitation to the flight envelope of the drone for enhanced safety. The main added value brought by this drone to the Passport platform can be summarized as follows:

- ✓ Persistent surveillance operations (no interruption in video stream acquisition due to take-off and landing operations)
- ✓ Live video feed from up to 70 meters of height with the possibility to zoom in – zoom out up to 180x Optical/digital in day conditions and 8x (digital) in night conditions. The video is forwarded directly in real time through Internet to the main SW platform for ships (or objects) detection and identification with A.I. algorithm.
- ✓ Zoom Optical or Thermal infrared Camera payload available for day and night operations.
- ✓ Estimation of position of ships or object thanks to GNSS Receivers and Stable and accurate IMU with a reasonable accuracy compliant with the ship dimensions and distance.



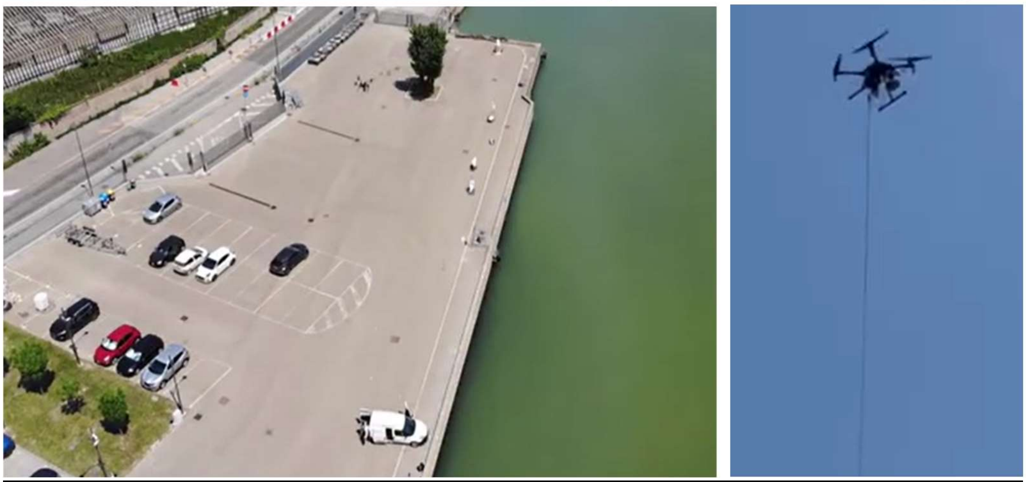
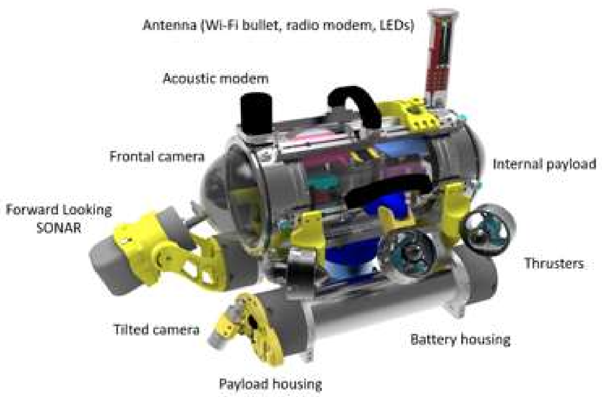


Figure 4-7 Tethered drone during Ravenna campaign

4.2.4 THE UNDERWATER DRONE FOR INSPECTION AND MONITORING

The current state of port underwater safety and security relies on outdated, human-dependent technologies and guidelines. This includes methods such as divers, acoustic and visual video monitoring, and manned vessel patrolling. However, these approaches lack automated subsea surveillance and require time-consuming, logistically complex operations. The PASSport project seeks to address these limitations by proposing an architecture relying on an Underwater Drone (UD) which aims to shift towards automated and enhanced surveillance strategies in ports. Indeed, Autonomous Underwater Vehicles (AUVs), capable of inspecting the surrounding environment with a heterogeneous gamma of sensors with no human operators involved, do mark a pivotal shift in the current paradigm, offering the potential for significantly safer and more effective surveillance strategies where human involvement is minimized or eliminated altogether. Regarding the PASSport project, the designated Underwater Drone (UD) is FeelHippo AUV. With its heterogeneous exteroceptive sensors, e.g., optical cameras and Forward Looking SONAR (FLS), FeelHippo AUV has shown the capability to offer a diverse set of valuable functions for underwater surveillance bolstering port safety and security and enhancing protection against potential underwater threats.



FeelHippo AUV main characteristics	
Autonomy [h]	2-3
Controlled DOFs	5
Max longitudinal speed [m/s] (kn)	approx. 1 (2)
Max lateral speed [m/s] (kn)	approx. 0.2 (0.4)
Max depth [m]	30
Dimensions [mm]	approx. 600×640×500
Dry mass [kg]	35

Figure 4-8 FeelHippo AUV main sensors and characteristics

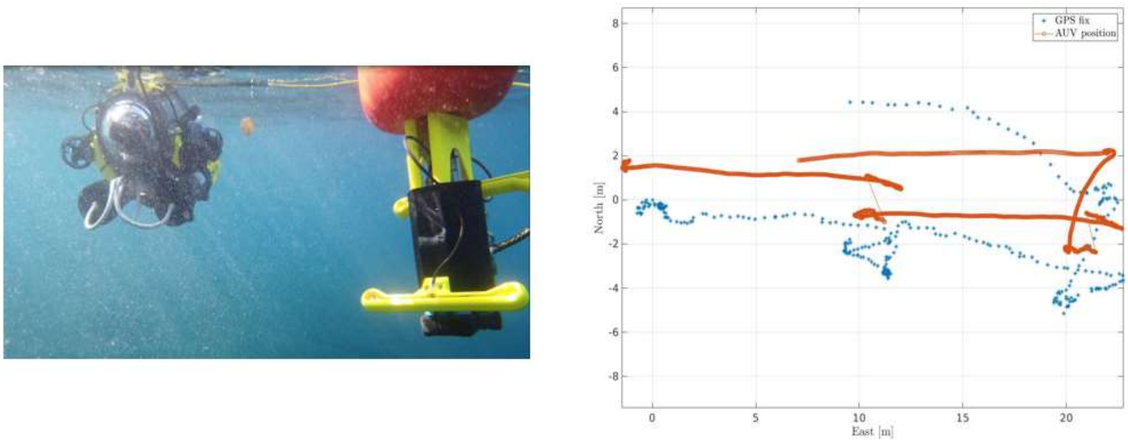


Figure 4-9 On the left, overview of FeelHippo AUV and the developed buoy in an experimental campaign in Stromboli Island. On the right, FeelHippo AUV position (in red) and the buoy GNSS receiver values (in dotted blue) during a survey in such a campaign.

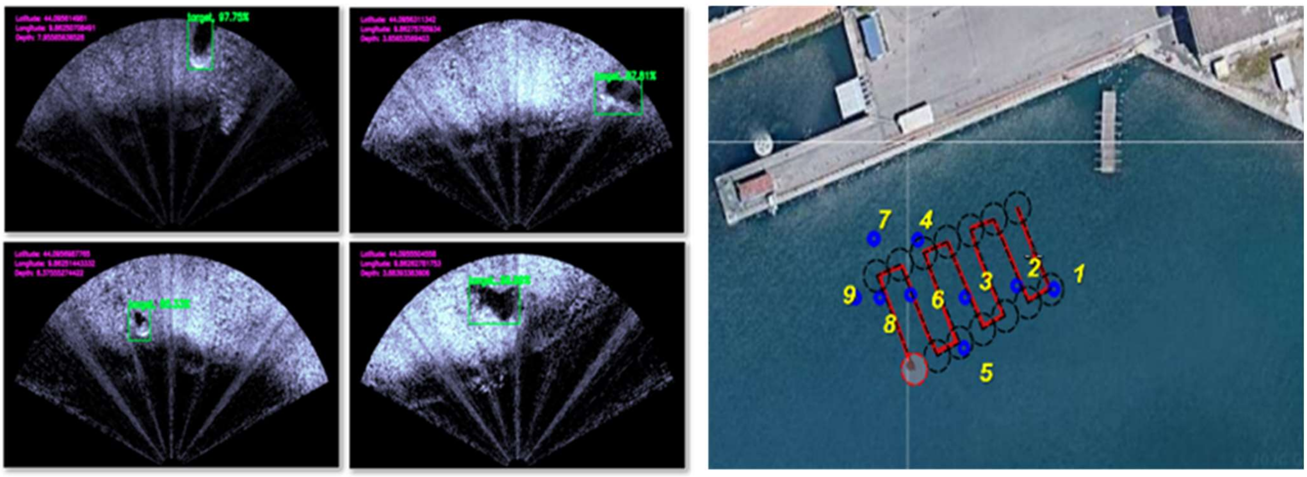


Figure 4-10 On the left, examples of the detections and localizations with the developed ATR strategy during an experimental campaign conducted at the Naval Experimentation and Support Centre (CSSN) of the Italian Navy, La Spezia, Italy. On the right, the several ATR detections and localizations were clustered in nine objects of potential interest by using a world modelling process.

In support to the UD, a small towed buoy has been also designed and exploited. This buoy has been essential for establishing Wi-Fi links between the UD during underwater inspections and other substructures in the multi-station PASSport architecture while streaming the desired data. Additionally, a GNSS sensor on the buoy enables the UD to obtain a reliable positioning estimate, enhancing localization accuracy or serving as a safety measure if the UD localization algorithms encounter difficulties. This is crucial as the underwater environment not only hinders surface communication but also presents challenges in precise position estimation without access to GNSS signals beneath the marine surface.

To demonstrate the effectiveness of AUVs as a viable alternative to traditional surveillance methods in port areas, an Artificial Intelligence-based Automatic Target Recognition (ATR) architecture has been developed. This system has been designed to detect and geolocalize potential threats and hazards on the seafloor of the port with FLS-supplied acoustic imagery. FeelHippo AUV was capable of performing ATR real-time as well as onboard and the several detections, provided by the ATR system, were employed to create a world model of 3D-localized and labeled objects of potential interest (Figure 3).

To study the morphology of the port seafloor and identify potential threats stemming from unforeseen changes or hazardous protruding objects, bathymetries of the port seabed have been computed. These bathymetries are based on measurements obtained from the Doppler Velocity Log (DVL), an acoustic sensor utilized to measure water velocity and the altitude of a UD either through water or over the seafloor. The four DVL acoustic beams, oriented in different directions, have been employed to determine a local approximation of the seafloor geometry as the UD navigates. The amalgamation of these local approximations into an overall map, computed onboard in real-time, enables the generation of a bathymetry which can offer port authorities a visual representation of the seafloor morphology.

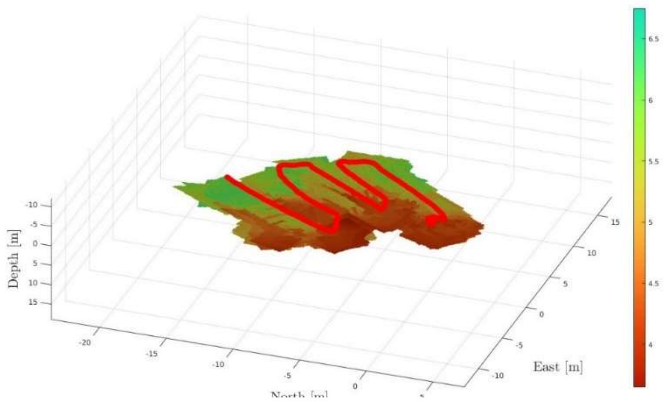


Figure 4-11 Bathymetry of the Ravenna Port seabed performed during the experimental campaign in May 2022.

5 PASSPORT ACHIEVEMENTS

5.1 GNSS/ GALILEO TO SUPPORT GNC AND PAYLOAD DATA ACQUISITION

PASSport is a project that responds to port entities by extending situational awareness to improve safety and security in port areas based on the novelty represented by the usage of a fleet of aerial and underwater automated drones integrating Galileo services for a safe and efficient guidance, navigation and control (GNC).

The analysis of PASSport user needs revealed that GNSS, and in particular Galileo can significantly contribute to PASSport at three levels:

- **Safe trajectory for automated drone**: drones will fly in a challenging environment including the presence of obstacles (buildings and other ground assets) and potentially unfavourable weather conditions. This means that the GNSS solution to be used to know drone position shall be highly accurate and reliable.
- **Geo-localisation of detected target**: the surveillance service shall be accurate and reliable, allowing the imagery obtained from drone to detect and localise any potential target. This means that the GNSS solution to be used shall be accurate (also to provide a safe trajectory of drone), but more importantly, allow to know the integrity of the system.
- **System resilience**: The presence of Radio Frequency Interference (RFI) in licensed spectrum bands such as GNSS has become ubiquitous on air, land and sea. As drone are inserted in port areas, GNSS signal needs to be robust and protected against any possible deliberate attack (spoofing, meaconing), mitigating, locating and/or locating threats against the SiS.

In order to achieve these objectives, the solutions implemented in PASSport solution are:

- One the one hand, PASSport drones integrate GNSS receivers developed with dedicated capabilities to mitigate potential GNSS deficiencies . The selected GNSS receivers shall also take advantage of high accuracy techniques (e.g. PPP), and integrity mechanism based on the provision of protection levels (PLs) that bound the positioning provided by the GNSS receiver to a certain area with a given probability.
- On the other hand , the most convenient technology for PASSport purposes at system level is to deploy GNSS interference detector solutions which may warn users of the presence of GNSS interferences, which may trigger different actions from PASSport operator side (e.g. abort drone missions)

One of the key features of PASSport is the use of Galileo's **OSNMA** service, which is a data authentication function for Galileo that provides receivers with the assurance that the received Galileo navigation message is coming from the system itself and has not been modified. The authentication protocol used by this service is based on the TESLA protocol, which employs message authentication codes generated with a key that is broadcasted with certain delay, and data is transmitted in the I/NAV navigation message from the E1-B Galileo Open Service (OS) signal. The use of this service in the PASSport solution helps in the **distinction between genuine Galileo signal-in-space (SIS) from unlawful and possibly manipulated signals, enabling the GNSS receiver with the capability to warn the user when data from the navigation message cannot be authenticated**. The GNSS receivers that include these capabilities and have been used/developed for PASSport are the **magicUT OSNMA** (specifically developed for PASSport) and the **magicUT PPP**, presented in the following image.

Figure 5-1 magicUT OSNMA and magicUT PPP receivers.

The **magicUT OSNMA** presents a modular design and it can integrate a Dongle 4G for communications, and a battery in case power is not provided externally. The receiver is multifrequency and multiconstellation, with GPS L1/L5 and GAL E1/E5a, and includes **authentication with OSNMA** (compatible with ICD V1.0 and SiS) as well as the Isotropy-Based Protection Level (**IBPL)** integrity algorithm developed. Three different configurations can be established for its operation: GPS only, GAL OSNMA only, and GAL OSNMA + GPS. The functionalities of these receivers have been verified and validated throughout the project following the timeline presented below:

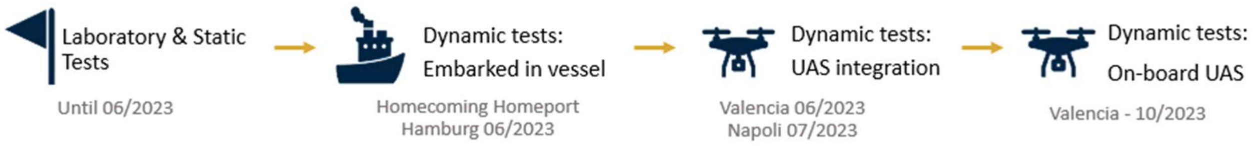


Figure 5-2 Verification and validation timeline.

For interference detection, **DINTEL/srx-10i** provides a cost-effective, dual-band, simultaneous monitoring of GNSS bands to detect interference events. It consists of two RF frontends and an embedded Single Board Computer (SBC) whose functionality is oriented towards the monitoring of the electromagnetic spectrum, typically L1/E1 and L5/E5a, for GPS and Galileo. This system is currently operational in more than 10 airports and has also been demonstrated in PASSport .

Laboratory and Static Tests

The functionality of the OSNMA library developed for the GNSS receiver was verified with the execution of EUSPA's test vectors, which included satellite and ADKDs authentication in four different scenarios, and the Public Key and TESLA Chain management processess assessment. This **verification was completed successfully** as **authentication was 100%** in all satellites and ADKDs, the **TESLA chain and Public Key renewals** were performed as expected, and the SW was also able to **revoke the Public Key** and **detect the presence of an OSNMA Alert Message** and accordingly stop the authentication process.

Hamburg Port Campaign

The goal was to evaluate PPP as a reference source and assess the effect of GNSS environment on the performance of OSNMA. To do so, the receivers were tested in static settings in open sky and degraded environments, and then also embarked on a vessel on the Elbe River. As a result, PPP was validated as a suitable reference source for open sky applications (with 2σ error deviations for latitude and longitude below 0.2m). In degraded environments, the error deviations escalated, but they remained below 0.7m. From the OSNMA assessment, the results observed for the TTFA and the MTBA were independent of the scenario (open-sky or degraded) and authentications were 100% successful.

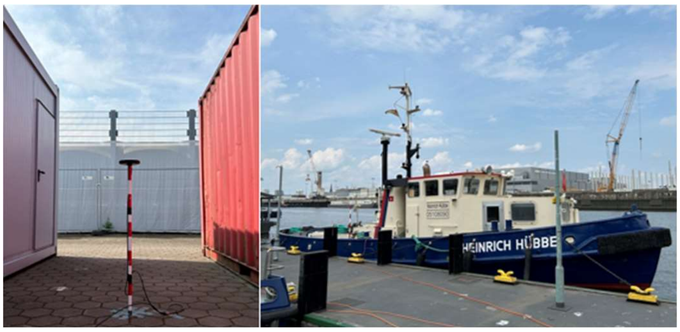


Figure 5-3 Hamburg campaign, static and dynamic scenarios.

Precampaigns: Valencia Port and Napoli

The goal was to validate the integration of the GNSS receivers installed on the drone and to assess the performance of the magicUTs when replicating real life operations. The magicUT OSNMA was embarked on a DJI Matrice 210 and tested near Naples. In one drone, both the magicUT OSNMA and PPP were embarked and tested on a Skyjib X4 Ti-QR and tested in the port of Valencia. All the tests from these pre-campaigns were performed in open-sky conditions.

Figure 5-4 Valencia Precampaign scenario.

The authentication results obtained both in Valencia and Naples were similar to those observed in Hamburg: authentications were 100% successful and the average TTFA and MTBA were about 2min and 1min, respectively. In Valencia, it was also tested the general performance of the magicUT OSNMA in its three different configurations. The availability and continuity were maximum, and it should be noted that the mean number of satellites for the GAL OSNMA configuration was higher compared to GPS. Integrity performance provided HPLs and VPLs of about 20m and 30m, but of course it was dependant on the number of satellites.

Valencia Port Campaign

The goal was to test the GNSS receivers' integration with the PASSport platform as a whole while operating in harbour conditions embarked on PASSport 's drones. Due to the adverse weather conditions (wind and rain), only one test with magicUT OSNMA could be performed. The drone was flown manually to capture images to be sent to the PASSport platform, and the position obtained with the magicUT OSNMA receiver using authenticated Galileo satellites was also shared, sending NMEA messages to the platform to display the drone position in each moment. From the few tests that were performed, the results matched those obtained in previous campaigns and pre-campaigns. PPP results showed a 2σ latitude and longitude error deviations below 0.15m, and OSNMA performed all authentications successfully with the mean TTFA and MTBA being again 2min and 1min. In terms of accuracy, the errors of the three configurations were of the same order, below 1.5m and 2m for the horizontal and vertical components. Availability and continuity were at their maximum, and integrity PLs were higher than previous campaigns because there were less satellites in view.

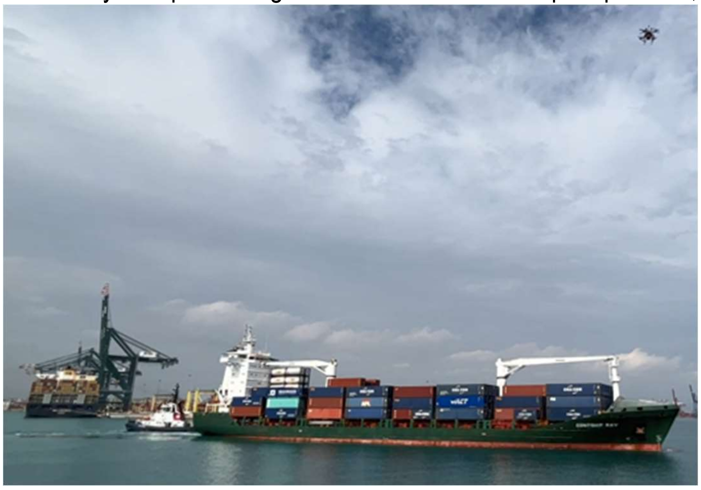


Figure 5-5 Image of a drone surveying a cargo vessel.

Conclusions

The conclusions drawn from these campaigns and the project are:

- **PPP** has been successfully validated as a **reference source for open-sky scenarios**.
- The OSNMA library implementation has been successfully validated:
  - As part of the service, few minutes of **initialisation** are needed to ensure Galileo availability.
  - There are **different logic or strategies** when implementing the OSNMA functionality.
  - OSNMA does not allow authenticating the pseudoranges used to calculate the position.
  - It is interesting to **combine OSNMA with** other measures such as integrity mechanisms, such as **IBPL**.
- **Potential future developments**
  - Upon the development of an authentication service that includes GPS (direct/cross authentication): **to work on a multiconstellation double frequency solution with all navigation data authenticated and protection levels**.
  - **Hybridisation** with other sensors such as IMUs.
  - **Integration** of PASSport GNSS receivers **in the drones' autopilots** for GNC.

5.2 EARTH OBSERVATION (EO)/ COPERNICUS FOR INSPECTION AND MONITORING

Within the PASSport project, PASSport team has analyzed the Copernicus programme, the world's largest Earth Observation (EO) programme, whose objective is to deliver data, information, services and knowledge at global level and within a variety of applications and within several domains. The scope of the activities was to evaluate and assess the usability and applicability of Copernicus services to the PASSport scenarios and to deduce attainable performances applicable for PASSport related applications.

Potentials and limits of the EO observation have been analyzed for those port areas selected for the validation campaign within the PASSport project, in tight synergy with local port authorities. Selected port areas are represented by:

- ✓ Kolobrzeg in Poland, with a focus on air pollution monitoring;
- ✓ Valencia in Spain, with a focus on supporting vessel traffic monitoring;
- ✓ Hamburg, in Germany, focusing on ground stability assessment;
- ✓ Le Havre in France, with a focus on supporting to vessel traffic monitoring;
- ✓ Ravenna, focusing on the assessment of wind speed and direction.

The different applications took advantage of the great variability of data provided by the Copernicus programme which relies on the synergic use of different satellite platforms, hosting either active or passive sensors, observing different portions of the electromagnetic spectrum. Each region of the electromagnetic spectrum has its own unique applicability for environmental observations.

Among the several operative services currently available, a major role in the PASSport activities has been played by the EGMS (European Ground Motion Services). Implemented under the responsibility of the EEA (European Environment Agency), the EGMS represents a unique initiative for performing ground deformation monitoring on a continental scale. The aim of the service is to provide consistent, updated, standardized, harmonized information regarding natural and anthropogenic ground motion phenomena over Europe. The data are free and open, following the Copernicus open data policy. The EGMS products have been accessible through a dedicated dissemination platform (https://egms.land.copernicus.eu/). The EGMS provides tools for data visualization, interactive exploration and preliminary analysis of the service products. As it is now, the EGMS includes a first release acting as baseline (created by processing Sentinel-1 archive imagery from 2015 to 2021) and an update covering the time interval 2018-2022.

The service is based on Sentinel-1 radar images, processed at full resolution, using advanced interferometric approaches. These techniques allow for the identification of reliable measurement points for which ground motion values and time series of displacement are extracted. Such measurement points usually coincide with buildings, artificial structures and non-vegetated areas in general. Global navigation satellite systems data are used as calibration of the interferometric measurements. The service uses both ascending and descending images, acquired with a revisit time of six days. An important characteristic of this service is the provision of a unique seamless, mosaicked product. This facilitates the end user interpretation and exploitation of the results.

Data provided by the EGMS turned out to be particularly valuable in assessing ground instability for the port of Hamburg, a seaport in the inner delta of the vast Elbe estuary in Germany, 110 kilometres (68 mi) from its mouth on the North Sea. Known as Germany's "Gateway to the World" (*Tor zur Welt*), it is the country's largest seaport by volume. Hamburg is the third-busiest port in Europe (after Rotterdam and Antwerp) and 15th largest worldwide. It dates back to the first port established in the ninth century. The foundation, expansion, and maintenance of Hamburg's port required the reconfiguration of the estuary and its inner delta. Dredging and reclamation, deepening and widening of channels to accommodate larger vessel classes have transformed aquatic spaces and provided the material framework conditions for the shipping and port industry.

The stability of the Hamburg port has been assessed by leveraging on the second delivery of the EGMS service, released at the end of October 2023 (Figure 5-6). The city and the port area of Hamburg show very low deformation rates, ranging between −2.0 and +2.0 mm/yr, indicating relatively stable ground conditions (green to light blue regions).

Some active movements (yellow to red points) are recorded in spot areas within and surrounding the port, with velocity values in the order of -15 mm/yr. In satellite interferometry, negative values indicate movements away from the satellite: considering the acquisition geometry and the morphology of the area (flat areas), the measured deformation rates are consistent with the occurrence of subsidence phenomena, *i.e.*, movements with a dominant vertical component.

EGMS analysis provides also, for each measurement point, a time series of deformation, which describes the evolution of displacement over the entire period. Each measurement of the time series corresponds to a single satellite acquisition. A time series shows the temporal pattern of the deformation, highlighting non-linear movements, seasonal trends, ground acceleration and any potential changes occurring during the analyzed period. Four measurement points have been selected and the corresponding deformation time series are presented in Figure 5-6. Points are located in the most active areas, *i.e.*, the areas characterized by the highest deformation velocities, and have been selected to identify and to evaluate any potential changes in the deformation rate. Areas with active deformation can be related to the imposition of load over former marshland zones, located in the inner delta of the estuary, that have been reclaimed for centuries to manage the Elba estuary and to accommodate space for the construction of the port.

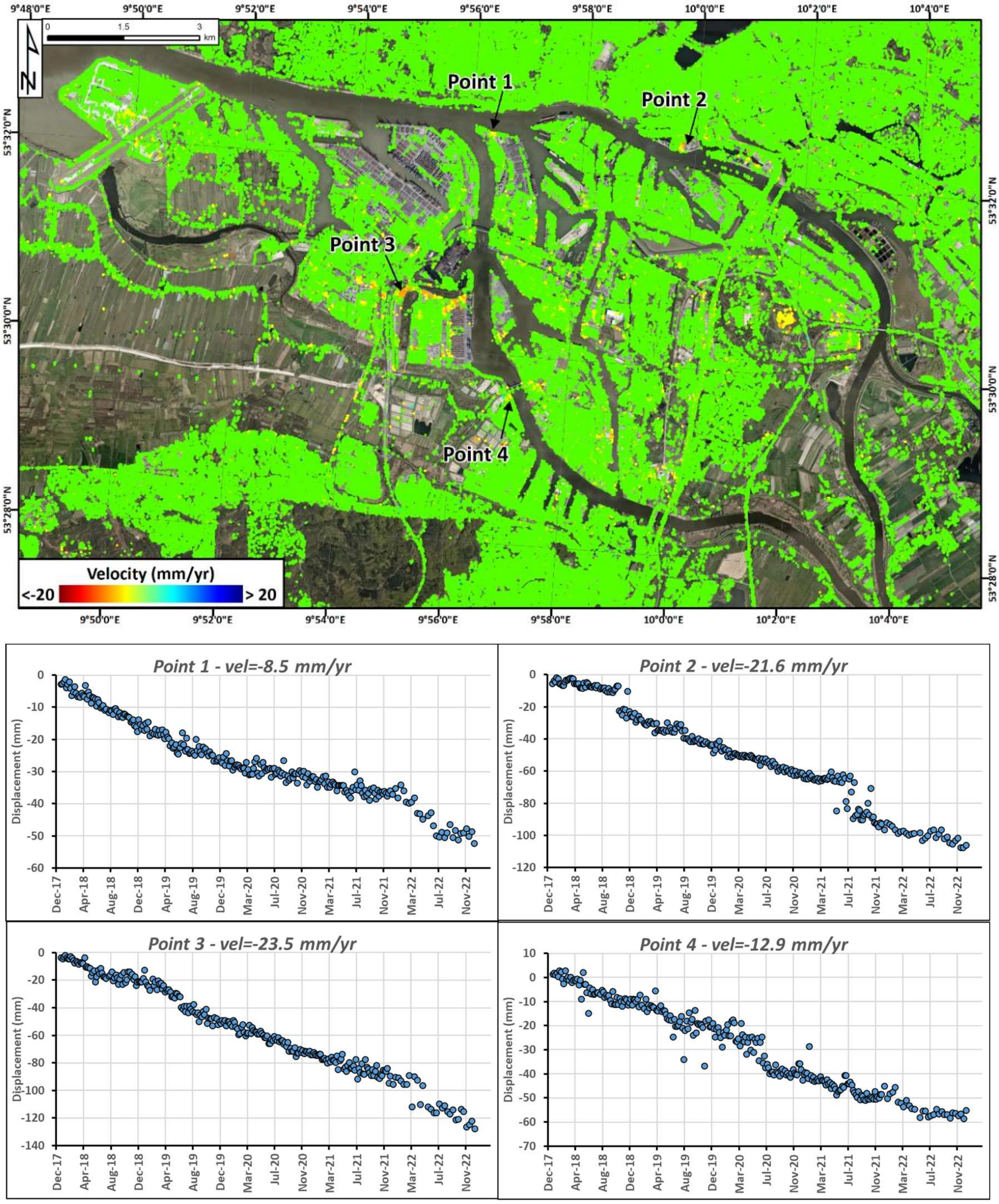


Figure 5-6 Sentinel-1 data for the wide area of the port of Hamburg from the EGMS service. Time series of displacement for selected points within the port of Hamburg are also included.

5.3 ARTIFICIAL INTELLIGENCE (AI) FOR DETECTION AND LOCALISATION

PASSport delved into the transformative impact of technology on port management, specifically leveraging AI for enhanced safety and security monitoring in port areas. The developed solution employs autonomous rotary-wing aerial vehicles, commonly known as drones, to conduct thorough surveillance, automatically identifying and locating vessels, individuals, and other port elements, including buoys. This innovative approach significantly heightens the environmental awareness of port operators. The entire solution exploits additional developments such as data hybridization and sensor fusion techniques, and it is completed with their implementation in a non-commercial, specifically adapted aerial platform.

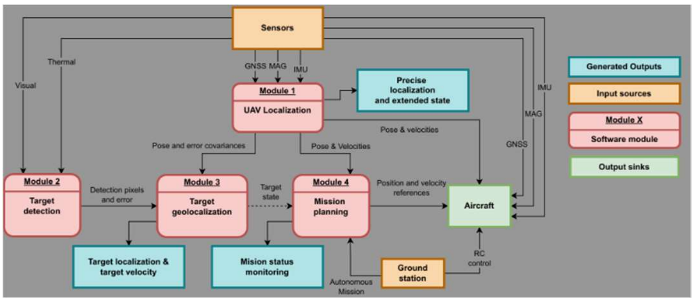


Figure 5-7 Left: interconnection between inputs, Software modules and outputs. Right: PASSport EUT aerial platform

Figure 5-8 Results of the AI vessel detection algorithm

Addressing the challenges of vessel detection on drone images involves tackling specific issues posed by drone imagery under the scarcity of resources to run state of the art AI on-board. The dynamic nature of scenes captured by drones includes continuous changes in viewpoint and scale due to drone motion. Notably, small changes in the drone's pitch and roll contribute to non-neglective variations in the captured images complicating the detection process. Robustness of the object detection algorithms is therefore primordial to make the application useful. This is traditionally tackled by using extensive sets of training images. However, the limited availability of datasets tailored to drone-captured maritime scenes emphasizes the need for innovative solutions to address data scarcity issues. In response, within PASSport , EUT explores various deep learning methodologies, including Faster R-CNN, SSD, and YOLO for region-based and single-shot detection methods. Following testing and evaluation, the project settles on the implementation of YOLOv5. This decision is backed by the network accuracy in real-time inference scenarios and its easiness to be deployed and run in hardware accelerated devices as the NVIDIA Orin implemented as on-board computer. The refinement of the detection network, trained with a Valencia port dataset, demonstrates a significant enhancement in vessel detection accuracy versus the base networks trained with general dataset. The integration of the SORT algorithm for tracking objects in subsequent images further solidifies the robustness and efficiency system for detecting and tracking vessels in dynamic aerial scenarios.

Dedicated to refining the positions of detected targets in the world frame based on image detections and the amalgamation of aircraft localization data, this module leverages Schmidt Kalman filters' intrinsics to address the challenge of multiple solutions when solving re-projection errors. The solution introduces constraints on the vertical motion of targets, ensuring a robust and singular outcome. Employing rigid transformations and meticulous consideration of drone state and detection bounding boxes, this integrated system facilitates precise latitude and longitude estimations for each detected target, spanning vessels, buoys, and individuals. The adaptability of the implementation, characterized by its library nature and parallelizable structure, enables simultaneous solutions for multiple targets, enhancing the system's efficiency and versatility.

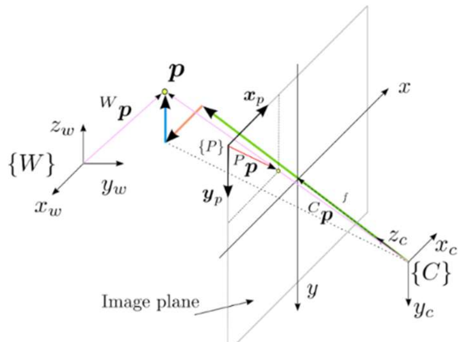


Figure 5-9 Projection of a point defined in the world into the camera frame

High-level mission planning serves as the autonomous decision-making backbone for flight missions on PASSport , relying on an intricate interplay between the AI task planning framework and the plan controller. The task planning is in charge of elaborating and dispatching a sorted list of tasks that optimally serve the prescribed mission. Compared to traditional programming approaches, such as finite-state machines or behavior trees, the advantages of AI planning become apparent when considering its domain independence. It requires only a definition of the domain—actions and predicates—to generate plans, allowing for effortless adaptation in dynamic environments without the need to reprogram all possible states and transitions. In this context, the AI task planning chosen is based on PDDL and its integration into the ROSPlan stack, enabling easy implementation of the paradigm on the rotary-wing vehicle. Additionally, the plan controller monitors the environment and commands agent behaviors while issuing replan instructions as needed. The defined actions include takeoff, land, move, coverage, recharge, and inspect. The composition of these actions allows the drone to take off, patrol, follow detected vessels, and return to the ground if commanded or before running out of battery. Behavior interfaces for each of the defined actions have also been implemented, providing a link between the high-level actions for AI planning and their low-level implementation (low-level controller interface) on the aircraft.

The developments proposed underwent a comprehensive three-phase process departing from user requirements to operational deployment, demonstrating the robustness of technology integration and its utility in increasing port environmental awareness. The deliberate adoption of the Robot Operating System (ROS), an open-source framework for robot software, proved instrumental in managing the intricate flow of information between sensors, compute modules, and external sources. This choice facilitated seamless development, testing, and refinement on local machines, leading to almost transparent deployment on the real robot. Through ROS, the team conducted rigorous simulations, testing perception, localization, and geolocalization modules. This approach not only validated the system but also provided valuable accuracy metrics and insights for iterative improvements. Following the simulated results, a significant pre-campaign conducted in Valencia in June 2023 provided essential insights and refinements. This phase encompassed diverse validations, including data gathering with drones and assessing the performance of magicUT receivers on board. Crucially, the data collected during the pre-campaign played an important role in refining image detectors, enhancing the system's capacity to identify vessels, persons, and other elements. The three-days final campaign in November 2023 showcased the culmination of these efforts, highlighting PASSport 's solution proficiency in conducting aerial missions reporting vessel and person geolocation information to the ground. Notably, the system demonstrated consistent vessel geolocation up to distances of 300 meters, with positioning accuracies of around 5 meters validated from buoy detections. Accuracies exhibited in the person detection scenarios were around 1 meter for targets positioned between 5 and 30 meters from the drone. These results underscore the robustness and effectiveness of the PASSport autonomous rotary-wing system increasing security and safety in real-port scenarios.

1: (takeoff wp_land wp_takeoff)
2: (coverage wp_takeoff wp3)
3a: (move wp3 wp_takeoff)
4a: (land wp_takeoff wp_land)

Replan after target detection event:

3b: (move wp_coverage wp_inspection)
4b: (inspect wp_inspection)
5: (move wp_inspection wp_coverage)
6: (coverage wp_coverage wp3)
7: (move wp3 wp_takeoff)
8: (land wp_takeoff wp_land)

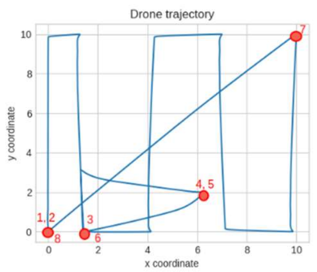


Figure 5-10: Plan with target inspection detection at way point 4

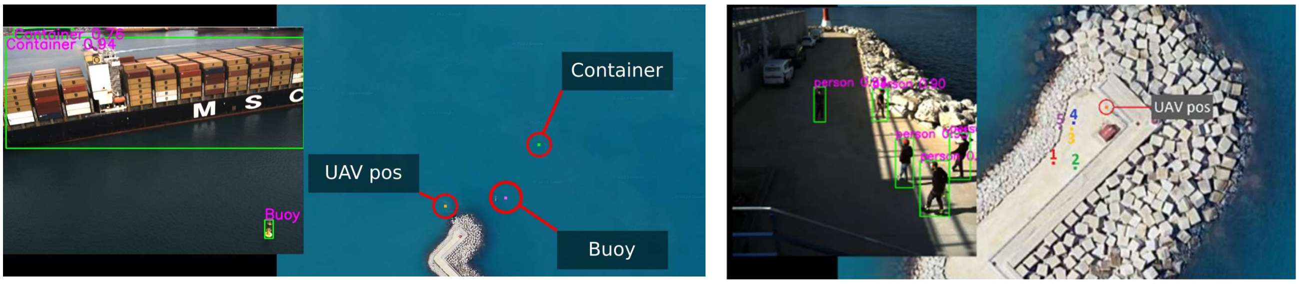


Figure 5-11 Left: AI-based real-time vessel geolocalization.
Left: AI-based object detection with location of drone and geolocalization of container vessel and port buoy.
Right: AI-based real-tieme person detection with positioning of drone and geolocalization of persons

5.4 MIXED REALITY (MR) FRO SUBMERSIVE OPERATIONS

Mixed Reality (MR) technology, which merges the physical world with digital elements, is increasingly recognized for its potential in enhancing decision-making processes. In the context of managing drone fleets, MR serves as a critical component in decision support systems, providing operators with an immersive and interactive interface. This integration enables more informed decisions by combining real-time data with virtual overlays, thus enhancing the effectiveness and efficiency of drone fleet management. As a part of the PASSport project MR interface has been developed and tested during the Kołobrzeg pollution monitoring campaign.

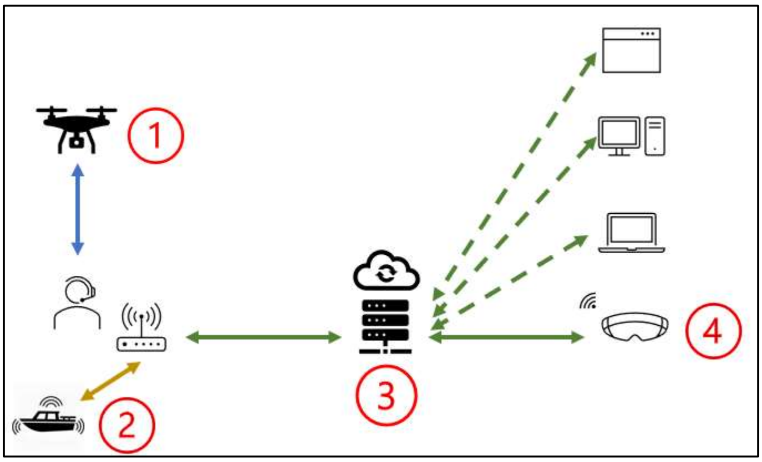


Figure 5-12 Architecture of the system for Kołobrzeg campaign

The MR module (3) is an end point module of the system where the central part is a cloud server (3) processing and distributing from all actors of the PASSport system (1, 2). The drone has been tested for pollution monitoring mission with two different payloads:

1) A rotary wings drone, i.e. DJI Matrice 300 RTK. 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 RTK system to achieve in-flight positioning accuracy of up to 10 cm. A Sniffer 4D was used 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:

- Particulate matter:
  - PM1 (0.3 - 10 μm),
  - PM2.5 (0.3 - 10 μm),
  - PM10 (0.3 - 10 μm),
- O3 + NO2 (0-10 ppm),
- SO2 (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 Kołobrzeg due to the inability to simulate spillage.

2) A double-hulled USV 'Sharky' 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^{o} C. The freeboard height is 0.6m and the minimum draught of 0.3m 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 (BLDC) allows infinitely variable speed control from 0 to 6 knots. The drone is supplied with a single-beam probe and water sampling kit.

MR module has been implemented using:

- Unity Engine 2019.4, the most commonly used engine for developing mixed reality applications, offering support for range of platform and devices,
- Microsoft Mixed Reality Toolkit, an open-source SDK focused on developing single app for multiple AR and VR systems, including Microsoft Hololens and Meta Quest families of devices,
- Microsoft Maps SDK for Unity, using free Bing Maps API for a non-commercial applications

Figure 5-13 DJI Matrice 300 RTK drone with Sniffer 4D air pollution sensor and thermal imaging camera installed

Figure 5-14 The USV "Sharky" floating drone in preparation for testing during the validation campaign

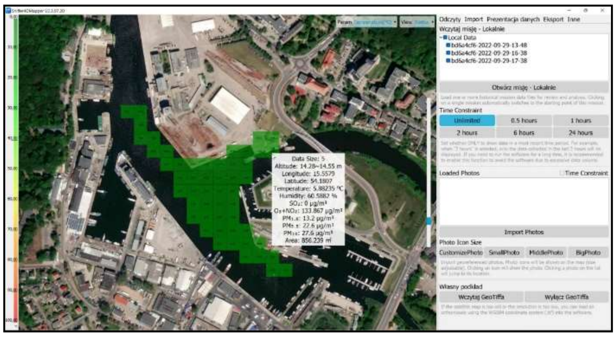


Figure 5-15 Visualization of data from Kołobrzeg campaign using Sniffer4D Mapper™ Analytic Software

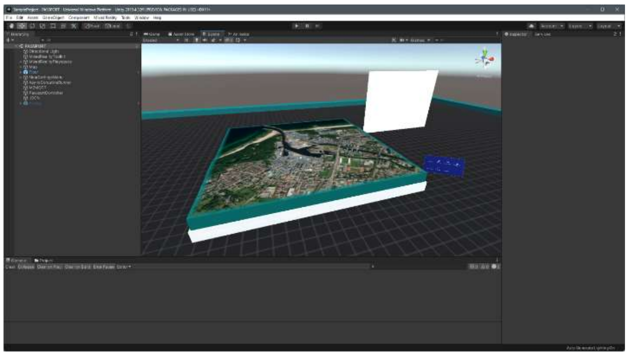


Figure 5-16 Dedicated MR application. View from the Unity Engine Editor

This particular set of tools makes it possible to develop a solution that can be built 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.

Final application has been developed as a Unity Package, that can be imported, modified to display any selected port, extended with custom 3d models and functions, registered with a commercial version of the Bing Maps API if necessary, configured build for any type of MR device. Results achieved during the campaign showed that the drone can be used to measure air quality in an otherwise unreachable locations, creating 3D map of the pollution and that the IR camera is capable of detecting oil spills. Since it is impossible and unsafe to pollute air and water in a port the air and water pollution detection test were performed at off-site locations. During the port mission the MR module has been tested using Microsoft Hololens gen. 1 device and DJI Matrice 300 RTK drone equipped with the Sniffer 4D air pollution monitor and the Zenmuse H20t camera with integrated IR sensor. Additional tests with a Meta Quest 2 VR device have been performed. The developed MR module has been tested by the port authorities and administrative personnel none of which and any prior experience in piloting drones, managing drone operations or using mixed reality equipment in any professional capacity. When managing a fleet of drones, it's crucial to have a comprehensive understanding of each drone's status and the environment they are operating in. PASSport MR module accomplishes this by overlaying real-time data from drones onto a virtual environment. This includes information such as drone location, battery life, operational status, and environmental conditions with an option to stream real-life camera data with a 1Hz frequency. By having all this information readily visualized in an MR interface, operators can quickly assess situations and make well-informed decisions.

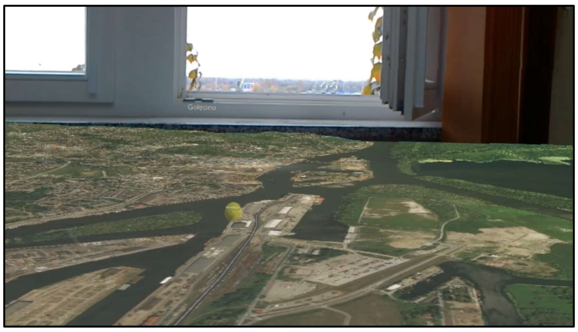


Figure 5-17 View from a Mixed reality system showing digital map of Port of Szczecin overlaid on a real environment using Microsoft Hololens device

Figure 5-18 CEO of Port of Kołobrzeg using Microsoft Hololens during PASSport air pollution campaign

Executed campaign and interviews with end users helped to define a role of Mixed Reality in a PASSport project and draw out several conclusions. Out of tested devices MS Hololens as an Augmented Reality device was favoured over Meta Quest 2 as a Virtual reality device. It scored higher on comfort, situational awareness, and collaboration. Users especially pointed out that they didn't feel disconnected from the environment and other people, making it possible to have a normal contact and perform all other tasks while having access to a full 3d visualization of port area with each drone and air pollution data in real-time. As a major drawbacks battery life, resolution, field of view and no tracking outside during a bright day were pointed out.

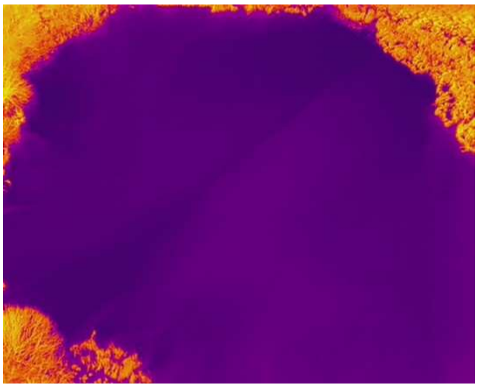
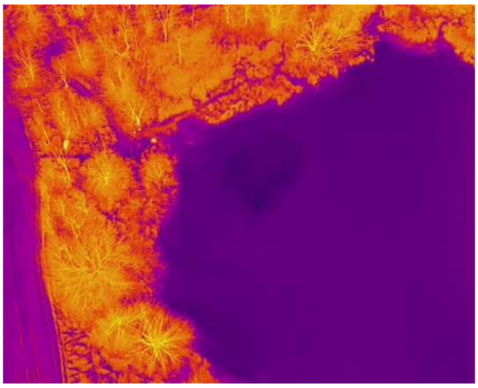
A single frame from a thermal camera after introducing an oil into the water. A clear indication of an oil spill is visible with a clear border.	A single frame from a thermal camera showing whole body of water before introducing any oil. Ambient temperature distribution looks normal with clear, gradient changes of temperature.
	

Figure 5-19 Two frames from a thermal camera before the oil spill (left) and after the spill (right). Right frame has a visible darker area in a location were the oil has been spilled

Concluding PASSport campaign showed a potential of MR as a part of decision support system with definite technological boundaries that need to be overcome.

6 PASSPORT CONSORTIUM

This section reports the structure of consortium members.
Further info is available at www.h2020-passport.eu

Figure 6-1 *Consortium members*

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