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# IMPROVING THE SAFETY OF NAVIGATION IN REDUCED VISIBILITY USING AUGMENTED REALITY DURING NARROW-CHANNEL MANEUVERING IN THE PORT OF VARNA AREA

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***Abstract.*** *Navigation in restricted visibility (fog, snow, heavy rain) in the Port of Varna area (sea–lake) is a serious challenge that can lead to catastrophic consequences. Fog reduced visibility, which often forms solely over the water surface and descends rapidly over the port basin or canal system within ten minutes, drastically decreases visibility. Accurate forecasting of this phenomenon is of critical importance, since a short maneuver takes about 30 minutes, while a maneuver involving the turning of a large vessel can take up to four hours. Weather element forecasting must be localized with high spatial resolution of 2–3 km and with a 2–3-hour lead time, achievable through Nowcasting Forecast methods. Solving the issue of navigation safety in restricted visibility will increase the economic efficiency of maneuvers. This can be achieved through a highly accurate mobile device, independent of ship systems, developed based on the "Blind Passage" concept, including a digital twin that meets navigation safety requirements in narrow areas and canals during restricted visibility, increasing the economic efficiency of shipping under such meteorological conditions in specific geographic regions, raising situational awareness, and supporting the bridge team's decision-making process through tested algorithms, Artificial Intelligence, and augmented-reality visualization.*

***Keywords:*** *navigation safety, reduced visibility, AR*

## 1. Introduction

The geographical location of the Port of Varna and its associated lakes and canals determines the predominance of meteorological elements affecting navigation safety, with visibility being the parameter of greatest influence. Restricted visibility (fog, snow, heavy rain) poses a serious problem that can lead to catastrophic consequences. Fog often forms solely over the water surface, descending rapidly, and the visibility across the entire Varna-West basin drops drastically to 15-20 meters within 10 minutes. Accurate forecasting of this phenomenon is crucial, as the shortest maneuver in the Port of Varna takes around 30 minutes, while a maneuver involving a large vessel turning in Varna-West may take up to four hours. Forecasting must be local and at the highest possible resolution (2-3 km spatial resolution and 2-3 hours predictive period, achievable with Nowcasting Forecast methods). If the issue of navigation in restricted visibility due to fog is resolved, the economic efficiency of maneuvers may increase by up to 10% (optimally 6–8%).

Maneuvering in restricted visibility requires a highly accurate mobile device independent of ship systems (integration with the AIS Pilot Plug cannot guarantee safety-small input errors from the crew, momentary signal loss, etc. will result in complete loss of orientation).

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The device must include its own mobile sensors for positioning the ship itself, the quay, and navigation hazards in the maneuvering zone (such as a ship ahead), as well as a high-accuracy map of the navigation environment displaying real-time conditions (each buoy equipped with its own sensor for drift detection, etc.). Such a mobile device would form part of a pilotage system for so-called "Blind Navigation", based on the corresponding pilotage concept.

The sensor stations of the State Enterprise "Port Infrastructure" are equipped with modern technological systems -advanced sensors (radar, video, current meters, meteorological sensors) are installed to ensure navigation safety in the responsible operational area. Additionally, statistical meteorological data covering more than 10 years serve as a reference for expected weather conditions. This has increased the economic efficiency of maneuvers thanks to the timely, real-time information on the navigational situation compared to the recent past.

## 2. Theoretical Background

The aim of the study is to demonstrate that it is possible to ensure the safety of navigation in narrow channels and waterways under restricted visibility using augmented reality.

To achieve this goal:

1. A digital twin (VR) of the area was created. Figure 1 shows the region of Varna Bay, Port Varna-East, Canal 1, the Old Canal, and the western part of Lake Varna.

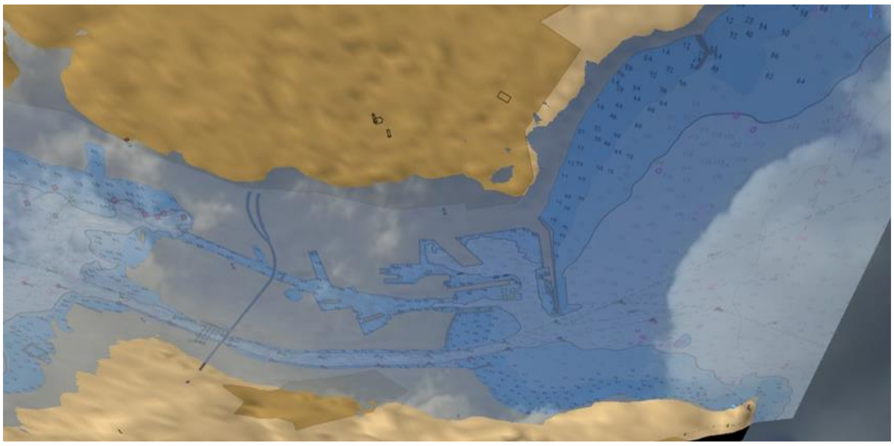

**Fig. 1. Digital twin of the area**

2. An algorithm for weather prediction was developed, based on statistical data for the region from the past 10 years.

3. An algorithm based on ADrone Code was created for visualizing objects from the VR environment, including added meteorological phenomena for the navigation area, to be used with augmented-reality glasses – see Fig. 2.

4. An algorithm was developed to support decision-making for performing maneuvers, based on predicted meteorological conditions and comparison of their parameters with maneuver limitations according to the directives of the "MA" Directorate ensuring safety – see Fig. 5.

5. Simulation tests were conducted on a 360º Class A Navigation Simulator – see Fig. 6 to Fig. 10.

6. Tests were carried out on board a vessel passing through the area – see Fig. 11 and Fig. 12.

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## 3. Concept

### 3.1. Brief description

The concept of "Blind Passage" is based on a digital twin that meets the safety requirements for navigation through narrow areas and canals under reduced visibility, increasing the economic efficiency of shipping under such meteorological conditions in specific geographic regions, and raising the level of situational awareness and decision-making support for the bridge team.

Such a pilot system comprises proximity sensors, Artificial Intelligence (AI) with adapted high-resolution spatial algorithms, short-term weather forecasting (Nowcasting), VR and AR, and an integrated decision-support application.

The pilot system is designed as a solution aimed at four customer groups:

1. **Pilotage services** – stakeholders/clients: pilots, fishermen, captains, and shipowners. This pilot project consists of three models:
   - (1) Weather prediction model
   - (2) Machine-learning model
   - (3) AI comparison model for decision-making support
2. **Shipowners and bridge teams** (captain, watch officers) - stakeholders/clients: shipowners, company management, bridge crew, etc.
3. **Port authorities** (VTS, Maritime Administration, Port facilities) -stakeholders/clients: government, port management, etc.
4. **Non-SOLAS users.**

The Pilot code must include a digital VR model of the port approaches, canals, lakes, quays, and structures - in this specific case, of the Port of Varna. The AR solution may also be delivered on board the ship, the tugboat(s), and to the VTS operator. With the model from the Pilot system, it is possible to run simulations over time and observe the development of meteorological conditions.

The Pilot uses an AI comparison model to support the bridge team's decision-making - comparing **Safety of Navigation Rules** (Directive No. 1 of the Director of Maritime Administration - Varna: "Requirements for Ensuring the Safety of Navigation in the Area of Responsibility of the Maritime Administration –Varna") with meteorological conditions.

Economic benefits arise from reduced delays in port entry caused by reduced visibility.

### 3.2. Functionalities

For realistic environmental visualization (VR), the Pilot model incorporates algorithms defining the interactions between objects: water system and its 3D models and animations, seabed relief and contact reaction, and applied real-time meteorological data.

To produce a dynamic geospatial display for the end user, the Pilot integrates the VR environment, real-time ship-movement data, operator head-position data (the AR glasses must be worn by the operator), operator viewing direction, real-time meteorological information, and the mode selected by the operator (pilot, captain, or watch officer). The augmented-reality view includes the real environmental image from the AR glasses, combined with a VR model cleared of meteorological obstructions (fog, sea state).

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The “Blind Passage” Pilot can ensure navigation safety in narrow channels and waterways using its built-in geographic data (high-resolution VR 3D environment), self-learning AI for predicting meteorological factors in a restricted region for a short period ahead (2–3 hours, based on statistical meteorological data), and positioning sensors. The system also allows upgrading with additional positioning sensors and onboard local coordinate-system sensors.

To ensure maximum navigation safety, the system must be available onboard the vessel, onboard the assisting tugboat(s), and to the duty operator at VTS. The final user interface is the augmented-reality glasses shown in Fig. 2.

**Fig. 2. Augmented reality glasses – Pilot system peripheral**

**Decision-making process for using the “Blind Passage” system**

For the system to be approved for operational use:

1. The “Blind Passage” system must be certified by a classification organization such as IACS – International Association of Classification Societies, with members including Bureau Veritas, DNV, Lloyd’s Register, RINA, etc.
2. The system must be approved by the Executive Agency “Maritime Administration”/ Maritime Administration Directorate and the State Enterprise “Port Infrastructure”.
3. Members of the bridge team, the pilot(s), and the VTS duty operator must undergo training and be authorized to operate the system.
4. Familiarization and training must be conducted in approved simulators, such as those available at BMKC, Technical University of Varna, and others.
5. The Port Captain must authorize individuals or training centers to conduct familiarization and training with the system.
6. The training center must be aware of the system’s capabilities and limitations, including situations in which its use must be discontinued.
7. VTS duty operators must be trained to guide a vessel using the “Blind Passage” system, while the bridge team and the pilot must follow the instructions of the VTS duty operator.
8. A local navigation system consisting of 4 sensors (located at the bow, stern, and port/starboard sides) must be installed on board the vessel.
9. When moored, the quay must be equipped with reference markers to increase measurement accuracy from 0.20 to 0.50 m.
10. Assisting tugboats must be equipped in the same way as the vessel being guided.

- The system uses an independent navigation system based on land reference markers.

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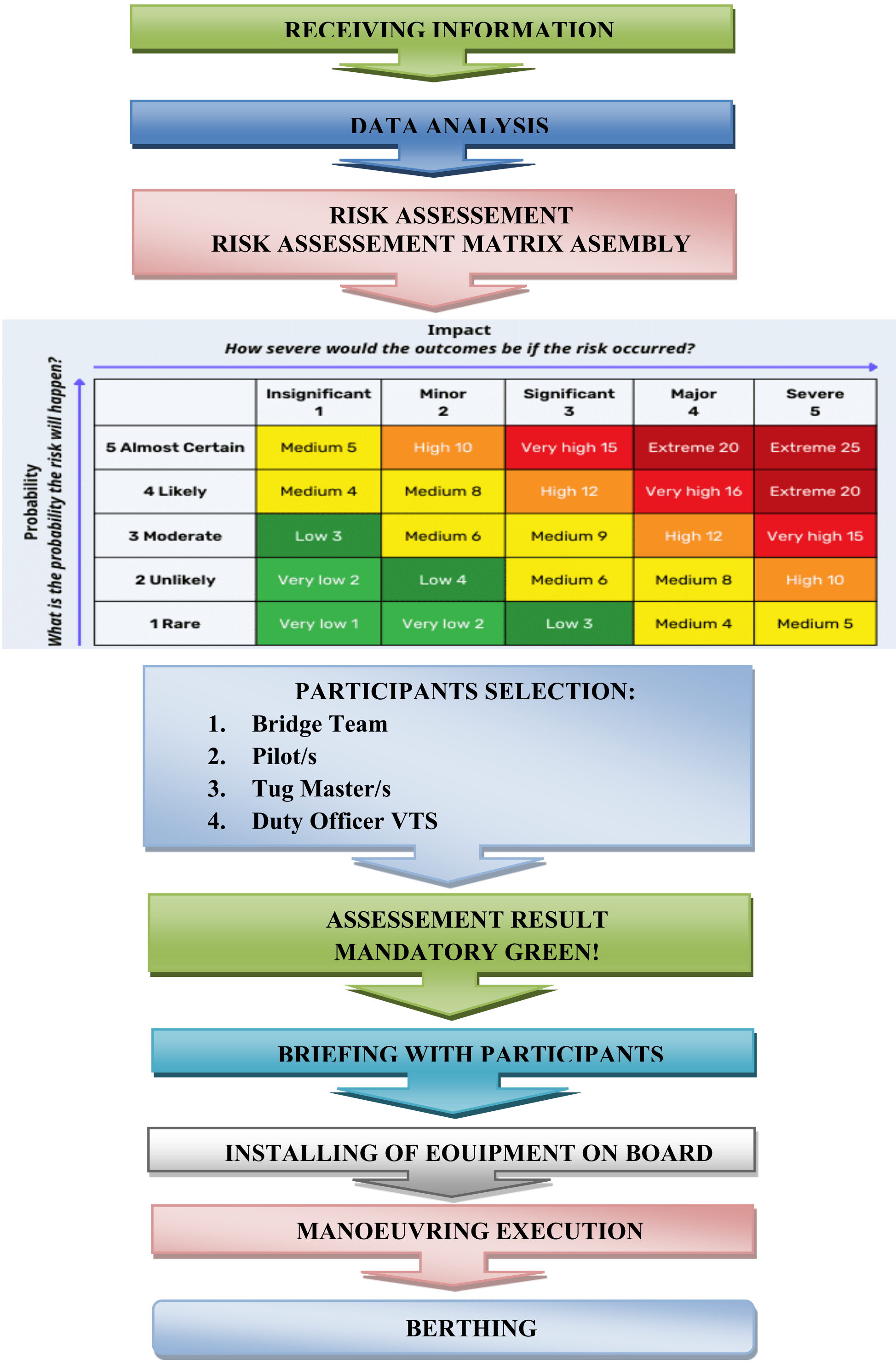
- The system is auxiliary, not primary, unlike RADAR/ARPA and ECDIS. It complements these primary systems and can integrate RADAR and ECDIS displays into the AR glasses.

**4. Sequence of actions for decision-making and performing a maneuver using the "Blind Passage" system with augmented reality – Fig. 3.**




| | Insignificant 1 | Minor 2 | Significant 3 | Major 4 | Severe 5 |
|---|---|---|---|---|---|
| 5 Almost Certain | Medium 5 | High 10 | Very high 15 | Extreme 20 | Extreme 25 |
| 4 Likely | Medium 4 | Medium 8 | High 12 | Very high 16 | Extreme 20 |
| 3 Moderate | Low 3 | Medium 6 | Medium 9 | High 12 | Very high 15 |
| 2 Unlikely | Very low 2 | Low 4 | Medium 6 | Medium 8 | High 10 |
| 1 Rare | Very low 1 | Very low 2 | Low 3 | Medium 4 | Medium 5 |

**Fig.3. Flowchart of the sequence of actions for decision-making and performing a maneuver using the "Blind Passage" system**

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## 5. Test Results

### 5.1. Simulator Tests

After the development of the Pilot system and the implementation of the presented functionality algorithms, simulation tests were conducted using the 360º Class A Navigation Simulator by V-Step. The tests covered the area of Varna Bay, the approaches to the Port of Varna, and the Port of Varna itself (Varna-East, Canal 1 and 2, and Varna-West) using several ship models.

Testing of the Pilot system was carried out according to the simulation shown in Fig. 4, and the steps were documented and are presented in the figures below.

**Fig.4. Simulation of a maneuver in Port of Varna-East**

Using the application with Artificial Intelligence for weather prediction and comparing the results with the constraints of the Directive of the Director of DMA Varna to assist in decision-making for the execution of the maneuver, Fig. 5.

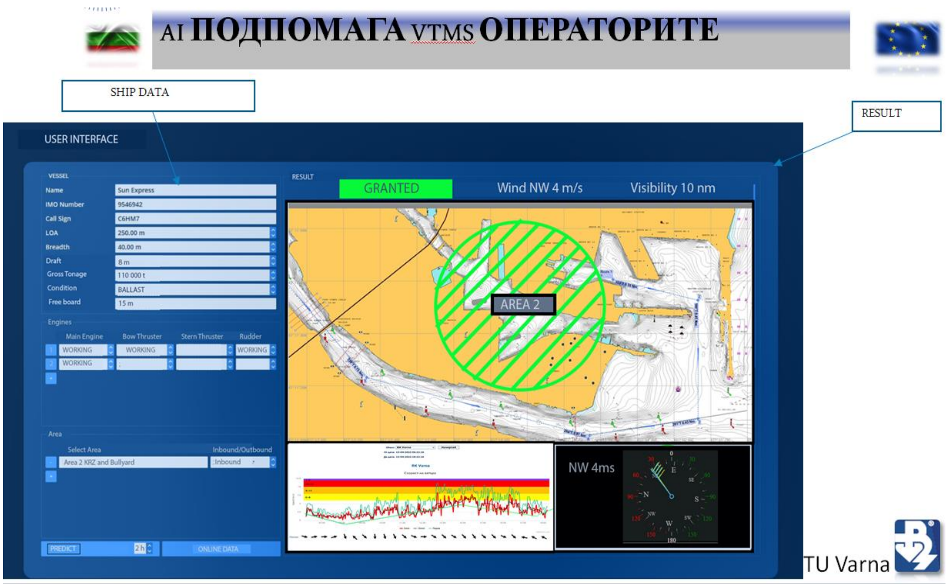


**Fig. 5. Results from applying the data in the Pilot**

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**Fig. 6. Configuration of safety assessment parameters**

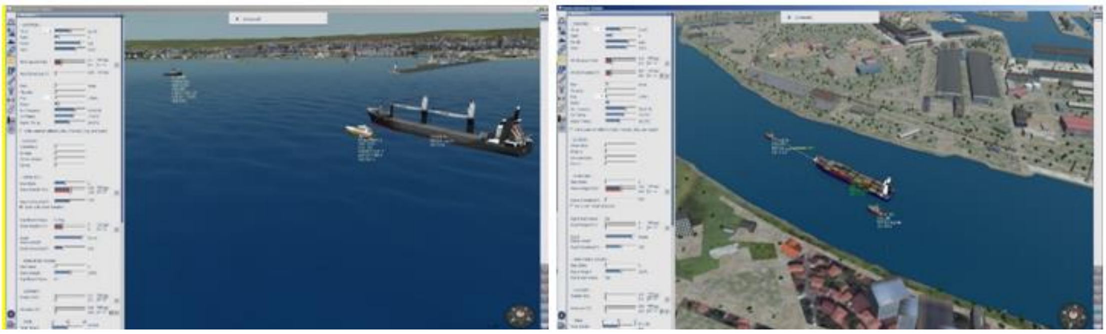

**Fig. 7. Configuration of the environment parameters and involved vessels (Note: Fog has been removed for better visibility / illustration purposes)**

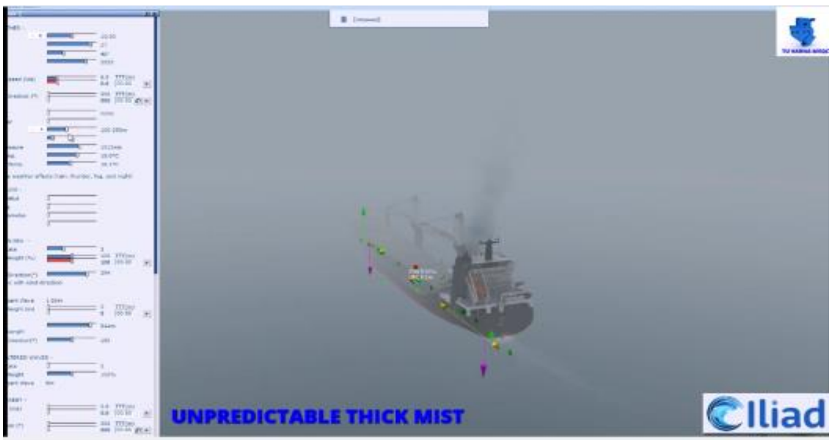


**Fig. 8. Application of meteorological elements**

The key element of the test was the real-time execution of the maneuver while fully accounting for meteorological conditions, geographical particularities, and realistic VR dynamics through the peripheral AR headset. This included accurate head-tracking for the cap-

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tain at the defined observer eye height He (shown in the bottom-left corner of Fig. 9), together with the implementation of standard VTS communication and control procedures.


**Fig. 9. Maneuver execution and VTS operator interaction procedure**

**Fig. 10. Results following maneuver completion**

The comprehensive simulation assessment software logs all kinematic parameters of the vessel and allows quantitative evaluation of maneuver performance relative to the predefined safety criteria (Fig. 6) and the implemented meteorological conditions (Fig. 8).

Currently, the system employs GPS positioning augmented by GSM cell triangulation correction. Tests carried out both in the virtual environment and during real vessel trials – including approach, channel transit through channels and port lakes of Varna Port – demonstrated positional accuracy of better than 1 meter.

### 5.2. Sea Trials On Board a Vessel

A series of sea trials were performed on board m/v CASTOR within Varna Bay, Varna-East Port, Channel 1, Varna Lake, the connecting channel, and Varna-West Port.

The following equipment was deployed on the bridge for the trials:

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- high-performance computer running the VR digital twin of the area and the full ADrone Code functionality,
- see-through heads-up display providing duplicated visualization of the AR glasses image,
- external GPS receiver,
    - GSM handset interfaced with the system for positional accuracy enhancement through cell triangulation,
    - augmented-reality headset,
    - predefined observer eye height He.

To facilitate external monitoring, recording, and control observations during maneuvers, a secondary transparent monitoring screen was connected to the AR glasses (Fig. 11).

The initial series of trials on board m/v CASTOR was conducted exclusively during daylight and in favorable weather and visibility conditions, allowing cross-checking against visual shore references.

**Fig. 11. Maneuver execution using the Pilot system and AR headset during daylight for validation of positional accuracy and real-time dynamic performance**

After confirming reliable performance in daylight, trials were extended to reduced-visibility conditions. Reference was maintained using shore landmarks and channel boundary buoys, with the buoy/object marked in red in the upper-right corner of Fig. 12 being the primary control point.

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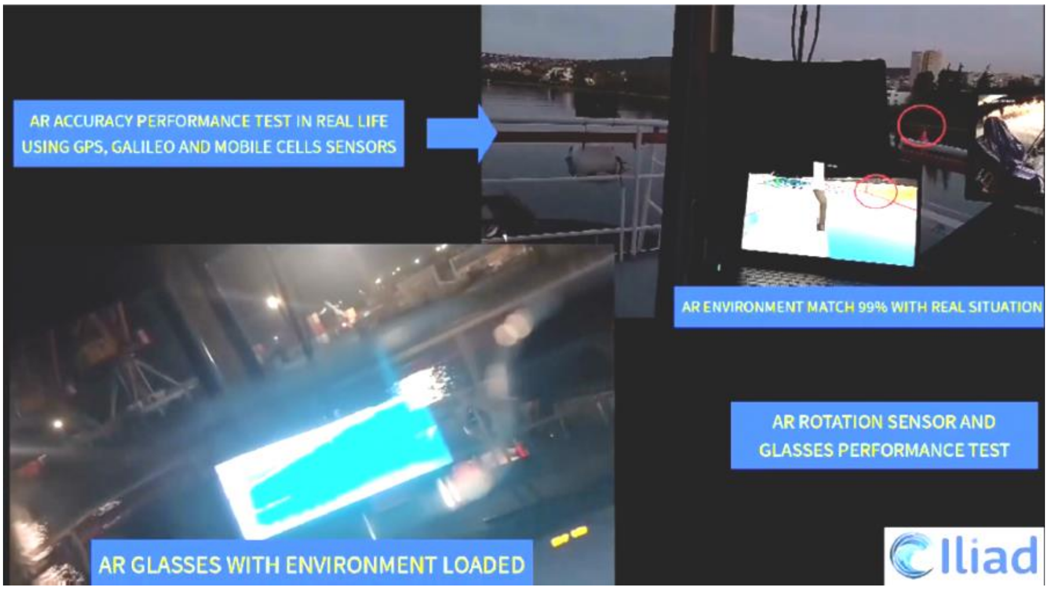


**Fig. 12. Maneuver execution using the Pilot and AR headset in reduced-visibility conditions**

Currently, the system relies on GPS positioning augmented by GSM cell-triangulation correction. Real-world experiments performed on board m/v Castor during transit of the Varna Port approach, channels, and port lakes, and internal waterways demonstrated a positional accuracy of better than 1 meter.

## 6. Conclusion

To enhance the safety of navigation in restricted waters of Varna Port under reduced-visibility conditions, an augmented-reality-based "Blind Passage" system has been developed and successfully tested. The system incorporates artificial intelligence for high-resolution local-area weather prediction (2–3 km area, nowcasting horizon 2–3 hours) and automatically checks compliance with the restrictions imposed by the Regulations of the Director of Maritime Administration – Varna.

For the "Blind Passage" system to become fully operational and officially accepted as a tool for improving navigational safety in the port's narrow channels during low visibility, the following conditions must be met:

- The "Blind Passage" system must be type-approved and certified by a recognized classification society;
- The system must be formally approved by the Bulgarian Maritime Administration (EMA), the Directorate "Maritime Administration" – Varna, and State Enterprise "Port Infrastructure";
- Bridge team members, pilot(s), and the on-duty VTS operators must undergo specific training and be certified to operate the system;
- Familiarization and training may be conducted in approved simulators;
- The Harbour Master shall authorize qualified persons or training centres to deliver the system familiarization and training courses;

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- The training centre shall explicitly cover the system's capabilities, limitations, and the conditions under which its use must be discontinued;
- VTS duty operators shall be trained to actively lead vessels using the "Blind Passage" system, while the bridge team and pilot shall follow the instructions issued by the VTS operator;
- Vessels shall be equipped with a local positioning system consisting of at least four sensors installed at the bow, stern, and both sides;
- When berthing, the quay shall be fitted with reference beacons/markers to improve positioning accuracy to 0.20–0.50 m;
- Escort and assisting tugs shall be equipped in the same manner as the main vessel;
- The system employs an independent local reference-beacon positioning subsystem;
- The system is supplementary and shall not replace primary navigation systems such as RADAR/ARPA and ECDIS; it serves as an additional layer and is capable of overlaying RADAR and ECDIS data directly into the augmented-reality headset.

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