

AUTONOMOUS PLATFORM TO PROTECT MARITIME INFRASTRUCTURE FACILITIES

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ABSTRACT

Problems regarding the security of maritime infrastructure, especially harbours and offshore infrastructure, are currently a very hot topic. Due to these problems, there are some research projects in which the main goal is to decrease the gap and improve the methods of observation in the chosen area, for both in-air and underwater areas. The main goal of the paper is to show a new complex system for improving the security of the maritime infrastructure by means of many methods of observation – such as thermovision, optical devices, and radar systems – generally by means of an electromagnetic wave as a carrier of information in the air and acoustical methods in water. The system can be applied to the protection of maritime infrastructure as well as the coastal zone.

Keywords: maritime infrastructure protection, offshore facilities, systems of surface and underwater observation

INTRODUCTION

The problem of the protection of military and civilian ports against terrorist attacks from the sea, as well as the security of other critical maritime infrastructure facilities is gaining more and more interest in recent years. Offshore areas may represent the best type of environment to conduct clandestine operations, especially from the sea: the features of such an environment weaken the detection and identification processes carried out by defenders, while allowing the covert execution of illegal activities.

The most significant illegal activities conducted in such an environment include infiltration, drugs/weapons smuggling, sabotage/disruption of infrastructures, and even terrorist acts [10].

The danger of terrorist attacks exists also during peacetime, and naval forces are not always ready to counter unexpected terrorist attacks. Such attacks may occur during the forced withdrawal phase of peacekeeping operations, when the state of alertness is sometimes lowered. The threat of terrorist attack arises as the crisis situation develops, and in such crisis

situations sabotage and espionage acts are also likely to take place. The attacks conducted by terrorists or other groups or individual persons against naval bases, harbours, and other infrastructure can be accomplished, among other means, in the following manner [12]:

- surface attacks with manned and unmanned vessels used to carry explosives or as weapons platforms;
- underwater attacks using divers, mini subs (manned or remote-controlled), and explosives or sea mines.

These activities are accomplished through the use of a variety of means of transportation, which include cigarette boats and power boats, rigid hull inflatable boats (RHIBs), sailing/leisure boats, midget boats, swimmers/divers (with open/closed breathing systems), and swimmer delivery vehicles (SDVs).

Requirements such as flexibility, rapid reaction, resilience, high-level automation, and modularity have a key role in modern surveillance systems.

This paper proposes a system developed for critical infrastructure protection in accordance with the previous requirements.

THE CONCEPT OF A MARITIME INFRASTRUCTURE SECURITY SYSTEM

There are many types of commercially available surveillance systems for the protection of large-area objects such as harbours, wind farms, and other offshore critical infrastructure [1, 4, 5, 11, 13]. However, some observations can be made regarding basic concepts of such systems, because there is a general tendency to include such components as:

- radar-visual observation systems with automatic target detection and tracking by a radar, followed by cueing of cameras for visual recognition;
- CCTV paired with thermal cameras for day and night observation capability;
- fusion of daylight and thermal camera images to obtain easy-to-comprehend output for a system operator;
- merging the radar and image data and visualization of the target trajectory on a digital map.

The above systems, primarily developed for land surveillance, are adapted to sea surface monitoring tasks. This sometimes creates problems because radar-visual observation systems can produce significant noise in cases of windy weather and rippled sea. As a result, noise filtration algorithms have to be implemented, both in radar and camera systems [2, 3].

Underwater and surface zones should be also monitored; this monitoring is provided by passive and active systems. Such solutions (sonars and magnetic barriers) are used in restricted harbour areas highly sensitive to unauthorized access (e.g., entrances to gas and oil terminals, pipelines, and ships anchored at terminals) [8, 9]. A system with integrated passive and active sensors, signal processing, and fusion units should be able to detect and identify surface and underwater targets, including divers [6, 7].

Both systems – radar camera for sea surface monitoring and hydroacoustic system for underwater sea area monitoring – are autonomous and can be deployed independently in the protected area. By connecting them via a network, a complex perimeter protection system can be obtained. Such a solution is then suggested by the authors as a coherent system for the protection of sea areas, managed by a single command and control centre, and connected by a cable or radio Ethernet network.

What is more, the proposed observation system is a mobile system, which can easily be transported to a selected point and transferred to another location, depending on needs.

The system consists of two main observation points: a mobile platform that is the main element of underwater and surface observations, and a long-range thermal imaging and long-range camera set on land as a basic element of observation in an air environment. The system integrates different types of sensors (e.g., radar, thermovision, and optical cameras or underwater acoustic and magnetic sensors) which cooperate in a multi-environmental scenario, above water and under water and sea surfaces.

The proposed concept of a protection system assumes the use and arrangement of its individual elements (sensors, system components, tool and software interfaces, and the operator

console) in agreed places, allowing effective protection of a given object or area. The concept assumes the integration, processing, and depiction of situations coming from all sensors of the security system at the command centre, which will be located on land. This information will also be transferred to the patrol boat to allow immediate response in the event of an emergency (Fig. 1).

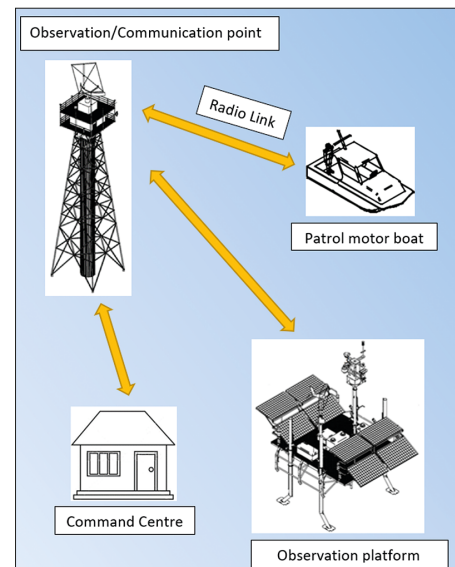


Fig. 1. Elements of the maritime infrastructure security system

MULTI-SENSOR OBSERVATION PLATFORM

The sensor carrier for detecting objects moving both on and under the water surface is a multi-sensor measuring platform. The concept of the platform is shown in Fig 2. It consists of two main parts:

- an underwater part situated on the sea bottom of a protected water area, consisting of sensors and systems for recording and analysing signals;
- a surface part to which the underwater part is connected. Elements placed on the surface part ensure autonomous work of sensors in terms of energy (i.e., a set of batteries, photovoltaic panels, a wind turbine).

In addition, part of the surface observation sensors and a radio module for sending data to the communication point will be placed on the platform.

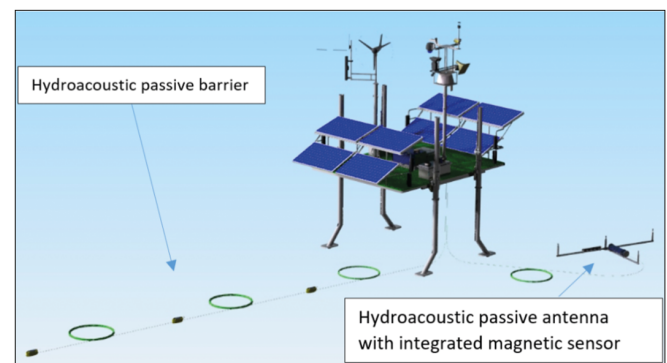


Fig. 2. The concept of a multi-sensor platform

On the platform, surface and underwater sensors are integrated. The measurement data, in full form or in the form of alarms about events, are sent by radio via the communication point to the command centre located on land. These data are also transferred to the patrol boat. The platform is generally designed as a stationary object that can be moved to any point using a specially designed carrier in the form of a catamaran equipped with a motor (Fig. 3). In this sense, the platform is an autonomous floating object.



Fig. 3. Observation platform with a transport catamaran

In addition, the platform is fully autonomous in the energy sense, i.e., powering and measuring devices and data transmission. It is equipped with large capacity batteries and natural, solar and wind energy sources. The platform is energy balance prepared, taking into account the demands of all measuring sensors tied to the platform; this allows us to conclude that given the atmospheric conditions typical of the Polish coast, the platform can operate without service during the spring–summer period for about 6 months. In the event of a lowering of the supply voltage below the permitted value, an alarm is sent to the command centre, from which it is possible to turn off or limit the power supply of selected sensors. The possibility of quick service intervention in such a situation is provided – the platform is equipped with a power generator that allows the batteries to be recharged.

SURFACE PROTECTION VIA SENSORS INSTALLED ON THE PLATFORM MAST

The measuring platform has been equipped with a group of independent sensors, providing the operator with information about the situation prevailing in the upper hemisphere; these devices include a thermal imaging camera, a visible light camera, and a continuous wave radar. In addition, there are devices on the platform which support the platform's own protection: a searchlight with a remotely controlled head, a fisheye camera, a megaphone for generating messages, and devices necessary for the platform's operation in marine conditions, i.e., top lamp and weather station (Fig. 4).

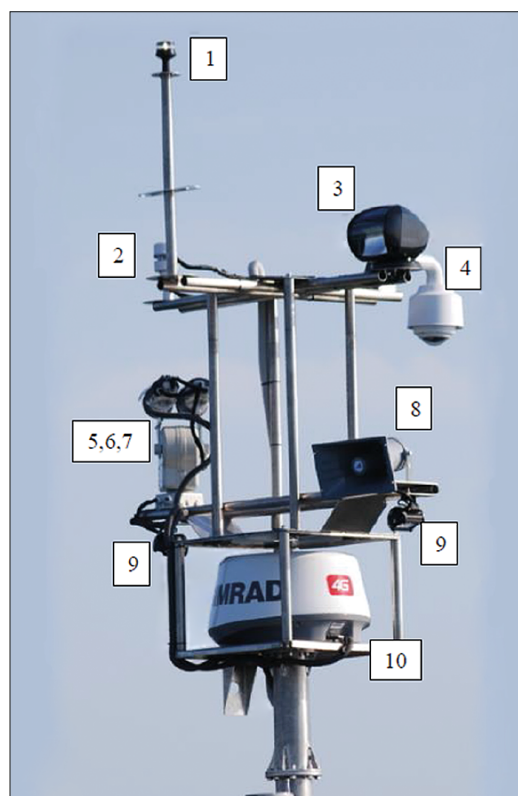


Fig. 4. Devices on the platform mast: 1) top lamp, 2) weather station, 3) searchlight – controlled head, 4) fisheye camera – platform supervision, 5) thermal imaging camera, 6) camera of visible light, 7) positioning system of thermal imaging camera and visible light, 8) megaphone for generating messages, 9) work lighting – LED, 10) radar

The main task of the surface observation subsystem on the platform is to protect the area that is difficult to access for observation from the camera located on the observation tower. This system consists of combined thermal imaging cameras and visible light, as well as a continuous wave radar.

Camera range studies were carried out for various scenarios in order to check the algorithms for detecting and tracking objects, and the quality of the obtained results. On the map (Fig. 5), two zones are marked off from the cameras: Zone I by 400 m–550 m and Zone II by 700 m–950 m. The object used for research – in this case, a pontoon with a length of 3.3 m and a width of 1.3 m driven by a 5 HP engine – moved along the indicated trajectories to obtain images in the following scenarios:

1. Initially, the object is outside the observation zone. Then, it appears on the left side and flows through the entire observation zone (trajectory 2 and trajectory 3).
2. The object has moved away from the camera to the maximum designated distance (trajectory 1).
3. The object approaches the camera from the set maximum distance (trajectory 1).
4. The object moves during the measurements: slowly at the speed of 2 knots, quickly at 10 knots (trajectory 2 and trajectory 3).
5. The object flows next to another object on the water (trajectory 1).

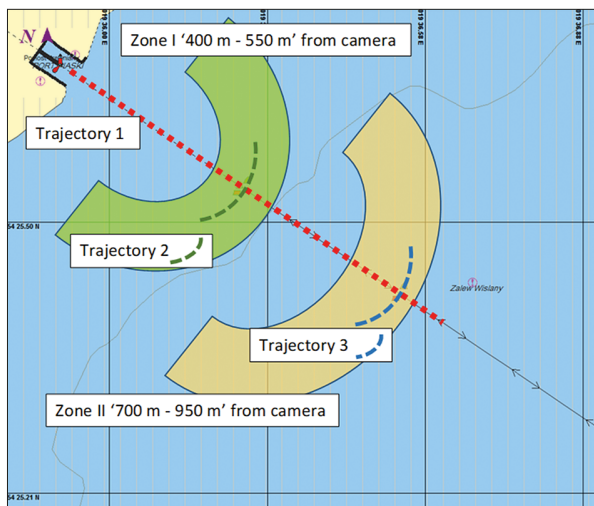


Fig. 5. Scenarios for the coverage of cameras

The object observed during the tests did not have any elements enhancing its image for both the thermal imaging cameras and radar imaging (no electromagnetic wave reflecting system used on ships). Below are two presentations of a pontoon from a thermal imaging camera at a distance of 500 m and 900 m (Figure 6).

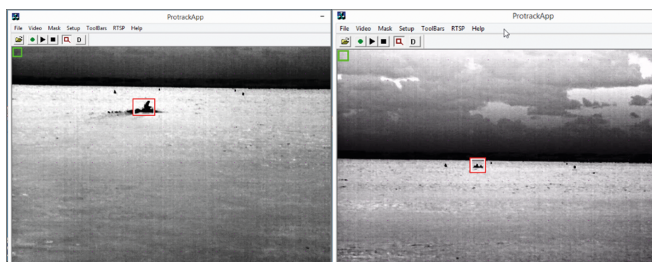


Fig. 6. Image from a thermal imaging camera at a distance of 500 m (left) and 900 m (right). The rectangle means the object 'tracked' using the ProTrack software

In addition, for comparison, the depiction of a visible light camera (Fig. 7) cooperating with a given thermal imaging camera is shown. The image allows full identification of the object and the crew that is on it. Imaging from the infrared camera when the pontoon is away from the sensor at a distance of 900 m enables detection and recognition of the floating object on the surface of the water.

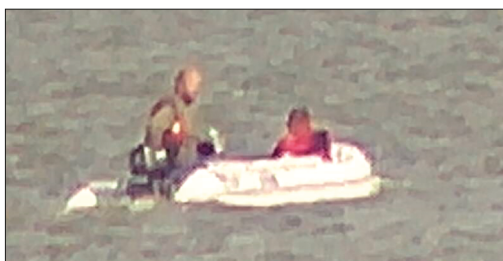


Fig. 7. An image from a video camera at a distance of 500 m

During the tests, the effectiveness of the algorithm for detecting objects moving on the water surface was tested; the ProTrack program was implemented in the software version, integrating the complete system. The detection algorithms

correctly followed a 3.3 m long pontoon at a distance of up to 590 m; most of the tests were carried out in this vessel. To sum up, the optical sensors installed on the mast of the platform enable full supervision of the water reservoir to a distance of about 1 km.

UNDERWATER SUBSYSTEM INTEGRATED WITH THE PLATFORM

The sensors used for underwater observation were configured in the form of two systems:

- a hydroacoustic antenna integrated with a magnetic sensor;
- multi-sensor hydroacoustic barrier.

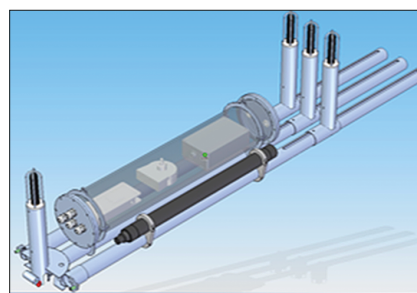


Fig. 8. Hydroacoustic antenna with magnetic sensor

A hydroacoustic antenna consisting of four measuring hydrophones enables the detection of an underwater signal and determination of the parameters of the detected object. By investigating the time of delay of signals arriving to individual hydrophones, we can determine the following parameters: bearing of the object, distance from the sound source, speed of movement of the underwater object, and geographical coordinates of the object.

The magnetic field from objects such as boats made of plastic is at a very low level; that is why the range of the magnetic sensor is a few metres.

A multi-sensor antenna consisting of digital hydroacoustic sensors connected by a cable makes it possible to create an acoustic barrier, for example, between the platform and the land (Fig. 9). Data transmission takes place via an Ethernet connection.

The hydroacoustic antenna and underwater barrier sensors connected to it are powered by a cable connecting the central antenna module with the surface part of this subsystem placed on the platform.

Due to the high mobility of the system, individual elements of the acoustic barrier module are connected in series, which makes it possible to minimize its weight, and also facilitates inserting and taking over the module in a given water reservoir.

The modularity of the system allows adding additional hydrophones, magnetometers, and entire blocks forming a hydroacoustic antenna. As a result, it is possible to easily expand and shape the configuration of the subsystem for detection of events in the lower half-sphere in a way that allows protection of any area of the basin.

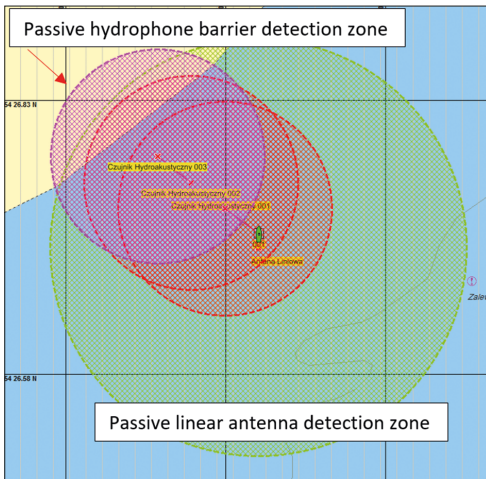


Fig. 9. Boundaries of protected areas by a hydroacoustic antenna (green area) and individual hydrophones included in the acoustic barrier (red circles)

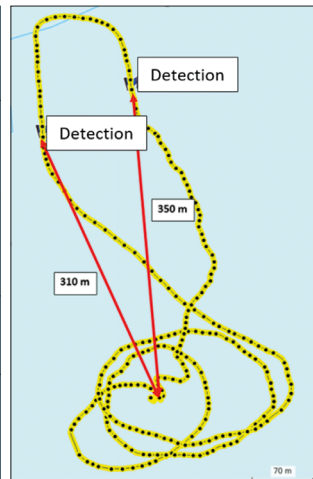


Fig. 10. The movement path of the floating object

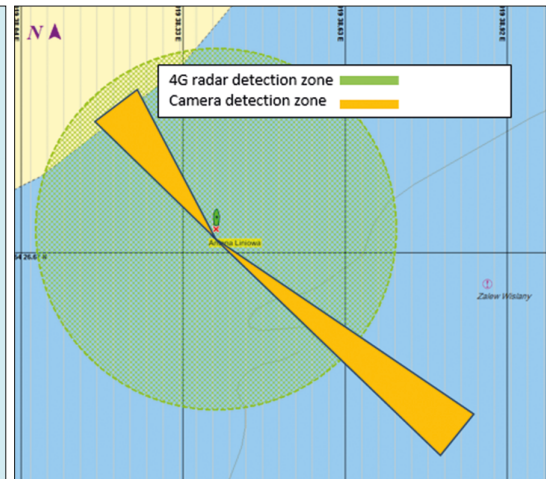


Fig. 11. Limits of the area protected by a hydroacoustic antenna (green area) and the radar alarm zone

INTEROPERABILITY OF THE RADAR AND UNDERWATER OBSERVATION SYSTEM

Surface and underwater observation subsystems, for which the platform is a base, cooperate in detecting objects at a small distance from the observation point, which is especially important due to the purpose of the system. Observation areas of the underwater subsystem and radar subsystem coincide.

During measurement in natural conditions, tests were carried out in accordance with the following scenario:

A pontoon with a GPS receiver placed on it moves along the water in an irregular way. The observation is carried out simultaneously using:

- radar;
- hydroacoustic sensor barriers;
- a hydroacoustic antenna, which simultaneously sets the bearing on the object;
- and a differential magnetometer.

The movement path of the floating object is shown in Figure 10. The object was noticed and registered by all subsystems. Obtaining an alarm signal from the magnetometer required special procedures; i.e., it had to float in the area where the antenna was placed. There is no possibility of detection of the object from a greater distance, although the gradiometer used is a high quality device.

Underwater noise was received by all hydrophones – individual and included in the antenna – and the trace of the object was visible on the radar screen. In addition, up to the distance of about 350 m, it was possible to set the bearing.

The radar used in the system makes it possible to declare guarded zones (Fig. 11). The radar alarm occurred each time the object appeared in the guarded area.

LONG-RANGE CAMERA TESTS

Long-range camera coverage tests were performed both during the day and at night. The following two images

(Fig. 12) present the possibilities of transmitting the image by means of a visible light camera and a thermal imaging camera placed on an observation tower on land. The distance from the camera transducers to the observed platform is 733 m; the distance was measured using a laser rangefinder integrated with the camera.



Fig. 12. Image from long-range cameras during the day: visible light camera (left), thermal imaging camera (right)

One of the main advantages of the long-range thermal imaging camera used in the maritime infrastructure support system is the focal variable. It enables observation of distant images by more than 14 km in the absence of visible light.

INTEROPERABILITY OF A LONG-RANGE CAMERA WITH AN UNDERWATER OBSERVATION SYSTEM

Due to the integration of the system – thanks to which signals received from all observation subsystems as well as control signals of these systems are available in the command centre – it is possible to complement each part with various observation subsystems. The cooperation of the underwater observation system and the long-range thermal imaging camera is particularly important in night conditions when there is no lighting. The occurrence of an alarm from hydroacoustic sensors causes the camera to rotate in the direction of their arrangement, as shown in Fig. 13.

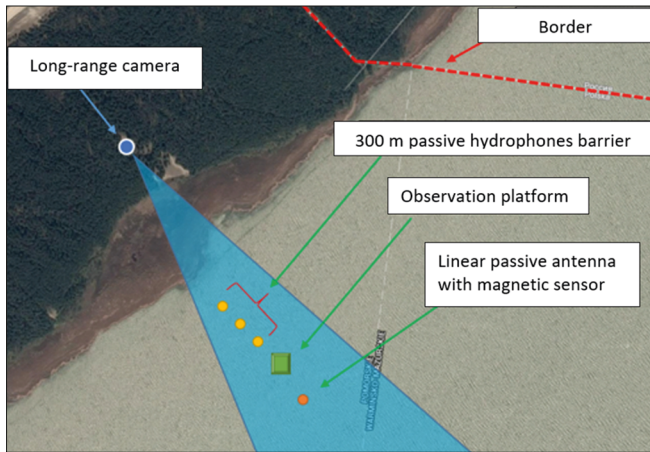


Fig. 13. Rotation of a long-range camera in response to a signal from the subsystem of underwater observation

Broadband observation of the protected zone enables detecting and identifying objects and unwanted people, regardless of the time of day. The system has the ability to visually track an object (human, vessel) that violates the protected zone.

INTEGRATION OF SUBSYSTEMS: THE COMMAND CENTRE

The designed and implemented support system for maritime infrastructure protection using modern methods of event detection consists of several observation subsystems, from which data are transferred in real time to the command centre.

The command centre actually consists of two parts: the main part is located on land and an auxiliary is located on a patrol boat. In principle, the overriding authority to manage the border protection subsystems has a land station, but in a justified situation these can be programmatically transferred by the system administrator to the station on the patrol boat.

All observation subsystems are integrated in both places. All alarms and auxiliary information from observation subsystems reach both of these positions. Also, from both locations it is possible to manage subsystems in real time, such as changing sensor settings, turning them on or off, viewing camera images, listening to acoustic signals, switching on lights and alarms protecting the subsystems themselves, checking proper functioning of sensors, powering them, switching on emergency power, and broadcasting messages through megaphones, etc.

Our research into the maritime infrastructure protection system, carried

out in natural conditions, enabled us to check the functioning of all subsystems and the ability to transfer data between particular observation and surveillance points, as well as the quality of these signals. On this occasion, information necessary to prepare the visualization of events at the command centre was gathered. On account of limited space, the visualization of events system on the patrol boat console cannot be as extensive as in the case of the command centre on land.

The collected information on the functioning of all subsystems and all sensors in the natural environment was used to develop an interface that was implemented using a multi-layered geoinformatic system. The interface combines the following functions:

- visualization of data on a map covering the protected land and water areas;
- presentation of alarms generated in individual subsystems with the accuracy of individual sensors;
- control of sensor settings (detection thresholds, band filters);
- power system control;
- and control of the data transmission system.

A detailed functional outline of the interface was developed, which is presented in Fig. 14. The diagram depicts a set of sensors from which information should be adopted and presented in the interface.

Visualization of events and system operation takes place on two screens:

- main screen
- secondary screen

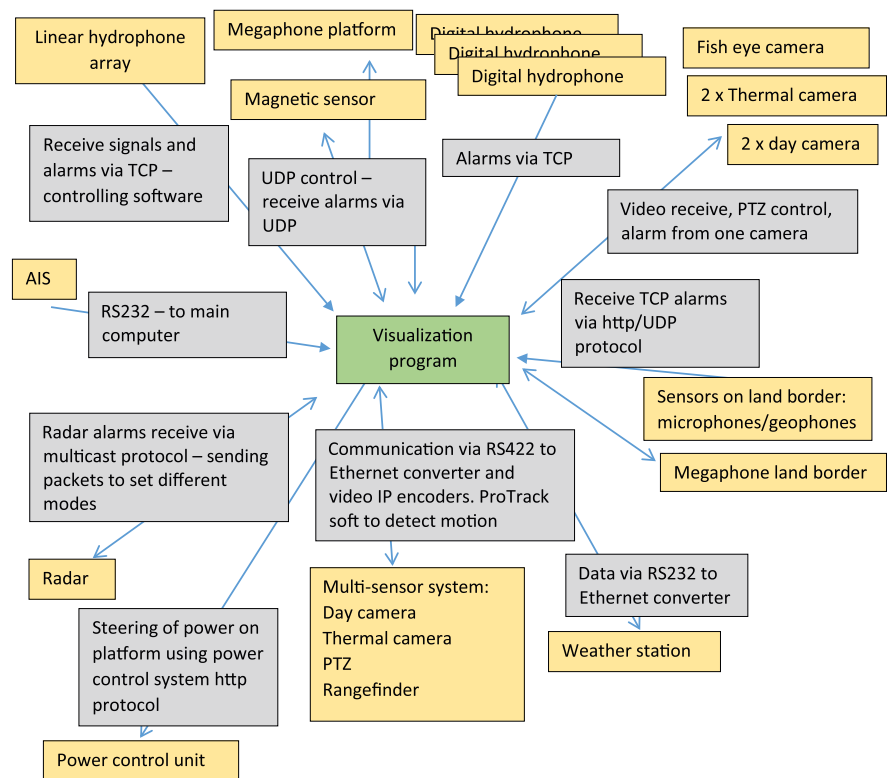


Fig. 14. Functional diagram of the user interface in the Command Centre

On the main screen there is a window with a map of the area under surveillance with the icons marked with points where the sensors are located (Fig. 15) and two windows for reading images from cameras.

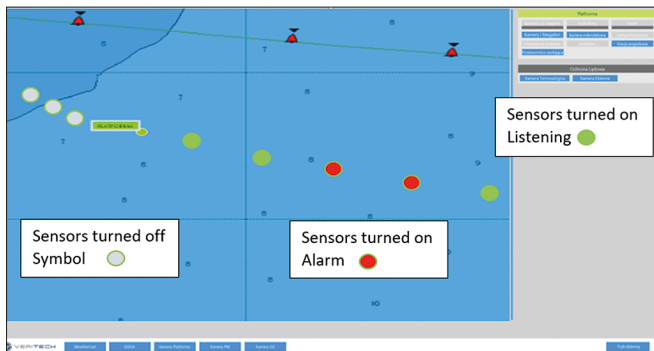


Fig. 15. Map with marked sensors

On the secondary screen there is a window for reading the image from any chosen camera or other sensors and a summary of information on the operating status of the devices in the form of a table (Fig. 16). At this point, the user can also turn on or off the power of individual subsystems or individual sensors.

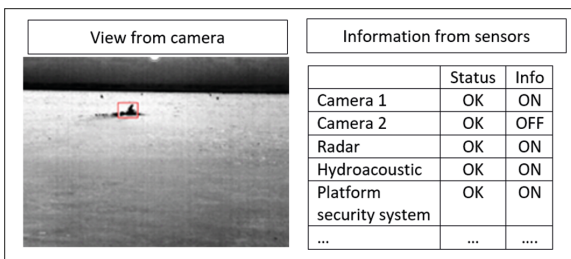


Fig. 16. Auxiliary screen – information on the state of the sensors

In addition, the settings of all devices and sensors operating in the system can be changed on the auxiliary screen (Fig. 17).

SUMMARY

The presented system for monitoring the areas, both in the air and under water, uses modern methods of observation. Simultaneous operation of several systems allows for a relatively accurate observation of the chosen area. This applies to the area on the water itself as well as the underwater area. Its major advantage is that the independent components of the system can be applied in areas where a global system has areas of shadow. The advantage is also the mobility and energy independence of the observation platform.

The system uses the latest measurement, IT, and telecommunication technologies in image and signal processing from all sensors used for environmental observation and event detection. All software components have been integrated into one common platform. This means, among other benefits, there is access for all modules to shared resources and a possibility of cooperation of various elements in the unified user interface. The created software has interfaces that enable cooperation with other systems and provides full situational information to the command centre. The system has been developed in a way which enables the extension of cooperation with new sensors and devices, as well as systems that may be created in the future, without access restriction or limited implementation possibilities; this ensures the interoperability of the created system.

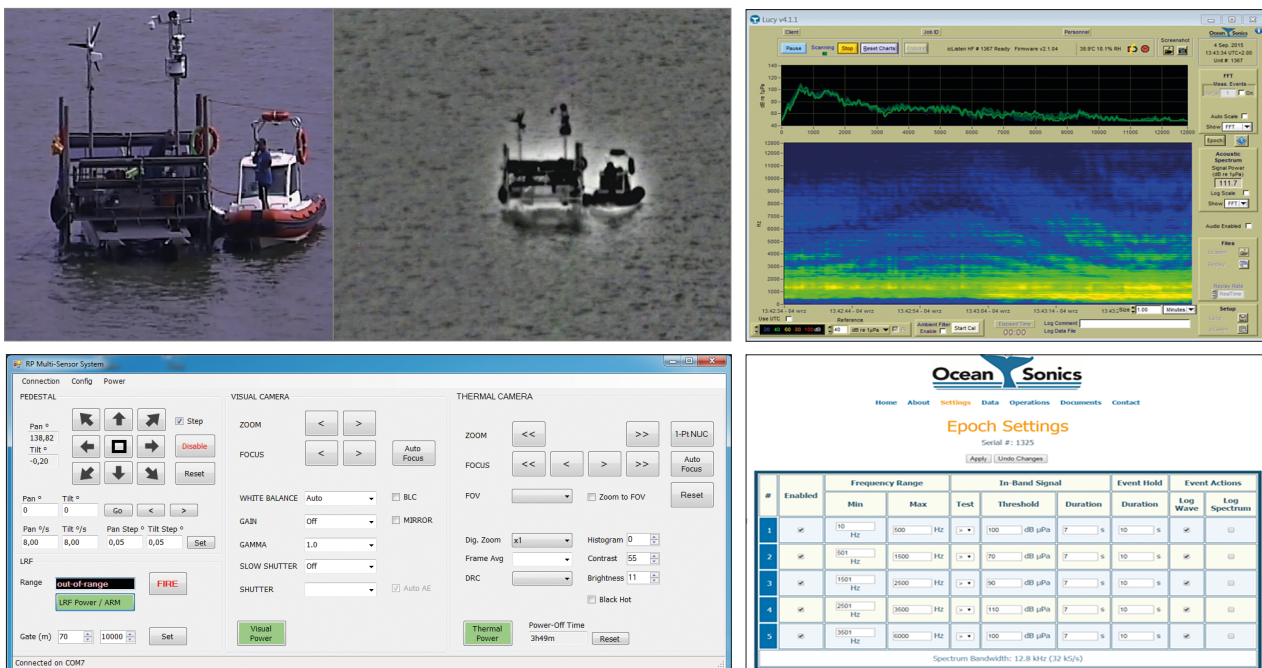


Fig. 17. Auxiliary screen – adjustment of long distance camera settings (left) and one of the hydrophones (right)

ACKNOWLEDGMENTS

The investigation was supported by the National Centre for Research and Development, Grant No. DOBR/0020/R/ID3/2013/03.

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