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Design and Application of an Automated Smart Buoy in Increasing Navigation Safety and Environmental Standards in Ports

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ABSTRACT: The growing demand for transportation has brought even larger quantities of traffic in spatially limited port areas. Considering a diverse traffic mix, infrastructural overcapacity and busy schedule, port communities have started to face possible degradation of safety and environmental standards. To mitigate these problems, a number of different monitoring solutions of marine environment were deployed. Since conventional environmental and traffic data gathering by physical monitoring and sampling was logistically complicated and inefficient in time and resources, different approaches had to be considered. With the rise of accessible Internet of Things (IoT) technology some ports already installed smart monitoring devices such as smart buoys. The goal of this paper is to examine the concept and benefits of an automated smart buoy as a cost effective, easy to install device capable of real-time remote information sharing. Furthermore, the design and operational processes of existing automated smart buoy will be presented, along with solutions for tackling navigational safety and environmental problems.

1 INTRODUCTION

Regardless of their size or purpose, seaports, as part of global transportation system, have the character of traffic complexity, especially in their maritime domain. Tendency of port officials to attract and produce a higher shipping activity can sometimes cause a traffic overcapacity of infrastructurally limited port areas. If the diverse traffic mix and external influences such as wind or sea are also taken into account, then the possibility for degradation of ports safety and environmental standards is quite likely. In order to control the maritime activity's and address mentioned challenges, some seaports are investing their resources in development and application of new methods and technologies.

In recent years, there is an increasing number of researches where risk appraisals were conducted with an aim of providing safe navigation and level of ecological sustainability of port areas. Manny of them based their input on historical data, but also on an information gathered by Automatic Identification System (AIS), device that is essentially used for marine traffic surveillance. Because of its ability for displaying up-to-date vessel position tracking, speed, ship particulars, etc. AIS is very convenient source of input info for traffic control operations. In research conducted by S. L. Kao et al. both historic databases and AIS data were used for calculating safe vessel manoeuvring speeds that should mitigate navigational and air pollution danger in Keelung Port [4]. X. B. Olba et al. also included AIS data in their paper with a goal of enhancing navigational safety through risk assessment model and defining risk index that could be applicable on various ports [3]. AIS-sourced info about ships and their movement progression were examined and applied in scientific studies for Shanghai Yangshan port done by S. Song and Las Palmas Port carried out by M. Tichavska and B. Tovar, that aimed to secure more precise prediction of air pollution [8, 9]. Dynamic ship information such as speed and time spent in a particular activity proved to be significantly important for obtaining relevant results in both air quality studies, and this data would be very difficult to accurately determine without the AIS transponder.

Although AIS offers detailed and in near-real time insight about static and dynamic marine traffic data, content that it displays includes only vessels that are required to have transponder installed on board [14]. Because of limitation which excludes small scale ships that sometimes make up a significant share of traffic, especially in the wider port areas, new ship-movement monitoring solutions are more often deployed.

Development of Internet of Things (IoT) technology offered opportunity for integration and communication between various devices and users. Generally, IoT web can be described as a three-layered system [7]. First one is physical unit, typically a type of sensor that collects data from environment. Second component is responsible for wireless distribution of data to central computing unit where collected info are stored and processed. Lastly, application layer on its interface visualizes processed data and can sometimes offer operational options or solutions to the user [15]. Because of its adaptability IoT-based system are more frequently being applied in different port segments. In terms of navigational safety and environmental control inside port areas, maybe the best example of IoT application is novel smart buoy concept.

As a system integrated in IoT network, smart buoy is technological solution that has function of a sensor, designated for data collection in the marine environment. Depending on the design and specialized purpose, it can be able to monitor traffic and hydrometeorological conditions, sample the water and communicate with its surroundings.

This paper is arranged in five different sections that explore the design and role of smart buoys in traffic and environment monitoring. Section 2., divided in two Subsections, elaborates general concept of smart buoy system, their design and technologies used for development. Section 3 examines various application of smart buoy devices. Two Subsection of Section 4. provide detailed insight in design and application of the Marine Eye, first smart buoy concept deployed in region. Finally, in Section 5. Conclusion and observation of current and future smart buoy concept benefits are provided.

2 SMART BUOY DESIGN

To reduce navigational danger and the negative impact of the maritime transport industry on the environment, port communities are continuously developing ways to monitor maritime traffic with a goal of collecting relevant data that can be used as an input values in different models of risk assessments. It is essential to gather information on large enough spatial and time scales to assure effective monitoring of port environment and to be able to produce solutions to reduce the negative impact of human activity on these ecosystems [2]. In order to achieve that, a number of ports rely on AIS transponder for marine traffic monitoring, but most recently, this tracking method is supplemented with new smart buoy device. As a part of IoT system, buoy-based coastal monitoring systems are suitable for surveying and controlling the status of waters, as installation and maintenance are simple to perform and not very costly [2]. Also, they can have the technical means that enable sampling and variable adjustment of sampling frequency [1].

2.1 *General configuration, components and main features of smart buoy concept*

Like many other smart systems based on the IoT technology, general concept of smart buoy devices can be defined as a three-layer structure. Sensor layer is responsible for gathering data from physical environment and its transformation into digital form. This type of sampling is performed by various types of specialized sensors for traffic or environmental survey. Primary function of connection and data preparation layer is to transfer gathered information from the sensor layer, using different wireless communication technologies, in order to be received, stored and processed by central computing system. The goal of this process is to secure wireless and automatised data transmission without any deficiencies and to prepare collected info for next phase. Also, different communication networks can be used, depending on the needed of coverage area. Application layer provides interface that contains the possibility of viewing the collected data and sometimes tools for remote management of operations and processes. Commonly, specialised software is compatible with different operating systems and can be accessed through smart devices. General smart buoy composition concept is illustrated in Figure 1.

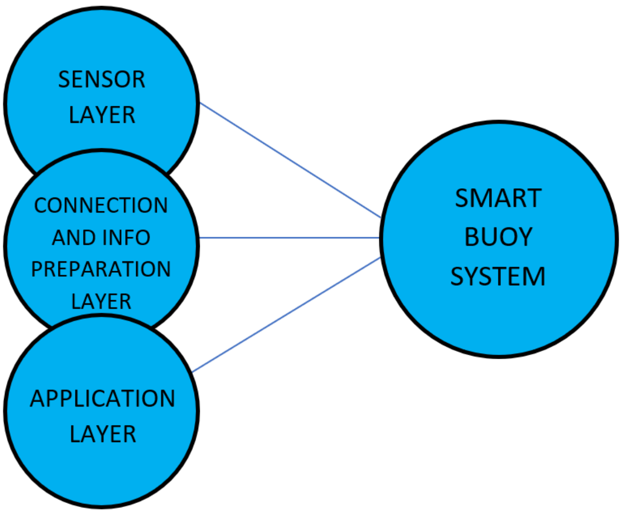

Figure 1. General three-layered concept of smart buoy devices

Although, the conceptual arrangement of smart buoys can be universally described as three-layered structure, it's the design depends on specific operational purposes. So, to apply buoy-based monitoring system in port areas with a goal of collecting traffic and environment data, it should have next features:

– Wireless communication – collected data exchange via Bluetooth, ZigBee, Wi-Fi, etc. for low-range transmission or WiMAX, GSM, GPRS for long-range transmission [11]
– Energy consumption – achieving power efficiency by autonomous activation of sampling processes and power management system
– Autonomy – possibility of continuous and real-time environment and traffic tracking
– Remote access – remote management of operations and processes (sampling when required, external communication, repairing if system error occurs, etc.) for end-user via application interface
– Energy harvesting – enabled to derive energy from external sources. Equipment type should correspond to characteristics of available ambient energy sources.
– Cost effectiveness - system design that assures efficient resource utilization to reduce the costs of manufacture, deployment, operation and maintenance [2]
– Simple deployment – easy to install without requiring any onsite configuration and specialist equipment and can ideally be done by a single person. Also, simple transferability of the device should be enabled [10]
– Redundancy – if system encounters break-down of connection or low battery power it should be complemented with the extra components to ensure no data loss and continuous sampling until repaired
– Integrity – device case has to be water tight and highly resistant against complex marine environment. Corrosion and biofouling protection is also required. Automatized cleaning of sampling and monitoring systems should need to be installed to avoid frequent maintenance interventions. Also, strong stability against adverse atmospheric conditions needs to be obtained [2, 11]
– Maintenance - the design of the buoys should facilitate access to their components for maintenance and eventual dismantling. On top of that, system support for remote access has to be enabled [2]
– Modularity – the device should be designed in a way that enables additional modifications for improvement of its current components and adaption to the new technologies. System should be flexible and customizable enough to accommodate heterogeneous devices and communication technologies[2, 10]

Although, general concept of smart buoy system displayed in Figure 1. should incorporate all features that define individual device, the technology and equipment implemented for completing main operations can vary.

2.2 *Common physical, communication and central computing technology*

The right choice of marine environment monitoring sensors depends on the user requirements of deployment area, measurement range, accuracy, resolution, power consumption, and intended deployment time [11]. For monitoring port related traffic activities and sounding environment, camera system should be integrated inside waterproof case. To ensure accurate meteorological conditions that could negatively affect navigational safety, physical parameters, such as temperature, humidity, pressure, wind speed and wind direction should also be continuously monitored [11].

For data transferring from physical smart buoy component to control centre that is responsible for its processing, system must use at least one of various wireless communication technologies (WCT). Wireless communication has different standards, frequencies and transmitting distances, so there are several options for data transferring. For example, Wi-Fi, ZigBee, Bluetooth, LTE, etc. are often used for smaller distance, while WiMax, GSM or GPRS are used for long range communication [11]. Wi-Fi is a wireless network of exceptional similarity to a wired one, with the difference that data transmission cables are not required in this way [5]. It operates at a frequency of 5.8 GHz and speed of 7Gbps. ZigBee is low power consumption device. It operates at 868 MHz and data is sent using a packet of size of max. 1024 bits. Also, it is possible to establish network with more than 60,000 devices connected to network. Figure 2. shows ZibBee network.

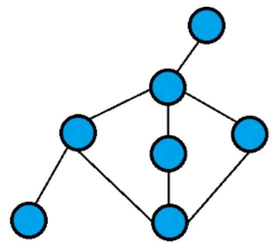

Figure 2. ZigBee network topology [5]

Bluetooth is a low power technology. It is suitable to transfer data between two or more devices. There are two types of this technology – Basic rate/Ehchanged and Bluetooth Low Energy (BluetoothLE). The LTE (Long Term Evolution) is based on IP protocol. It supports IPv4 and IPv6 standard [5]. The speed of data transfer with this technology can be higher than 1 Gbps. WiMax enables stable data transfer speeds of up to 40 Mbps, and in the experimental phase the speed is up to 1 Gbps [5]. Also, WiMax can cover more are then previously mentioned WCTs but more importantly it can help service providers to meet many of the challenges they face due to increasing operational demands without discarding their existing infrastructure. This is possible because of its ability to seamlessly interoperate across various network types [19]. GSM is standard system for communication via mobile telephones incorporating digital technology. In addition to the fact that it covers wide areas, GSM offers low-cost, high-quality and compatible communication net [11, 13]. Since, GPRS is based on GSM standards it offers similar futures but on the 2G and 3G standards that enable faster and constant communication.

Table 1. shows a comparative overview available data transfer solution. According to the presented

data, but also some technical details presented previously, it is evident that none of the available technologies is solution without shortcomings. This is due to short range, insufficient number of base stations, low data transfer speed or high-power consumption [5]. Based on this, it is possible to encompass two technologies, which synergistically provide the possibility of networking and monitoring many types of buoys on different micro locations.

Table 1. Comparison of available data transfer solutions [5, 11]

Technology	Frequency	Range (max.)	Speed
Wi-Fi	2.4 GHz, 3.6 GHz, 4.9 GHz, 5 GHz, 5.9 GHz	100 m	1-54 Mb/s
WiMAX	3.5 GHz	50 km	75 Mb/s
LTE/LTE-A	2.5 GHz, 5 GHz, 10 GHz, 15 GHz, 20 GHz	30 km	300 Mb/s (DL) 75 Mb/s (UL)/ 1 Gb/s (DL) 500 Mb/s (UL)
Bluetooth	2.4 GHz	100 m	1 Mb/s
ZigBee	2.4 GHz	20 km	250 kb/s
WiMAX	2–11 GHz	<10 km	<75 Mb/s
GSM	850/900/1800/ 1900 MHz	Dependent on service provider	9.6 Kb/s
GPRS	850/900/1800/ 1900 MHz	Dependent on service provider	56–144 Kb/s

Using any of the above communication solutions, for the proper operation of smart buoys it is crucial to establish a complete system, whose primary function is to collect and display data or signals that are sampled on individual buoys.

As it is illustrated in Figure 1. complete smart buoy system should incorporate physical equipment of buoys (PLC - Programmable Logical Controller, sensors, etc.), communication infrastructure that operates through different WCT and control centre. If there are several control centres, they are connected to a VPN (Virtual Private Network) network based on TCP / IP technology, while the buoys are connected to the centre using one of the mentioned WCT technologies previously mentioned.

Data collected from smart buoys are stored in databases and depends on type of equipment installed and the primary purpose of each buoy, such as:

- Video surveillance of maritime traffic
- Measuring the density of maritime traffic at a particular location
- Vessel identification
- Seawater sampling
- Pollution control

Control centre of smart buoy systems is equipped with a specialized computer application such as SCADA (Supervisory control and data acquisition), web-based SCADA or similar applications developed specifically for this purpose. Modern SCADA systems enable the display of buoy data at more different locations and on a few types of platforms, as shown in Figure 3.

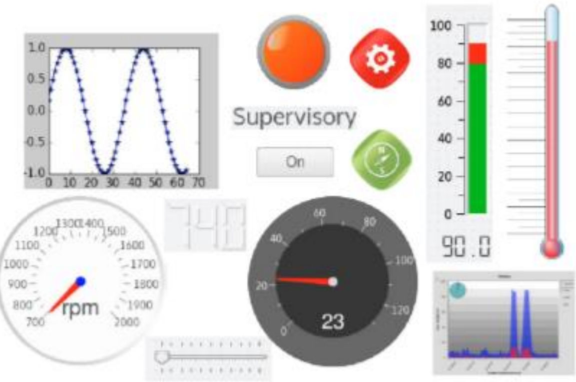

Figure 3. SCADA computer application [6]

As mentioned before, described physical, communication and central computing component are key elements for development of a smart buoy system, but the diversity of monitoring applications makes differences between smart buoy designs.

3 GOOD PRACTICES OF DIFFERENT SMART BUOY APPLICATIONS

Wireless sensor networks are a highly promising technique for monitoring marine environments because of their advantages of easy deployment, real-time monitoring, automatic operation, and low cost [11]. So, this chapter explores and describes good examples of some smart buoys in the world, regardless of the basic application of each of them.

The following is an example of meteorological add-ons installed in Sidney - Australia, listed by AXYS. The buoy was installed at the micro-location of the port of Port Aux Basques at a depth of about 50 meters. Its main purpose is to monitor meteorological and oceanographic data in order to support operational efficiency, safety and other segments important for maritime transport [18]. The same data are transmitted in real time, equipped with devices that have the ability to measure different atmospheric and surface conditions such as wind speed and direction, humidity, temperature, dew point, pressure and more. In addition to the above, the buoy is also equipped with navigation information systems such as AIS, which gives it the ability to directly transfer data to ship bridges. Figure 4. shows meteorological buoy.

Figure 4. Meteorological buoy

MariaBox buoys that have been installed in Cyprus - Spain, are used for the purpose of wireless analysis of the marine environment for the control of chemical and biological pollutants [12]. Some of the more significant features of the device are high sensitivity, the ability to repeat measurements over a long period of time and the ability to stand permanently at sea. Also in the final stage of development is the upgrade of the buoy with bio sensors for chemicals created by human influence and micro algae toxins relevant to shellfish, fish and the marine environment. The system will be implemented at micro locations in Cyprus, Ireland, Spain and Norway at depths of 30 m. The MariaBox buoy is shown in Figure 5.

Figure 5. MariaBOX buoy

Traffic and environment monitoring smart buoy system shown in Figure 6. was deployed in Stockholm Norvik Port.

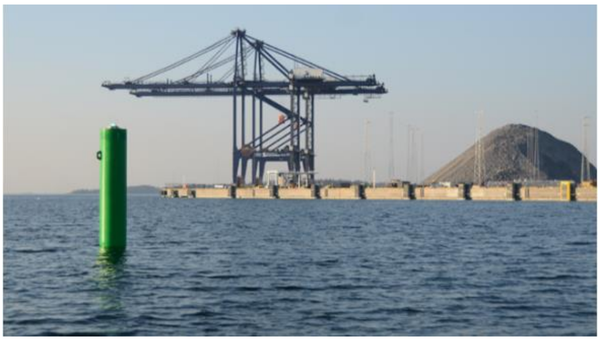

Figure 6. Smart buoy in Stockholm port

The buoy is an energy efficient navigation beacon with technology for position monitoring and remote adjustment of the buoy's light intensity, which changes depending on the weather [17]. The buoy is 0.8 meters in diameter and is about 10 meters high, of what 3.5 meters can be seen above sea level. It is equipped with LED lights and batteries with a capacity sufficient for five years of continuous operation. A 25-meter-long anchor line, connected to a 14-ton concrete block, secures the buoy on a sloping seabed. It is made of polyethylene plastic, which is an excellent choice of material for buoys because maintenance is not required and the longevity of the material in the sea is guaranteed. The plastic is resistant to various ice and weather conditions, retains colour and does not wear out due to seasonal variations or UV radiation. The slippery surface is less prone to marine fouling, and the buoy does not need to be lifted for maintenance such as sandblasting and painting, as is the case with steel buoys that need overhaul at least every two years.

The plastic buoy is lighter than a similar steel buoy, so it can be installed and maintained by smaller ships and lifting equipment. As the inclinations of the buoy are smaller than the inclinations of a similar steel buoy, the required weights and anchor chains may be smaller. In addition, the chain consumes less, which will save hundreds of meters of chain over the life of the buoy. It is equipped with a remote control and monitoring system so that maintenance can be planned based on accurate real-time data transmitted from the buoy.

Information such as battery power level, exact buoy position and other possible monitored functions are available via a web browser. The said surveillance system is equipped with a battery with a capacity sufficient for continuous operation for five years, and the manufacturer is working on the development of attack systems related to alternative energy sources.

4 MARINE EYE - NEW NAVIGATIONAL SAFETY AND ENVIRONMENTAL MONITORING SMART SOLUTION

Supervision and management of maritime domain has exceptional strategic interest for all maritime countries, including the Republic of Croatia, mainly due to the fact that maritime domain is one third of Croatian territory. The lack of high-tech solutions on the market that can improve safety on the maritime domain was the motivation to construct and deploy a new smart buoy system called Marine Eye. This system is designed as a combination of computer vision and artificial intelligence technology with the hardware solution [16]. The project initiator is a local company from Split. Technical and logistical support for the project is provided by two other companies based in Split, one specialized in the design and manufacture of electronic devices, and the other specialized in the maintenance of maritime domain. The project was recognized as innovative by city and county public organizations as well as a state agency specializing in investments in innovative projects. Through their public tenders for co-financing innovative projects Marine Eye project received funds that helped developing a prototype. Professional support for the project was provided by the Project Office of the University of Split [16].

4.1 *Systems design*

The Marine Eye system is intended for continuous monitoring of the number of vessels on a certain part of the sea in real time. The system, presented in Figure 7., consists of two parts: 1) a central software system for data processing and 2) an electronic device equipped with a specialized system for collecting and sending data. The electronic device operates autonomously because it has its own power supply consisting of a solar panel and an associated battery. The electronic device also has the software for automated periodic production of photos at an angle of 360° and sending these photos to a central computer system. The electronic device is designed so it can be easily set on a custom buoy which is then placed on the certain part of the sea surface to be monitored.

Figure 7. Electronic device - Marine Eye, 3D model

The development of the electronic device began with the development of the so-called pre-prototype of limited possibilities. That is actually a common action in the process of developing more complex electronic devices during which unforeseen circumstances often occur, but also errors that are then corrected when making a prototype It happens very often that components ordered from suppliers online do not correspond to the characteristics listed in the available documentation and catalogues. Therefore, it is necessary to perform your own testing of components to make sure of their functionality. The pre-prototype phase revealed errors in the initially ordered cameras that were supposed to generate 360° photos. Therefore, new cameras were ordered that proved to be functional and a total of seven cameras were installed in order to generate 360° high quality photos. In addition to making the electronic device needed to take photos, it was necessary to design an adequate waterproof case that would then be simply applied to the buoy. The case consists of a base in which the battery and antenna were located, as well as a cover for powering and charging the battery. A transparent wall cover was attached to the base of the case, in which the device for taking photographs was placed [16].

Solar power supply, enabled by panels placed on the buoy, with wireless data transmission allows full autonomy of the system. Data collected from an electronic device, which is mounted on a buoy, is stored and processed in a central computer system. The central computer system through a specially adapted interface offers the possibility of viewing the collected data on the daily basis of which certain trends can be monitored, and also certain statistics can be made. The development of the software system was divided into three parts:

- a vessel recognition algorithm
- a system for receiving and processing data collected from the electronic device attached on the buoy
- an application interface for reviewing the collected and processed data

Marine Eye system is constructed in a way that secures resistance from various movements caused by wind and waves. The system works by sending high-resolution photos taken by a seven-camera system on an electronic device attached on a buoy to a central computer system using GSM technology. By processing photographs obtained from an electronic device attached on a buoy, vessels are detected using computer vision technology. The application for potential users of the Marine Eye system is available on personal computers, tablets and smartphones [16].

4.2 *Systems application*

As part of the research and development process, with the technical and logistical support of a local specialized company for the maintenance of maritime domain, a prototype of the Marine Eye System was installed in July 2020 in the port in front of the city of Trogir. An electronic device is applied to the existing buoy. Certain modifications have been made to the case of the electronic device, the solar panel as well as the buoy itself can fit well together and in order to make the system functional [16]. Installation process and its final position are illustrated in Figure 8. and Figure 9.

Figure 8. Installation of an electronic device of the Marine eye system on a buoy in the port of Trogir

Figure 9. Marine eye device and solar panels attached on a buoy in the port of Trogir

After several months of testing the prototype, it was concluded that over the certain period sufficient quality photos are generated from an electronic device attached on a buoy despite the negative environmental influences, such as sea waves. It was concluded that the whole process can be successfully repeated. It was also concluded that the central software system based on the delivered photos recognizes the vessel with high quality. Prototype testing has shown that the Marine eye system is perspective solution for monitoring the sea surface.

Since testing phase had shown that Marine Eye can be a reliable source for traffic data gathering through systems integrated autonomous cameras, now focus is on quantification and analysis of collected info. Data captured by systems cameras is processed by a vessel recognition algorithm, and after software showed adequate precision of its recognition ability, the info that is still being collected should in the end represent relevant data set of port traffic and its dynamic. Valid, real-time and complete information about marine traffic with its quantification and segregation makes basis for future development of precise gas emission inventory and navigational safety assessments. That is especially important for smaller ships that do not have AIS transponder installed on board. This category of ships has quite vague contribution in navigational safety and air pollution aspect of port areas, and by completing a survey through Marine Eye it will be possible to have an insight for all groups of ships that navigate in port area. With features that can improve, Marine Eye has a bright future.

As already mentioned, the Marine Eye system was initially intended to monitor vessels in a certain part of the sea surface. This system can be used in the segments of maritime safety and sea transport. The Marine Eye system can be capable for real-time detection that will contribute to a further pollution prevention of the sea surface, illegal anchoring and illegal fishing. The system can also be applied in the field of defence and maritime security. The data collected by the Marine Eye system can be used by specialized scientific institutions in the preparation of maritime studies.

5 CONCLUSIONS

Application of smart buoy systems inside port approaches and basins allowed continuous and automatised data gathering of traffic and environment. This novel, IoT-based device improved ports navigational safety and ecological standards by providing real-time and on-the spot survey of shipping processes and its influence on the environment.

As can be seen from the examples of different smart buoy applications, the benefits of integrating smart buoys in port systems are significant. The use of such buoy-based systems offers the possibility of up-to-date data collecting and autonomy of work, which creates savings in time and money. But more importantly, it provides users with a detailed and relevant access to the information on which the assessment of maritime safety and the port environment is based. In addition, the flexibility of technological solutions in creating a smart buoy architecture allows for a large number of different options for its design and application.

Deployment of the Marine Eye system in Trogir port approach channel was initially intended to monitor vessels in a certain part of the sea surface. After conducted trial process, it was concluded that system can generate photos of sufficient quality despite the negative environmental influences, such as sea waves. This system can be used in the segments of maritime safety and sea transport by enabling real-time monitoring and offering data for development of navigational risk assessments. The Marine Eye system will be able to detect and also prevent further pollution of the sea surface, illegal anchoring and illegal fishing, and with information about traffic it is possible to conduct pollution inventories of port area. Device can also be applied in the field of defence and maritime security. Finally, the data collected by the Marine Eye system can be used by specialized scientific institutions in the preparation of maritime studies.

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