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Assessment of selected remote sensing methods in detecting and tracking marine pollution

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Abstract

This paper discusses the use of satellite tracking during an environmental disaster at sea, and it assesses the possibility of using remote sensing imagery captured by satellites using multispectral cameras and synthetic-aperture radar (SAR). This study is based on scientific literature and satellite tracking of the *X-Press Pearl* container ship disaster, which involved the EO-Browser platform. The purpose of this paper is to assess selected remote sensing methods for detecting and tracking marine pollution. The first part of the paper discusses satellite tracking of the *X-Press Pearl* disaster. The second part focuses on evaluation of the quality of remote sensing imagery from satellites and aircraft, when taking weather conditions into consideration. It should be noted that the research was conducted in real time when the incident occurred. News about the accident was also tracked in real time, allowing for a thorough analysis of the incident and, thus, an assessment of the different sensing systems. Although research on such disasters is crucial for the protection of the marine environment, scientific literature on this topic remains limited. This research area is very important for the protection of the marine environment, in the context of looking for solutions to these issues.

Introduction

The existing maritime transport arrangements, despite using state-of-the-art technologies on ships, are not neutral to the marine environment. In recent years, despite the use of the latest safety systems, there have been several major environmental accidents on marine waters resulting in immense environmental hazards. Many of the contaminated bodies of water and land areas are expected to take years to recover to their full biological potential. Unfortunately, the current understanding of environmental approaches and technologies is still deficient, even in the newest ships. Even modern ships pose a potential threat to the aquatic ecosystem (Deja, Ulewicz & Kyrychenko, 2021). It should be kept in mind that an incidental fuel or oil spill from a vessel during a collision, grounding, or system malfunction is likely to cause irreversible changes to the human ecosystem. Currently, oil pollution remains the greatest of all threats posed by watercraft (Deja, Kabulak & Kaup, 2018). In view of the above, it is very important for the international community to undertake joint actions, with respect to state-of-the-art technologies, to directly contribute to reducing the adverse environmental impact of maritime transport.

One such international area of joint action is the monitoring of bodies of water, which plays a very important role in combating and preventing pollution in the marine environment. Remote sensing is particularly significant, as it can be used to observe vast areas (Hafeez et al., 2018). In broad terms, monitoring is understood as a process of repetitive measurements, for various defined purposes, of several elements of the environment according to pre-arranged schedules using available methodologies (Economic Commission for Europe, 2006). Research on the efficiency of the latest marine water monitoring technologies is very important in many respects. Reliable monitoring systems, above all, contribute to an improved organization of operations of different services with respect to prevention, as well as coordination between rescue services.

Materials and methods

The objective of this paper is to analyze selected satellite sensing methods for the control and detection of marine environmental pollution. The study is divided into four main stages (Figure 1). The first part analyses the literature on remote sensing solutions, which are currently used in environmental operations, in particular oil spills, as well as the causes, course, and consequences of the *X-Press Pearl* ship disaster. The second stage involves a study using the EO Browser – Sentinel Hub, a web-based platform for satellite sensing of oil pollution from the *X-Press Pearl* disaster. Images captured by two satellites of the Copernicus European Earth Observation Programme were downloaded from the platform. The first satellite, Sentinel 1, is in sun-synchronous orbit at an altitude of 693 km (ESA, 2021a), it is equipped with a C-band SAR radar. The second, Sentinel 2, is in sun-synchronous orbit at an altitude of 799 km (ESA, 2021b), it is equipped with a MultiSpectral Instrument.

Subsequently, based on the study inputs collected (observations were carried out between 20 May 2021 and 17 June 2021), a quality assessment was performed on the satellite images from the 2021 maritime disaster in the Laccadive Sea. The analysis relied on a three-step scale developed based on the literature, resulting in three quality levels:

- good quality (G) – the image is clear, there are no obstructions caused by visibility issues or cloud cover, changes or objects appearing on the water surface are observable, such as oil spill, fire, plankton, and marine vessels.
- medium quality (M) – the image includes some cloud cover and deteriorated visibility, changes or objects appearing on the water surface may be poorly visible.
- poor quality (L) – the image is obscure and unclear, there are obstructions caused by reduced visibility and cloud cover, changes or objects appearing on the surface of the water body are unobservable.

Based on this analysis, a detailed assessment of each satellite system was carried out as part of the summary.

Theoretical background

The purpose of remote sensing is to obtain information about the marine environment, using specialist equipment, without the need for human contact with the remote-tested subject (Khorram et al., 2012). Data can be obtained from land-based towers, ships, aircraft, drones, satellites, and underwater vehicles. The applications of remote sensing include preparing documentation to enforce marine environment protection regulations, surveillance of bodies of water, collecting evidence during environmental disasters, determination of trajectory, pollution mapping, and adjusting pollution prevention measures (Fingas & Brown, 2015). During remote sensing activities, it is important to obtain information in real-time, based on which inspection services can immediately identify the position, status, and type of threat, and then proceed with rescue operations. It should be noted that the remote sensing systems, which are currently in use, are not perfect. Their use entails several technical problems. For example, not

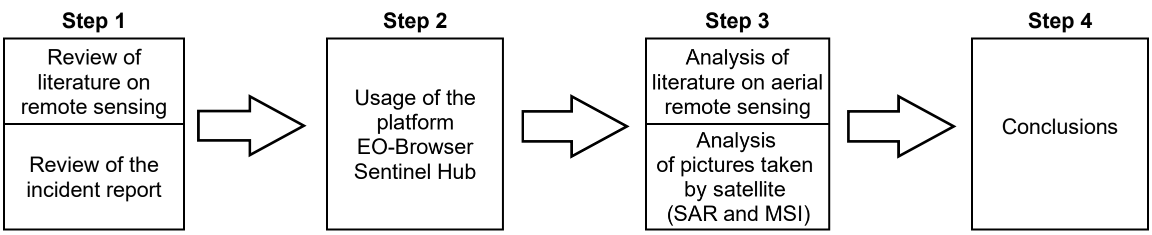

Figure 1. Research framework in four steps

Table 1. Remote sensing equipment (adapted from Fingas & Brown, 2017)

Synthetic aperture radar (SAR)	A device with a synthetic aperture that uses aircraft motion to synthesize a long antenna for good image resolution. Enables environmental monitoring under all weather conditions and at any time of the day (Liu et al., 2019).
Side looking air-borne radar (SLAR)	A less expensive predecessor to SAR, using a horizontal antenna to create imagery, most commonly used in aerial monitoring of the marine environment (Fingas & Brown, 2017).
Microwave radiometer	The device detects differences in microwave emissivity between water and oil. It is capable of distinguishing oil spills from objects (such as seaweed), ocean currents, and rough areas of water bodies (Pelyushenko, 1995). In oil spill monitoring, it is used to determine the thickness of oil patches (Fingas & Brown, 2017).
Still cameras	Cameras, partly because of their affordability, are most commonly used in marine environment observations. They can be used to capture still images and record videos. The cameras are equipped with special filters to improve image contrast, an artificial light source, and even a GPS (global positioning systems) function. There are RGB cameras, which are the most common, as well as professional multispectral cameras (Yao, Qin & Chen, 2019).
Infrared cameras	The device detects thermal energy radiation emitted by natural elements present in the environment. It is a relatively inexpensive and safe monitoring method (Nishar et al., 2016).
UV cameras	The technique of detecting oil spills by UV cameras is no longer used. In the past, UV cameras were employed to create oil thickness maps (Fingas & Brown, 2017).
Laser fluorosensor	Sensors that, through a process of fluorescence emission, can release electronic excitation created when UV light is absorbed, making it easier to detect petroleum products. Different elements of the environment exhibit different levels of fluorescence, owing to which the lasers are able to distinguish between oily and non-oily areas without much error (Brown, 2011).

all environmental monitoring devices available on the market, such as cameras or radars, offer good marine pollution detection capability. Most standard hardware requires expensive and time-consuming modifications, as well as long data transmission and verification times (Fingas & Brown, 2015). Currently, remote sensing of the marine environment is carried out using the equipment shown in Table 1.

Satellite monitoring – the *X-Press Pearl* disaster

In the spring of 2021, an environmental disaster occurred off the coast of Sri Lanka, in the Laccadive Sea between the port of Colombo and the port of Negombo, at anchorage about 9 nautical miles from the coastline. The accident involved a newly built container ship carrying 1,486 containers, 81 of which contained hazardous cargo (including 25 tons of nitric acid).

Between 20 May and 17 June 2021, in a research effort, satellite monitoring of the event was performed using the EO Browser – Sentinel Hub web platform. Figure 2 shows partial cloud cover and smoke coming directly from the ship, which reduced the visibility of the scene (in the center of the red square). The image was captured by the Sentinel-2 satellite on 20 May 2021.

Figure 3 shows a burning ship. There is visible smoke released from it. The satellite image was

Figure 2. Smoke and cloud cover obscuring the scene (prepared with the use of EO Browser)

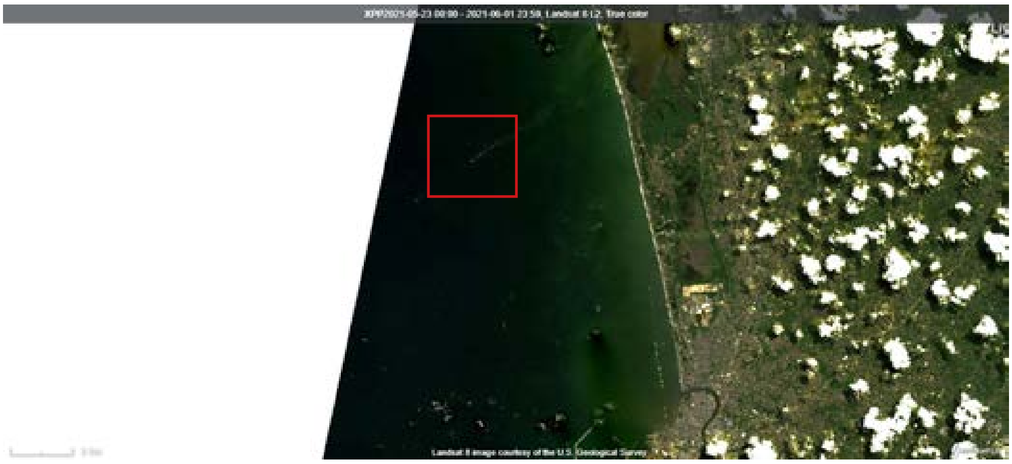

Figure 3. A smoking ship (prepared with the use of EO Browser)

Figure 4. Sheen at the accident scene (prepared with the use of EO Browser)

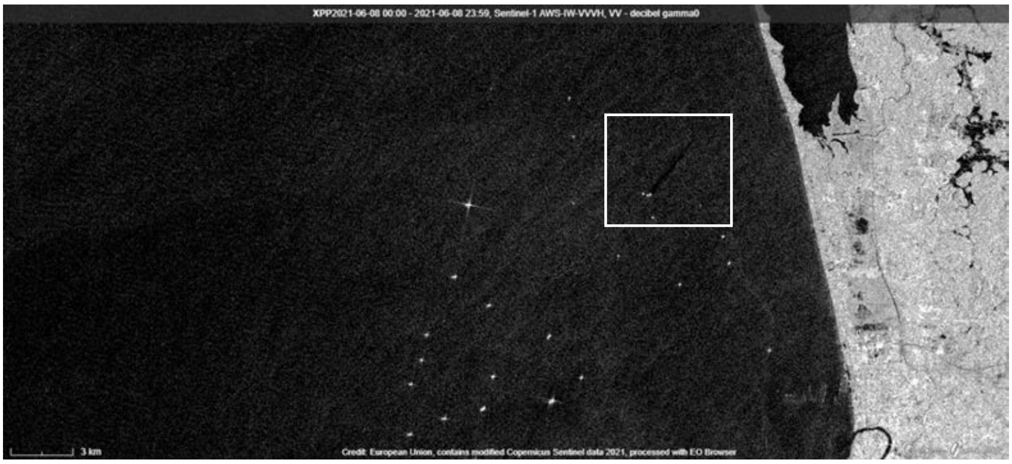

Figure 5. Glow from the ship (prepared with the use of EO Browser)

captured when no atmospheric disturbance was present. The vessel under observation is visible in the red square. The image was captured in true colors by the Landsat 8 satellite.

Figure 4 presents a single-polarized (VV) image captured by the Sentinel-1. The image is dated 27 May 2021 and features a sheen, which is marked in the white square.

Observations revealed that on 8 June 2021, the existing sheen (patch) began to move in another direction, which could have been caused by a change in wind or sea current direction. In Figure 5, within the area marked by the white square, a change of direction of the sheen is visible.

Conclusions from the accident under observation:

- In the satellite sensing images (Figures 2–5), captured using the EO Browser – Sentinel Hub via the Sentinel-1 equipped with SAR, an observable sheen appeared within the monitored area. The visible glow could imply a spill of petroleum substances into the sea, or a spill of the nitric acid that was on-board the ship in containers.
- The images captured by the Sentinel-2 do not represent the potential spill, which was shown by Sentinel-1 and SAR. However, this technology can be used to position the vessel and represent the smoke released from it.

Remote sensing – assessment of image quality considering atmospheric conditions

An image quality assessment was performed on the images from the EO Browser platform. The images were taken using a synthetic aperture radar (SAR) and multispectral camera. Both devices were mounted onto a satellite and placed into marine environment monitoring aircraft. Consideration was given, *inter alia*, to the prevailing atmospheric conditions. The cloud cover scale shown in Table 2 and the marine visibility scale given in Table 4, were both factored into the sensing process. The studies were carried out based on satellite imagery of the *X-Press Pearl* disaster retrieved from the EO Browser platform. The analysis relied on guidance from the literature on the remote sensing of marine oil pollution.

Table 2. Cloud cover scale (adapted from WPC, 2022)

Scale	Description
0/8	cloudless
1/8	sunny
2/8	scattered clouds
3/8	lightly cloudy
4/8	partly cloudy
5/8	cloudy
6/8	mostly cloudy
7/8	nearly overcast
8/8	overcast
9/8	sky obscured

Table 3 shows the relationships between the cloud cover scale and the selected marine environment monitoring method (i.e., the satellite remote sensing and the aerial remote sensing), splitting them further into SAR and multispectral camera images. The images were analyzed according to a three-step scale – good (G), moderate (M), and low (L) – as defined in detail in the *Materials and Methods* section.

Table 3. Selected remote sensing methods, which considers the scale of the cloud cover

Cloud Cover	Remote Sensing			
	Satellite – SAR	Satellite – Camera	Aerial – SAR	Aerial – Camera
0/8	G	G	G	G
1/8	G	G	G	G
2/8	G	G	G	G
3/8	G	M	G	G
4/8	G	M	G	M
5/8	G	M	G	M
6/8	G	L	G	M
7/8	G	L	G	M
8/8	G	L	G	L
9/8	M	L	G	L

Key: G – good; M – moderate; L – low

The study, carried out during an environmental accident (i.e., the *X-Press Pearl* container ship disaster), found the optimal image quality (good) was obtained from airborne SAR. The contrast was only slightly worse (moderate) in satellite SAR imagery. This is because SARs can operate at any time of day, and the reception of the radar waves is not affected by overcast skies.

When skies are overcast, the quality of the camera images is relatively poor (L-low) and limited (Müllerová et al., 2016; Müllerová et al., 2017). For airborne cameras, partial cloud cover will not affect image quality, to any great extent, due to the ability of the aircraft to move through different levels of the troposphere. As the satellite is in the thermosphere, no images of the concerned area can be captured

Table 4. Visibility scale (AM Gdynia, 2001)

Scale	Description	Range
0	very bad	0–50 m
1	very bad	50 m – 0.1 Nm
2	bad	0.1–0.3 Nm
3	low	0.3–0.5 Nm
4	poor	0.5–1 Nm
5	poor	1–2 Nm
6	moderate	2–5 Nm
7	good	5–11 Nm
8	very good	11–28 Nm
9	exceptional	> 28 Nm

when cloud cover exceeds 6/8 on the cloud cover scale. The optimum visibility of the area on satellite images is obtained when the weather is cloudless (0/8 on the cloud cover scale), sunny (1/8 on the cloud cover scale), or scattered clouds (2/8 on the cloud cover scale).

Table 5 shows the relationships between the marine visibility scale and several marine environment monitoring methods. The analysis covers both satellite remote sensing and aerial remote sensing, which are further split into SAR and multispectral camera images. As used previously, a three-step scale was employed to categorize the image quality as good, moderate, or low.

Table 5. Selected remote sensing methods, which considers the visibility scale

Visibility	Remote sensing			
	Satellite – SAR	Satellite – Camera	Aerial – SAR	Aerial – Camera
0	M	L	M	L
1	M	L	M	L
2	M	L	M	L
3	M	L	G	G
4	G	M	G	G
5	G	M	G	G
6	G	M	G	G
7	G	G	G	G
8	G	G	G	G
9	G	G	G	G

Key: G – good; M – moderate; L – low

The analysis shows that the optimum image quality (G – Good), which is required for environmental hazard monitoring (including oil patches), is provided by airborne SAR images. This is because the image quality is 'Good' up to the third level on the visibility scale. Moderate (M) image quality is only found on the zero, first, and second level on the visibility scale, as SARs can be used for observation in all weather conditions and at any time of the day. The only disturbances in the interpretation of the radar imagery of the oil spills can be caused by the roughness of the sea surface and wind speed (Fingas, 2017).

Airborne or satellite camera imagery is not capable of representing the monitored area in low visibility conditions (0–3 on visibility scale). On the other hand, this technology operates well in good conditions, i.e., 6–9 on the visibility scale. Phenomena such as fog, rainfall, or snowfall affect the quality of the images of the objects under study; these images become less clear and, thus, they are illegible (Müllerová et al., 2017). In the absence of adverse weather conditions (i.e., rain, snow, and fog), the legibility of the photographed objects improves and the environmental monitoring by the aircraft and drones becomes easier (Müllerová et al., 2017). In this case, they can be kept airborne without restrictions. The superior legibility of the images taken by the aircraft is due, *inter alia*, to the adjustable position of the airborne camera or radar, as the position of the aircraft can be controlled in flight (Pajares, 2015), while a satellite remains at a constant altitude.

Conclusions

Studies have shown that the most useful current technology to control and track marine pollution is SAR radar. Its greatest advantage, by far, is that its images can be taken in any weather conditions and at any time of the day. An additional advantage, offered by the SAR, is its ability to detect oil spills.

The multispectral camera, on the other hand, does not operate well when visibility is limited and skies are overcast, as confirmed during the tracking of the *X-Press Pearl* container ship disaster using the EO Browser – Sentinel Hub web platform. Therefore, this device is of little use in searching for oil spills on water. Furthermore, with camera imagery, it is not possible to be certain if a spill has occurred, as sheen can be caused by marine vegetation. On the other hand, it is well-suited for real-time tracking of an ongoing accident. The system can be used to represent a burning vessel, ship grounding, or collision. On comparing between a camera fitted onto a satellite and in an airplane, improved image quality is definitely obtained from an airborne multispectral camera, which is moveable.

This assessment has shown that the optimum method for remote sensing of the marine environment is monitoring based on an aircraft-mounted SAR. Aircraft can change their position and altitude in the atmosphere, which facilitates the observation of objects and improves the quality of radar imagery.

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