Overview of Research on Monitoring of Marine Oil Spill

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Abstract. Marine oil spill monitoring technology has become a hot topic of marine environmental protection. This article introduced the principles and characteristics of marine oil spill monitoring sensors, analysed the implementation methods of marine oil spill monitoring. Through the comparison of the application situation, the problems in the oil spill monitoring are drawn, finally the development of the offshore oil spill monitoring research is prospected.

1. Introduction
With the increasing demand for energy in countries around the world, many countries have turned their attention to energy development to the ocean. Although there are strict safety regulations for offshore oil development and marine ship transportation, marine oil spills still occur frequently. Once an oil spill accident occurs, it will cause serious damage to the marine ecological environment. If the oil spill occurs offshore, it may seriously affect the production and life of residents in coastal cities, and even endanger their lives. For example, on April 20, 2010, a drilling platform in the Gulf of Mexico in the United States exploded and caused a crude oil spill. Due to the delay and deliberate concealment of the oil spill, the continuous oil spill on the sea was not under control after the oil spill occurred. When the society intervened, the oil spill area on the sea surface had reached 2500 square kilometers. On July 16, 2010, a 300,000-ton tanker leaked oil in the waters of Dalian Xingang and caused an explosion of the oil pipeline, which caused pollution to nearly 50 kilometers of the sea area where the accident occurred. In mid-to-late June 2011, a serious oil spill occurred in the Penglai 19-3 oilfield in Bohai Bay. A large amount of crude oil overflowed from the wellhead, causing the area of pollution in this part of the sea to continue to expand. According to statistics from relevant departments, the area of oil spill pollution was about 840 square kilometers. On November 23, 2013, a crude oil leak and explosion occurred in the Qingdao offshore oil pipeline, causing residual oil to enter the sea, and a large area around the Jiaozhou Bay was severely polluted. On January 6, 2018, "Sangji" and "Changfeng Crystal" were launched and collided east of the Yangtze River estuary, causing the entire "Sangji" to catch fire. The "Sangji" with about 140,000 tons of oil burned. It sank after 8 days and 8 nights, causing a huge oil pollution accident. Marine oil spill monitoring can provide emergency response plans, provide legal basis and guarantee for the assessment and identification of oil spills, and is of great significance to social and economic development, navigation and transportation safety, resource protection, and marine strategic safety.
2. Oil spill monitoring sensor

2.1. Visible light sensor
The visible light sensor monitors oil spills based on the characteristic that the surface reflectivity of the oil film is significantly greater than the emissivity of seawater in the visible light band with a wavelength of 390-760nm. This type of sensor uses a camera or video camera to obtain images of the water surface, and combines digital image processing technology to identify oil spills. It has a low cost and is widely used. Its shortcomings are that it is easily affected by sunlight and wind, and its reflectivity is generated under sunlight, so it can only be used during the day. In addition, seagrass and darker coastlines are sometimes mistaken for oil by visible light sensors. Visible light sensors have now been widely used and are easy to carry on aircraft. The visible light sensor is low in cost and easy to use, and is usually used for oil spill monitoring in offshore areas[1-3].

2.2. Infrared sensor
The floating oil on the sea absorbs solar radiation and radiates energy outward. The heat is mainly concentrated in the infrared hot zone (8-14μm). In this waveband, the emissivity of oil is lower than that of water. Therefore, compared with seawater, the area of the infrared hot zone is larger, so oil can be identified. Thick slick oil absorbs more radiation and is hot in the thermal infrared region. Medium-thick oil is colder in this region, but gloss cannot be detected in the thinner thermal infrared region. Studies have shown that thermal infrared remote sensing can detect the relative thickness of an oil film of approximately 20μm-70μm, but cannot detect oil emulsions in water. Because the emulsion contains 70% water, and the thermal properties of the emulsion are similar to sea water. The heat radiation of seagrass and coastline is similar to that of oil, which can easily lead to erroneous detection of oil[4-8]. Since the oil and sea water have been radiating thermal infrared rays to the outside world, thermal infrared remote sensing can monitor oil spills in all weather conditions and without light.

2.3. UV sensor
The ultraviolet sensor uses the reflected light of ultraviolet light to detect oil spills. In the ultraviolet wavelength range, the reflectivity of oil is stronger than that of water, and even a very thin oil film has a strong reflectivity. This sensor can detect ultra-thin oil films even smaller than 0.1mm, but cannot detect oil films thicker than 10μm. It should be noted that the ultraviolet image recognition can only provide the relative thickness of the oil slick, and the detection results are affected by wind, sunlight and sea weeds. Since the UV image is based on reflected light, it cannot work at night. Ultraviolet remote sensing is very sensitive to the identification of thin oil film. If the ultraviolet and thermal infrared remote sensing are integratedly designed, the relative thickness of the oil film in seawater can be obtained.

2.4. Radar
Radar is an active sensor that operates in the radio wave area. The electromagnetic waves emitted by the radar reflect capillary waves when they hit the sea surface, and then obtain a bright image of the sea water. If there is oil slick on the sea surface, the tension of the sea water will decrease, and the Bragg scattering of the incident electromagnetic waves by some capillary waves and gravity waves will be prevented, making the waves at the oil film smoother than those without oil, resulting in weaker scattered echo signals received by the radar. The result reflected on the image is the phenomenon that the oil spill area presents a dark inner edge and a bright edge. Therefore, in the captured bright image, the radar can detect the presence of oil as a dark part, and realize the detection of a large area of oil spill. Qu Haichao used the support vector machine algorithm to identify the characteristics of marine oil spills. Xu Jin and others used navigational radar to use methods such as coordinate conversion, map projection, spatial registration, dynamic analysis, and spatial element generation to extract large-scale oil spill areas at sea[9-12].
2.5. **Microwave**

Microwave refers to electromagnetic waves with a wavelength between infrared and ultra-high frequency, which is suitable for the detection of oil slick on the sea surface and the measurement of oil film thickness. O’Neil et al. proposed in 1983 that the sea water in the ocean emits microwaves, and the oil spill area emits a stronger microwave signal than the sea water itself. The emissivity of sea water is about 0.4, and the emissivity of oil is about 0.8. In the displayed image data, the oil spill area presents a bright signal, and the strength of the signal is related to the thickness of the oil film. Zheng Quanan analyzed the microwave radiation mechanism of oil films of different types and thicknesses in a laboratory environment. Feng Aimei studied the relationship between the microwave emissivity and thickness of various oil films in the environment of the "gray body chamber". The disadvantage of MWR (microwave radiometer) lies in its low spatial resolution. With MWR, only oil films with a thickness of about 50 μm to several millimeters can be detected.

2.6. **Laser fluorescence**

The principle of the laser fluorescence sensor is to irradiate ultraviolet light on the oil liquid, and some components in the oil absorb energy and activate electrons and emit fluorescence. Other substances in seawater do not have such properties, so fluorescence can be used as the detection feature of oil. The spectral distribution and fluorescence intensity of different oils are different. Therefore, the laser fluorescence sensor can identify slick oil in seawater. This sensor is the only way to detect oil spills in icy and snowy weather conditions. For long-distance induced fluorescence spectroscopy, a laser is basically used as the excitation light source. The laser fluorescence system can use Raman scattering to estimate the thickness of the oil film. It has great application potential in oil spill monitoring. It can also distinguish between seaweed and oil in seawater. It is an effective tool for various types of oil pollution monitoring. Chen Peng et al. conducted an in-depth study on the types of oil spill based on the principle of laser fluorescence detection, using a combination of curvelet transform and support vector machine (SVM). Based on the principle of laser-induced fluorescence, Liu Xiaohua and others used principal component analysis combined with cluster analysis to achieve rapid identification and detection of engine oil. With the help of laser fluorescence induction method, Han Xiaoshuang and others adopted a support vector machine (SVM) model to realize the identification of crude oil.

2.7. **Laser Acoustic Oil Thickness Sensor**

The laser acoustic oil thickness sensor detects the oil slick on the sea surface according to the acoustic properties of the oil. The laser acoustic sensor is an active sensor that can operate day and night. Environment Canada and the National Research Council of Canada have conducted research and development on oil thickness laser ultrasonic remote sensing (LURSOT) sensors. The time required for the ultrasonic wave from the ultrasonic remote sensor to propagate in the oil is measured by three lasers, and the oil thickness is calculated based on the measured propagation time. The experimental results of Brown and Fingas using the LURSOT sensor to measure oil thickness show the great potential of this sensor. It should be noted that the laser acoustic oil thickness sensor is large in size, expensive, and cannot work in fog or cloud weather conditions.

| Sensor type         | Error detection | Oil film thickness | Spatial resolution | Weather condition | Run all day | Horizontal range |
|---------------------|-----------------|--------------------|--------------------|-------------------|-------------|------------------|
| Visible light sensor| When seagrass and coastline are dark | No                 | High               | Cloudless         | No          | Middle distance   |
| Infrared sensor     | Seagrass and coastline near relative thickness | Relative thickness | High               | Cloudless and    | Yes         | ±250m             |
| UV sensor           | Wind, sun and   | No                 | High               | Dense fog         | No          | ±250m             |
|                    | seaweed | Relative thickness | High | There are requirements for the atmosphere | Yes | ±30 km |
|--------------------|---------|--------------------|------|------------------------------------------|-----|--------|
| Radar              | A lot of interference |                    |      |                                          |     |        |
| Microwave          | No major interference | under certain conditions | High | There are requirements for wind speed | Yes | ±250 km |
| Laser fluorescence| Identify oil in any context | 50 µm to mm level | High | Weather except heavy rain | Yes | ±70 km |
| Laser Acoustic Oil Thickness Sensor | low | Yes, <20 µm | High | Can't penetrate clouds and fog | Yes | Close range |

### 3. Means of oil spill monitoring

#### 3.1. Satellite monitoring

Satellite remote sensing has the characteristics of wide coverage, convenient monitoring, low input cost, and easy analysis and processing of its image data, which is highly valued by researchers. For example, from 1972 to 1975, the United States, through cooperation with European countries, obtained remote sensing data of the sea surface through satellites, monitored and evaluated the oil pollution in the Mediterranean region, and finally determined the area, spread speed and drift direction of oil pollution in the sea area. As early as 1985, the United States used satellite remote sensing image data to carry out monitoring experiments on the oil spill in the southeastern waters of Assateague Island, Virginia, and estimated the area of oil pollution and inferred the source of the oil pollution. At present, satellite monitoring methods have been widely used, but due to the small imaging scale and low spatial resolution of satellite remote sensing, its application in marine environment monitoring is limited to a certain extent. In recent years, satellite remote sensing technology has developed rapidly. For example, Globe Company launched the World View-3 satellite in August 2014, which can produce 8-band short-wave infrared images. In May 2018, China launched a remote sensing satellite with high spectral resolution, with a thermal infrared spatial resolution of 40 m. With the continuous improvement of remote sensing satellite image resolution and data transmission rate, how to accurately identify marine pollutants and targets from massive satellite image data has become a hot research topic.

#### 3.2. Onboard monitoring

Airborne monitoring is a means of monitoring oil spills in the air using aeronautical tools such as helicopters and airships as sensor-carrying tools. Airborne monitoring has the advantages of sensitive and accurate monitoring and high resolution, and has developed rapidly in the application of oil spill monitoring. Because the aerial observation is mobile and flexible, it is suitable for large-scale inspections and key area excavation, and the airborne monitoring can be flexibly equipped with various types of sensors such as microwave, infrared, ultraviolet, fluorescent lidar, etc., to obtain all the information of the oil spill at the accident site in time. Airborne monitoring is now widely used in marine environmental monitoring. At present, as a new direction for the development of airborne monitoring, UAVs have reliable performance, can carry a variety of high-resolution detection equipment, have high mobility and low-cost advantages, and have been used in the fields of ecological environment and coastal zone monitoring. Putting it into use, I believe it will play a huge role in remote sensing oil spill emergency monitoring in the future.

#### 3.3. Shipborne monitoring

Onboard oil spill monitoring is to carry monitoring sensors on board and carry out oil spill monitoring while sailing. Compared with satellites and airborne means, shipboard is easy to operate, has high resolution, and can work in various weather conditions. The shipboard navigation radar can withstand...
severe weather conditions and can monitor the oil film on the sea surface in real time. However, the development of shipborne radar oil spill monitoring technology is limited by some factors, mainly reflected in (1) the resolution of the radar is not high, and it is often difficult to accurately extract the oil film area. (2) In shipborne radar images, oil film is easily disturbed by sea ice. Except for dense and relatively fine-textured sea ice, the display of other sea ice is almost the same as that of oil film. In addition, shipborne radar oil spill monitoring is also affected by sea wave conditions. When the sea surface is too calm, the wave echo signal is very weak, and the contrast between the inner and outer areas of the oil film is low, and it is difficult to be recognized. When the sea is rough, the ship cannot sail to the vicinity of the oil spill site for monitoring.

3.4. Fixed point monitoring

Fixed-point monitoring is the implementation of monitoring by arranging sensors in lakes, piers, coastlines, rivers and other waters. The sensor for fixed-point monitoring is usually a fixed device on the wharf, or a buoy or pontoon in the offshore waters. Fixed point monitoring is mainly used for oil identification, positioning and oil film thickness measurement, including optical sensors, laser sensors, microwave sensors and electric blanket energy absorption sensors.

4. The problem

Considering the technical requirements of offshore oil spill monitoring, researchers at home and abroad have carried out a large number of studies, and the results are very rich, but there are also some problems. For example, although satellite remote monitoring can monitor the sea surface around the clock, the monitoring scale is large, and the development trend of oil spills can be predicted, but the observation repetition period is too long to monitor the specific conditions of the sea area in real time, and the spatial resolution is low, so it is only applicable for the monitoring of large-scale marine oil spills, there are large errors in the monitoring of small marine oil spills, and it is not applicable to waters near ports, sewage outlets, and rivers. The disadvantage of airborne remote sensing monitoring is that it is mainly suitable for the detection of small targets on the sea, and the cost is high, and the requirements for the meteorological environmental conditions at sea are relatively high. Especially in bad weather such as fog or rain, airborne monitoring is not allowed. Shipborne radar can monitor oil spills over a long distance, wide range and low cost, but the maritime department has very little time for cruise at night. This method is only suitable for daytime inspections and tracking and monitoring after oil spills. Affected by meteorological conditions, sailing cannot be carried out during heavy wind and waves. The fixed-point monitoring is sensitive and can realize all-weather oil spill monitoring and automatic alarm. However, it has disadvantages such as the limitation of the sensor conditions used and the relatively small monitoring area.

5. Outlook

Marine oil spill monitoring is an important issue to protect the marine environment and prevent marine pollution. At present, the technology of oil spill monitoring sensors is developing rapidly. However, a single sensor cannot obtain all the information about oil spills. Many scientific researchers have begun to use multiple sensor combinations to carry out oil spill monitoring. In addition, marine oil spill
monitoring methods are diverse, and each method has its own advantages and disadvantages. Integrating existing oil spill sensors and monitoring methods to establish a complete sea, land, air and space integrated oil spill monitoring system is the development trend of marine oil spill monitoring in the future.

6. Conclusion
This article summarized the achievements of remote sensing technology in marine oil spill monitoring in recent years, discussed and analysed the characteristics of various oil spill monitoring methods and means, and pointed out the development prospects of marine oil spill monitoring, providing references for related practitioners and researchers.

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