

A Miniaturized Optical Online Sensor for the Detection of Oil Pollution on Water Surfaces

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Summary:

Oil contamination of surface waters poses serious environmental and economic risks, even at very low concentrations. To enable early detection, a miniaturized optical sensor based on UV-induced fluorescence was developed for real-time, contact-free monitoring of oil films on water surfaces. The system employs a UV LED excitation source and lock-in signal processing to achieve high sensitivity under varying environmental conditions. Laboratory tests demonstrate detection limits below $0.1 \mu\text{l}/\text{cm}^2$ for mineral oils such as diesel, gasoline, and engine oil. Owing to its compact design, low power consumption, and robust performance, the sensor is well suited for permanent deployment in early warning networks for water quality monitoring.

Keywords: Oil pollution detection, UV fluorescence sensor, Online water quality monitoring, Miniaturized optical sensor, Early warning system

Introduction

Oil pollution of surface waters remains a major environmental concern due to its adverse effects on aquatic ecosystems, drinking water resources, and socio-economic activities. Even very thin oil films can impair gas exchange at the water–air interface, harm aquatic organisms, and promote the transport of hazardous substances over long distances in rivers and drainage systems [1,2]. Accidental spills, traffic runoff, and diffuse urban or industrial emissions contribute continuously to oil contamination, making early detection and continuous monitoring essential.

Conventional oil detection methods rely mainly on manual sampling and laboratory analyses, which are time-consuming and unsuitable for real-time warning scenarios. Remote sensing techniques, such as satellite or airborne systems, offer broad spatial coverage but often lack the sensitivity and temporal resolution needed to detect small-scale or early-stage pollution events in inland waters [2,3]. Therefore, compact in-situ sensors capable of autonomous and continuous operation are increasingly sought.

Optical sensing approaches based on ultraviolet (UV) excitation are particularly promising, as many oils show strong fluorescence and high reflectivity under UV illumination, whereas clean water exhibits only weak background signals [2,4]. Advances in UV LEDs and miniaturized

optoelectronics have enabled compact, energy-efficient fluorescence sensors suitable for online water monitoring [3]. These developments form the basis of the sensor concept presented here.

Objectives

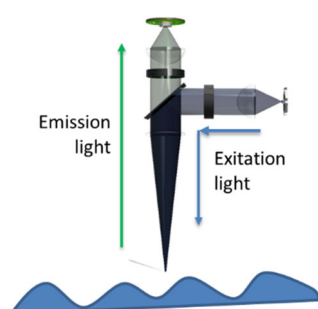
Oil pollution in surface waters poses significant environmental risks, even at very low concentrations. Thin oil films are difficult to detect visually but can already cause ecological damage. Consequently, there is a strong demand for robust, sensitive, and cost-effective sensors for continuous, real-time monitoring that can function as early warning systems. The goal of this work is the development of a miniaturized optical oil sensor that exploits UV-induced fluorescence to detect oil films on water surfaces using commercially available components and low power consumption.

Sensor Setup and Results

The optical setup consists of a UV LED with a central wavelength of 365 nm as excitation source, collimating and focusing optics to define a well-confined measurement spot on the water surface, and a fluorescence detection channel ($\sim 420\text{nm}$) equipped with spectral filters and a photodiode (Fig. 1A). Dichroic optics are used to spatially separate excitation and emission paths, ensuring efficient suppression of scattered UV light. To minimize disturbances caused by ambient light, especially sunlight, the excitation

source is intensity-modulated, and the detected signal is processed using a lock-in amplification principle. This significantly improves the signal-to-noise ratio and allows reliable measurements under varying environmental conditions, including changing illumination, temperature variations, and moderate surface waves. All optical and electronic components are integrated into a compact, watertight housing with dimensions of approximately $10 \times 10 \times 5 \text{ cm}^3$. The sensor operates contact-free at a distance of 10–20 cm above the water surface and can be installed in drainage channels, wastewater systems, riverbanks, or on floating platforms (Fig. 1B). The modular optical design enables adaptation to different deployment scenarios.

A)



B)



Fig. 1. **A)** Optical pathway of the confocal fluorescence detector. **B)** View of the assembled Detector.

The determined limits of detection demonstrate the high sensitivity of the system. For mineral oils, detection limits (LOD) below $0.1 \mu\text{l}/\text{cm}^2$ of water surface were achieved, corresponding to extremely thin oil films that are barely visible to the naked eye. For example, engine oil could be detected down to approximately $0.07 \mu\text{l}/\text{cm}^2$, while diesel fuel and gasoline showed comparable detection thresholds (Fig. 2, Table 1). As expected, vegetable oil exhibited weaker fluorescence and thus higher detection limits; nevertheless, even rapeseed oil could be reliably detected at concentrations relevant for environmental monitoring. Temperature tests between 5°C and 35°C revealed moderate signal variations mainly caused by photodiode sensitivity,

which can be compensated by calibration. Measurements under disturbed surface conditions confirmed reliable operation in dynamic water environments. Compared to conventional detection approaches, the presented sensor enables localization, real-time monitoring with low maintenance effort, no reagents, and reduced system cost. It is therefore well suited for integration into early warning networks for stormwater systems, industrial effluents, and sensitive surface waters.

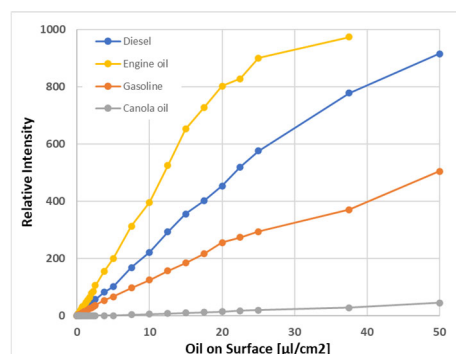


Fig. 2. Fluorescence intensity as a function of the amount of different types of oil.

Table 1. Limit of detection (LOD) for different types of oil.

	Diesel	Gasoline	Engine oil	Canola oil
LOD [μl]	12.24	13.26	27.68	155.76
LOD [$\mu\text{l}/\text{cm}^2$]	0.17	0.19	0.39	2.20

Conclusions

A compact and cost-effective optical sensor for real-time detection of oil pollution on water surfaces was developed and validated. The combination of UV fluorescence sensing, lock-in amplification, and miniaturized optoelectronics results in a robust system with high sensitivity for environmental monitoring. Future work will focus on long-term field validation, further miniaturization, and intelligent data processing for autonomous sensor networks.

References

- [1] Kvočka, D., Žagar, D., & Banovec, P. A review of river oil spill modeling. *Water*, 13(12), 1620, 2021.
- [2] Fingas, M., & Brown, C. E. A review of oil spill remote sensing. *Sensors*, 18(1), 91, 2017.
- [3] Duan, Z., Li, Y., Wang, J., Zhao, G., & Svanberg, S. Aquatic environment monitoring using a drone-based fluorosensor. *Applied Physics B*, 125(6), 2019.
- [4] Carl von Ossietzky University of Oldenburg. Remote Sensing Using Lasers (SEOS Project).