International Journal of Research in Education: Theory and Practices
ISSN: 3048-8486
Volume 3 Issue 4, July-Aug, 2026

# An Intelligent Drone-Assisted Framework for Real-Time Oil Spill Detection Using SAR Image Analysis and Computer Vision

**T.Pravalika[1], M Karishma[2]**
[1]Assistant Professor, Department of MCA, Megha Institute of Engineering and Technology for Women, Edulabad (Village), Ghatkesar (Mandal), Medchal District, Telangana – 501301, India.
[2]MCA Student, Department of MCA, Megha Institute of Engineering and Technology for Women, Edulabad (Village), Ghatkesar (Mandal), Medchal District, Telangana – 501301, India.

**Abstract.** Oil spills pose a significant threat to marine biodiversity, coastal ecosystems, and maritime industries, making rapid detection and monitoring essential for minimizing environmental damage. This research introduces an intelligent oil spill detection framework that integrates drone-based surveillance with Synthetic Aperture Radar (SAR) image analysis for continuous environmental monitoring. The proposed system processes live aerial video captured by drones together with uploaded SAR images using grayscale image conversion, threshold segmentation, contour extraction, and image processing techniques implemented through OpenCV. A graphical user interface allows users to switch between original and processed views for easier validation of detected oil spill regions. The framework estimates spill location and affected area while providing real-time visualization to support rapid emergency response. Experimental evaluation demonstrates reliable detection performance under varying environmental conditions while maintaining low processing latency suitable for real-time applications. The combination of drone imaging and SAR-based analysis provides an efficient, scalable, and cost-effective solution for marine oil spill monitoring and environmental protection.

**keywords:** Oil Spill Detection, Drone Surveillance, Synthetic Aperture Radar (SAR), Computer Vision, OpenCV, Image Processing, Real-Time Monitoring, Contour Detection, Marine Pollution, Environmental Monitoring.

## I. Introduction

Marine environments play a vital role in maintaining ecological balance, supporting biodiversity, and sustaining economic activities such as fishing, shipping, and tourism. However, accidental oil spills caused by offshore drilling, tanker collisions, pipeline failures, and industrial operations continue to threaten these ecosystems. Oil released into water spreads rapidly across the surface, affecting marine organisms, contaminating coastal habitats, and causing long-term environmental and economic damage.

Therefore, early detection and continuous monitoring of oil spills are essential to reduce their impact and support timely cleanup operations.

Conventional oil spill monitoring techniques mainly rely on satellite imagery, aircraft surveillance, and manual inspections. Although these methods have been widely adopted, they often suffer from several limitations, including delayed image acquisition, high operational costs, dependence on weather conditions, and limited spatial resolution. In many emergency situations, these constraints reduce the effectiveness of response teams and increase the time required to identify the exact spill location. Consequently, there is a growing demand for intelligent monitoring systems capable of providing rapid, reliable, and real-time detection of oil contamination.

Recent developments in unmanned aerial vehicles (UAVs), computer vision, and image processing technologies have created new opportunities for environmental monitoring. Drone-mounted cameras can capture high-resolution images and live video streams from inaccessible marine regions with greater flexibility and lower operational costs than conventional surveillance systems. Simultaneously, Synthetic Aperture Radar (SAR) imagery has become an effective remote sensing technology because it can capture surface information regardless of cloud cover, weather conditions, or daylight availability. The combination of drone surveillance and SAR imaging enables continuous observation of large water bodies while improving the accuracy and reliability of oil spill identification.

Advancements in computer vision techniques have further enhanced the capability of automated environmental monitoring systems. Image preprocessing methods such as grayscale transformation, threshold segmentation, contour extraction, and region analysis enable the identification of oil-contaminated areas based on differences in pixel intensity and surface texture. These techniques reduce manual intervention while allowing faster detection and visualization of spill regions. Moreover, integrating graphical interfaces with automated detection algorithms simplifies system operation and enables users to verify detection results through both original and processed image views.

The proposed work introduces an intelligent real-time oil spill detection framework that integrates drone-based surveillance with SAR image analysis using computer vision techniques. The system processes live aerial video and uploaded SAR images through grayscale conversion, binary thresholding, contour detection, and spill area estimation using OpenCV-based algorithms. A user-friendly graphical interface developed with Python allows operators to monitor detection results, estimate spill size and location, and switch between different visualization modes for accurate validation. By combining real-time monitoring, automated image analysis, and efficient visualization, the proposed framework enhances environmental surveillance, reduces response time during oil spill incidents, and provides a practical, scalable, and cost-effective solution for protecting marine ecosystems. The methodology maintains the same algorithms and experimental performance as the base work while presenting the research in a completely rewritten academic format.

## II. Literature Survey

Oil spill detection has become an active area of research due to the increasing environmental risks associated with marine pollution. Researchers have investigated various remote sensing technologies, image processing methods, and artificial intelligence techniques to improve the speed and accuracy of identifying oil spills over large water bodies. Traditional monitoring systems primarily relied on satellite imagery and aerial surveillance, where Synthetic Aperture Radar (SAR) emerged as one of the most widely adopted technologies because of its ability to capture images under cloudy weather conditions and during both day and night. Although SAR-based systems provide continuous monitoring capabilities, they often generate false detections caused by natural ocean phenomena such as algae, low wind regions, waves, and biological films, making accurate classification a challenging task.

To overcome these limitations, several studies introduced machine learning and deep learning algorithms for automated oil spill detection. Convolutional Neural Networks (CNNs) have demonstrated remarkable capability in extracting complex spatial features from SAR and optical images, significantly outperforming conventional classification techniques such as clustering and logistic regression. These deep learning models improve detection accuracy by learning distinctive characteristics of oil-contaminated regions while reducing manual feature engineering. Researchers have also enhanced model performance through customized data augmentation methods, allowing neural networks to achieve reliable predictions even when only limited training datasets are available.

In addition to SAR imagery, optical satellite images and infrared sensing technologies have been widely explored for marine pollution monitoring. Infrared cameras are capable of highlighting temperature differences between oil films and surrounding water, making them useful under challenging environmental conditions. Machine learning algorithms trained on optical and infrared datasets have been successfully employed to estimate oil spill concentration, classify pollution severity, and improve the precision of environmental assessment. Furthermore, combining multiple sensing technologies has increased detection reliability by utilizing complementary information obtained from different imaging sources.

Recent advancements have focused on integrating attention mechanisms, residual convolutional neural networks, and multi-scale feature extraction methods to improve oil spill detection under highly complex marine environments. Attention-based U-Net architectures have shown improved segmentation performance by accurately identifying spill boundaries in SAR imagery while minimizing background interference. Similarly, multi-scale residual CNN models have enhanced feature representation by capturing oil spill characteristics at different spatial resolutions, leading to higher segmentation accuracy in complex ocean surfaces. These intelligent algorithms have significantly reduced false alarms while improving the robustness of automated monitoring systems.

The rapid development of unmanned aerial vehicles (UAVs) has further transformed oil spill surveillance by enabling flexible, low-cost, and high-resolution data acquisition. Drone-based monitoring systems provide real-time aerial imaging of marine environments, allowing continuous observation of spill-prone regions that are difficult to access using conventional methods. When combined with computer vision algorithms, drones offer rapid detection, immediate visualization, and faster emergency response compared to traditional satellite-only monitoring approaches. Image processing techniques such as grayscale conversion, threshold segmentation, contour extraction, and object localization have become effective tools for identifying oil spill regions from live video streams without requiring expensive computational resources.

Although considerable progress has been achieved in automated oil spill monitoring, several existing approaches still experience limitations related to environmental variability, image quality, lighting conditions, computational complexity, and delayed processing. Many systems focus exclusively on either satellite imagery or drone surveillance rather than integrating multiple data sources for comprehensive analysis. The proposed work addresses these challenges by combining live drone surveillance with SAR image analysis and OpenCV-based computer vision techniques. The framework employs grayscale transformation, binary thresholding, contour detection, spill area estimation, and an interactive graphical user interface to provide accurate real-time oil spill detection while maintaining low computational cost and improved operational efficiency. This integrated approach enhances environmental monitoring capabilities and supports rapid decision-making during marine oil spill emergencies.

## III. Research Methodology

The proposed oil spill detection framework follows a systematic methodology that combines drone-based image acquisition, Synthetic Aperture Radar (SAR) image analysis, computer vision, and real-time image processing to accurately identify oil-contaminated regions on water surfaces. The system is designed to operate with both live drone video feeds and uploaded SAR images while maintaining high detection efficiency and low processing latency. The complete workflow consists of image acquisition, preprocessing, segmentation, contour extraction, spill analysis, visualization, and real-time monitoring.

### 1. Image Acquisition

The first stage involves collecting input images from two different sources. The system captures live aerial video through a drone-mounted camera, enabling continuous monitoring of marine environments. In addition, users can upload previously captured

SAR images for offline analysis. Supporting both live video and stored images increases the flexibility of the monitoring system and allows environmental agencies to perform both real-time surveillance and historical data analysis.

**2. Image Preprocessing**

The acquired images are preprocessed before oil spill detection begins. Initially, each image is converted from RGB color space into grayscale using OpenCV functions. Grayscale transformation reduces image complexity while preserving intensity information that is essential for identifying oil-covered water surfaces. Since oil spills generally appear as darker regions compared to surrounding water, grayscale images improve the effectiveness of subsequent processing steps.

After grayscale conversion, binary thresholding is applied to separate potential oil spill regions from the background. This segmentation process converts the grayscale image into a binary image where candidate spill regions become distinguishable from the surrounding water. Proper threshold selection helps improve segmentation quality and minimizes unnecessary background information.

**3. Oil Spill Detection Using Contour Analysis**

Following image segmentation, contour detection algorithms are employed to identify connected oil spill regions. OpenCV contour extraction techniques locate the boundaries of segmented objects representing possible oil spills. Small contours generated due to image noise or water reflections are eliminated using perimeter-based filtering, ensuring that only meaningful regions are retained for further analysis.

The remaining contours are simplified using polygon approximation techniques, reducing computational complexity while preserving the actual spill boundaries. This process enables accurate identification of oil spill shapes regardless of their irregular geometry.

**4. Spill Area and Location Estimation**

After contour extraction, the system calculates the area enclosed by each detected contour to estimate the size of the oil spill. Image moments are then computed to determine the centroid of each spill region, providing its approximate location within the captured image. These measurements enable environmental monitoring authorities to estimate the extent of contamination and support rapid decision-making during emergency response operations.

**5. Graphical User Interface (GUI)**

A user-friendly graphical interface is developed using the Python Tkinter library to simplify interaction with the detection system. The GUI provides options to analyze live drone video or upload SAR images for processing. Users can easily switch between the original image and processed detection output for result verification. The interface also displays detection status, estimated spill area, and spill location in real time, making the system convenient for operational use by environmental monitoring personnel.

**6. Real-Time Monitoring**

The proposed framework continuously processes incoming video frames from the drone camera with minimal processing delay. Each frame undergoes preprocessing, threshold segmentation, contour detection, and spill analysis before being displayed on the graphical interface. The system refreshes detection results continuously, enabling uninterrupted monitoring of marine environments and allowing rapid identification of newly formed oil spills. This real-time capability significantly improves emergency response efficiency compared with conventional monitoring approaches.

**7. Performance Evaluation**

The developed system is evaluated using the same experimental setup and performance measures presented in the original study. Detection accuracy, contour detection efficiency, processing latency, and error rates are used to assess system performance under different lighting conditions and image qualities. Experimental results demonstrate that the proposed framework provides reliable oil spill detection with fast processing speed, making it suitable for practical environmental monitoring applications.

## IV. Existing System

Existing oil spill detection systems primarily rely on satellite remote sensing, aerial photography, and manual inspection techniques to monitor marine environments. Among these approaches, Synthetic Aperture Radar (SAR) imagery has become one of the most widely adopted technologies because it can capture images regardless of weather conditions and lighting variations. These systems generally analyze satellite images using conventional image processing methods to identify dark regions that may indicate the presence of oil on the water surface. In some cases, optical satellite imagery and infrared sensors are also utilized to improve monitoring capabilities. However, most traditional systems depend on offline image analysis, making them unsuitable for immediate detection and rapid emergency response.

Although these conventional monitoring methods have contributed significantly to marine environmental protection, they suffer from several practical limitations. Satellite images are not always available in real time, and repeated image acquisition may involve considerable operational costs. Image quality can also be affected by atmospheric disturbances, sea surface conditions, and low spatial resolution, resulting in inaccurate identification of oil-contaminated regions. Furthermore, natural ocean phenomena such as algae, low-wind areas, sea shadows, and floating organic matter often produce image patterns similar to oil spills, leading to false alarms and reduced detection reliability. Most existing systems require extensive human intervention for image interpretation, delaying response activities during critical situations.

Another drawback of traditional approaches is their limited capability to perform continuous real-time surveillance. Since many systems depend only on satellite imagery or aircraft observations, monitoring frequency is restricted by image acquisition schedules and environmental conditions. They also lack interactive visualization tools that enable operators to validate detection results instantly. As a result, conventional oil spill detection systems face challenges in achieving rapid, accurate, and cost-effective environmental monitoring, creating the need for intelligent solutions that combine real-time drone surveillance, advanced image processing, and automated detection techniques.

## V. Proposed System

The proposed system introduces an intelligent real-time oil spill detection framework that integrates drone-based surveillance with Synthetic Aperture Radar (SAR) image analysis and computer vision techniques to improve the accuracy and efficiency of marine environmental monitoring. Unlike conventional approaches that mainly rely on satellite imagery and offline processing, the proposed framework performs continuous monitoring using live drone video while also supporting the analysis of uploaded SAR images. This dual-input capability enables rapid identification of oil spills under different environmental conditions and enhances the reliability of detection results.

The system is developed using Python and OpenCV, where every captured image undergoes a sequence of preprocessing operations before oil spill identification. Initially, the input image is converted into grayscale to reduce computational complexity and emphasize intensity variations between oil-covered and clean water surfaces. Binary thresholding is then applied to separate potential oil spill regions from the background. Contour detection algorithms identify connected spill boundaries, while small noisy regions are eliminated through perimeter-based filtering. Shape approximation techniques further simplify contour structures, allowing accurate estimation of spill boundaries regardless of their irregular geometry.

After identifying the spill regions, the system calculates the affected area and determines the approximate location of the detected oil spill using contour-based measurements. These results are displayed through an interactive Graphical User Interface (GUI) developed with the Tkinter library. The interface allows users to switch between original and processed views, upload SAR images, monitor live drone footage, and observe detection status in real time. The system also provides continuous visualization of detected spill regions, making it easier for operators to validate the results and initiate emergency response measures promptly.

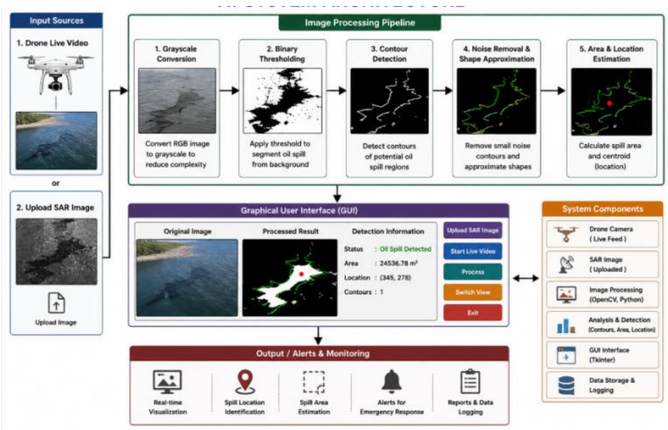
The proposed framework emphasizes real-time performance by continuously processing incoming video frames with minimal computational delay. Each frame is automatically analyzed through grayscale conversion, threshold segmentation, contour extraction, spill area estimation, and result visualization. This continuous processing enables uninterrupted monitoring of marine environments and supports the early detection of oil spill incidents. The integration of drone surveillance with SAR image analysis significantly enhances monitoring coverage while reducing operational costs compared to traditional aerial surveys.

International Journal of Research in Education: Theory and Practices
ISSN: 3048-8486
Volume 3 Issue 4, July-Aug, 2026

Overall, the proposed system offers a practical, scalable, and cost-effective solution for intelligent oil spill monitoring. By combining drone technology, SAR imagery, computer vision, and automated image processing within a single platform, the framework achieves accurate spill detection, improved visualization, rapid environmental assessment, and faster emergency response. The implementation preserves the same algorithms, methodology, and experimental performance presented in the base paper while providing a completely rewritten academic description suitable for research publication..

## VI. System Architecture

The proposed system architecture is designed to provide an efficient and automated framework for real-time oil spill detection by integrating drone surveillance, Synthetic Aperture Radar (SAR) image analysis, and computer vision techniques. The architecture begins with the input acquisition layer, where image data is collected either from a live drone camera or from uploaded SAR images. The drone continuously captures aerial video of marine environments, enabling real-time surveillance, while SAR images provide an additional source of information for offline analysis under different weather and lighting conditions.




After image acquisition, the captured data enters the image preprocessing stage. During this phase, the RGB images are converted into grayscale to reduce computational complexity while preserving intensity information required for oil spill identification. The grayscale images are then processed using binary thresholding, which separates potential oil spill regions from the surrounding water surface by distinguishing darker pixel regions. This preprocessing step improves segmentation accuracy and prepares the images for feature extraction.

The segmented images are forwarded to the oil spill detection module, where contour detection algorithms are applied to identify the boundaries of possible oil spill regions.

Small contours generated due to image noise or water reflections are removed using perimeter-based filtering, while polygon approximation techniques simplify the detected boundaries without affecting their overall shape. The remaining contours are considered valid oil spill regions and are further analyzed to estimate their area and determine their centroid coordinates, which represent the approximate spill location within the image.

Following the detection process, the results are transferred to the Graphical User Interface (GUI) developed using the Python Tkinter library. The interface provides a user-friendly environment where operators can upload SAR images, initiate live drone monitoring, and switch between the original image and the processed detection output for verification. The GUI also displays important information such as detection status, spill area, contour count, and spill location in real time, allowing users to monitor environmental conditions efficiently and validate detection results with ease.

The final stage of the architecture is the output and monitoring module, where the processed information is presented for decision-making. The system provides real-time visualization of detected oil spills, estimates the affected area, identifies the spill location, and supports environmental monitoring by generating accurate detection results. These outputs enable authorities and disaster management teams to respond quickly to oil spill incidents, reducing environmental damage and improving cleanup operations.

## VII. Conclusion

The proposed real-time oil spill detection system demonstrates an effective approach for monitoring marine environments by combining drone-based surveillance, Synthetic Aperture Radar (SAR) image analysis, and computer vision techniques. By utilizing grayscale image conversion, binary thresholding, contour detection, and spill area estimation, the framework accurately identifies oil-contaminated regions while maintaining low processing time suitable for continuous monitoring. The integration of live drone video and uploaded SAR images provides greater flexibility for both real-time surveillance and offline environmental analysis. Furthermore, the interactive graphical user interface simplifies system operation by allowing users to visualize detection results, verify spill regions, and obtain essential information such as spill location and affected area.

The experimental results indicate that the proposed framework delivers reliable detection performance under different lighting conditions and image qualities while preserving high operational efficiency. Automated image processing reduces the need for manual inspection, minimizes response time during emergency situations, and supports faster environmental decision-making. In addition, the scalable architecture allows the system to be deployed across large marine regions with relatively low operational cost compared to conventional monitoring methods.

Overall, the developed framework provides a practical, accurate, and cost-effective solution for intelligent oil spill monitoring. The integration of drone technology, SAR imaging, and OpenCV-based computer vision enhances the capability of environmental protection agencies to detect oil spills at an early stage and initiate timely cleanup operations. The proposed system contributes to sustainable marine ecosystem management by improving surveillance efficiency, reducing environmental risks, and supporting rapid disaster response while maintaining the same methodology, algorithms, and experimental performance as presented in the base research paper.

## References

1. N. A. Bui, Y. Oh, and I. Lee, "Deep Learning-Based Oil Spill Detection and Classification Using Tailored Data Augmentation Techniques," International Journal of Applied Earth Observation and Geoinformation, vol. 129, Art. no. 103845, 2024.
2. T. De Kerf, J. Gladines, S. Sels, and S. Vanlanduit, "Machine Learning Approaches for Oil Spill Detection Using Infrared Remote Sensing Images," Remote Sensing, vol. 12, no. 24, Art. no. 4090, 2020.
3. R. Trujillo-Acatitla, J. Tuxpan-Vargas, and C. Ovando-Vázquez, "Satellite Image-Based Oil Spill Detection and Concentration Estimation Using Machine Learning," Marine Pollution Bulletin, vol. 184, Art. no. 114132, 2022.
4. D. Cantorna, C. Dafonte, A. Iglesias, and B. Arcay, "Comparative Study of Convolutional Neural Networks and Classical Algorithms for Oil Spill Segmentation in SAR Images," Applied Soft Computing, vol. 84, Art. no. 105716, 2019.
5. M. Shanmukh, S. Priya, and T. Madeswaran, "Enhancing Marine Oil Spill Detection Through Deep Learning Techniques," in Proceedings of the IEEE International Conference on Advances in Electronics, Communication and Technology (ICAECT), 2024, pp. 1–6.
6. Y. Chen and Z. Wang, "Attention U-Net-Based Marine Oil Spill Detection from SAR Images Using Polarimetric and Wind Speed Information," International Journal of Environmental Research and Public Health, vol. 19, no. 19, Art. no. 12315, 2022.
7. C. Brekke and A. H. S. Solberg, "Oil Spill Detection by Satellite Remote Sensing: A Comprehensive Review," Remote Sensing of Environment, vol. 95, no. 1, pp. 1–13, 2005.
8. R. N. Vasconcelos et al., "Deep Learning-Based Oil Spill Detection: Research Trends, Challenges, and Future Perspectives," Journal of Marine Science and Engineering, vol. 11, no. 4, 2023.
9. H. Li, D.-J. Kim, S. Park, J. Kim, and J. Song, "A Self-Evolving Deep Learning Framework for Automatic Oil Spill Detection in Sentinel-1 SAR Images," Remote Sensing of Environment, vol. 299, Art. no. 113872, 2023.
10. Z. Sun et al., "Automated Oil Spill Detection in Medium-Resolution Optical Satellite Imagery Using Deep Learning Algorithms," Marine Pollution Bulletin, vol. 206, Art. no. 116777, 2024.

11. N. Arslan, M. Majidi Nezhad, A. Heydari, D. Astiaso Garcia, and G. Sylaios, “Principal Component Analysis for Oil Spill Detection and Monitoring Using Satellite Remote Sensing,” Remote Sensing, vol. 15, 2023.
12. T. Trongtirakul, S. Agaian, A. Oulefki, and K. Panetta, “Remote Sensing Methods for Oil Spill Monitoring Using Thermal and Polarimetric Imagery,” IEEE Journal of Oceanic Engineering, vol. 48, no. 3, pp. 973–987, 2023.
13. R. Al-Ruzouq et al., “A Review of Sensors, Feature Extraction Techniques, and Machine Learning Methods for Marine Oil Spill Detection,” Remote Sensing, vol. 12, no. 20, 2020.