Real-Time Disaster Classification Using UAV Imagery and Efficient Net for Resource-Constrained Environments

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Abstract: **Disaster management is essential for mitigating the effects of natural and human-made catastrophes on people and the environment. Rapid and precise assessment of disaster-affected areas is crucial for effective response and recovery efforts. Unmanned Aerial Vehicles (UAVs), equipped with high-resolution imaging systems, have proven to be indispensable for capturing real-time aerial views of disaster zones. However, efficiently processing these images for accurate disaster classification remains a significant challenge. This paper introduces an advanced disaster monitoring framework that utilizes Efficient-Net, a cutting-edge deep learning architecture, to classify UAV-acquired images based on different disaster scenarios. By fine-tuning a pretrained Efficient-Net model specifically for disaster detection, the system achieves remarkable accuracy in categorizing images into classes such as damaged infrastructure, fires, water-related disasters, human casualties, and non-critical conditions. The proposed solution is optimized to balance computational efficiency with real-time performance, making it suitable for deployment in environments with limited resources. Comprehensive evaluations on a disaster-specific image dataset demonstrate the model's superior accuracy and faster processing speeds compared to existing methods. This study emphasizes the potential of Efficient-Net to enhance UAV-based disaster monitoring systems by improving their scalability and real-time operational capabilities.**

Keywords: **Disaster Management, UAV Imagery, Efficient-Net, Deep Learning, Disaster Classification, Real-Time Monitoring, Resource-Constrained Systems, Aerial Image Processing**

1 INTRODUCTION

This project is centered on developing a system capable of identifying six key disaster scenarios: Damaged Infrastructure, Fire Disasters, Human Damage, Land Disasters, Non-Damage Events, and Water Disasters. The primary goal is to automate the recognition of these disaster types through advanced image classification techniques, significantly improving the efficiency and effectiveness of disaster response operations. By leveraging such automation, the system aims to provide timely and accurate insights, enabling faster decision-making and resource allocation during emergencies. Disaster management relies on various critical mechanisms, such as early warning systems, satellite imaging, predictive analytics, and data-driven planning. These tools are essential for proactive measures and effective disaster response. Among these technologies, Unmanned Aerial Vehicles (UAVs) have emerged as indispensable assets in modern disaster management. UAVs offer a unique advantage by delivering high-resolution imagery and real-time data from areas that are otherwise inaccessible or too hazardous for human intervention. They play a pivotal role in assessing damage, identifying survivors, and even aiding in the delivery of essential supplies during emergencies. With their ability to provide aerial surveillance and rapid situational awareness, UAVs have transformed the way disaster zones are monitored and managed, ensuring that response efforts are more targeted and efficient. Looking forward, this system has the potential to evolve significantly by incorporating multi-modal data sources, combining UAV drone imagery with satellite data, ground-level reports, and sensor inputs. Such integration would provide a comprehensive and layered understanding of disaster scenarios, enabling more accurate assessments and informed decision-making. Future enhancements could also include the development of predictive modelling capabilities, allowing the system to forecast potential disaster impacts based on historical and real-time data. Additionally, implementing real-time monitoring and alert systems could further strengthen preparedness and response strategies, ensuring timely interventions to mitigate damage and save lives. With the growing challenges posed by climate change and rapid urbanization, the frequency and intensity of disasters have increased dramatically worldwide. These complex and unpredictable events demand innovative, technology-driven solutions to ensure effective disaster management. By leveraging advancements in artificial intelligence, machine learning, and data fusion, this project can pave the way for more adaptive and resilient systems. The expanded capabilities would not only improve immediate disaster response but also contribute to long-term risk reduction and sustainable disaster mitigation efforts.

2 LITERATURE SURVEY

Hernández et.al [1] describes the significant strides toward enhancing UAV autonomy in disaster scenarios, specifically focusing on flood events. The study utilizes a dataset comprising UAV-captured images from various flood occurrences in Spain and applies an AI-driven approach for semantic image segmentation. By leveraging three widely recognized deep neural networks (DNNs), the system automatically identifies and segments areas most impacted by flooding. The algorithms are optimized for GPU-enabled edge computing platforms, enabling image processing to be performed directly on the UAVs. This approach ensures that only the processed outputs are transmitted to the cloud, facilitating real-time monitoring of flood-affected regions.

By minimizing reliance on external infrastructure and reducing network bandwidth usage, the system becomes more energy-efficient and resilient to connectivity issues. Experimental evaluations across diverse hardware setups and neural network architectures demonstrate the feasibility of executing complex real-time image analysis on UAV platforms using advanced DNN-based techniques. This innovation enhances the robustness, efficiency, and environmental sustainability of disaster monitoring operations.

Safavi et.al [2] To address these challenges, we train cutting-edge real-time semantic segmentation architectures using the Flood-Net dataset, which includes annotated aerial images captured in the aftermath of Hurricane Harvey. This study provides an in-depth analysis of several lightweight models, including encoder-decoder and two-pathway architectures, to assess their suitability for aerial image segmentation tasks. The research benchmarks the performance of these models on the Flood-Net dataset, evaluating their efficiency and accuracy to determine their practicality during emergency response scenarios.

Some lightweight models achieve over 60% test mIoU on the Flood-Net dataset and deliver high-quality segmentation results on aerial images. The study highlights the capabilities and limitations of current segmentation models, particularly focusing on those with low computational requirements and fast inference times. These findings have direct applications in managing catastrophic events, such as floods, by enhancing the efficiency and reliability of aerial image analysis during disaster response operations.

Khan et.al [3] proposes a Convolutional Neural Network (CNN)-based framework for smoke detection and segmentation, designed to work effectively in both clear and hazy environments. Unlike traditional methods, we utilize the EfficientNet architecture, known for its efficiency and improved accuracy in smoke detection. For segmentation, we employ DeepLabv3+, which incorporates robust encoders and decoders alongside a pixel-wise classifier to achieve precise localization of smoke regions. Our results demonstrate a noticeable improvement in detection accuracy, with an increase of up to 3% and a reduction of 0.46% in False Alarm Rate (FAR). Additionally, segmentation performance shows significant gains, with a 2% improvement in global accuracy and a 1% increase in mean Intersection over Union (IoU) scores. These results highlight the effectiveness of our approach for real-time smoke detection and segmentation in practical surveillance applications.

Liu et.al [4] proposed a lightweight neural network designed to address the semantic segmentation of UAV remote sensing images while minimizing model complexity. The network is based on an encoder-decoder architecture. In the encoder, we design a compact convolutional neural network with reduced channels in each layer to lower the total number of parameters. Feature maps of various scales are resized and concatenated for multiscale fusion, enabling the model to leverage information from multiple resolutions. Additionally, two attention modules are incorporated to capture global semantic context and channel correlations within UAV remote sensing images.

In the decoder, pixel-wise predictions are generated using the softmax function, ensuring precise segmentation. Experiments were conducted on datasets such as ISPRS Vaihingen, UAVid, and UDD6 to validate the effectiveness of the proposed network. With only 9 million parameters, the model achieves high-quality semantic segmentation results, demonstrating competitiveness with other state-of-the-art methods of similar size.

Khan et.al [5]explores the current theoretical foundations and practical applications of emerging technologies, including IoT, artificial intelligence, cloud computing, edge computing, deep learning, blockchain, social networks, robotics, machines, as well as privacy and security mechanisms. Focusing on their interplay during the COVID-19 pandemic, the review categorizes these technologies under the broader domain of AI-IoT systems using a concise classification framework. The analysis reveals that AI-IoT innovations have had a profound impact on the healthcare sector. Key technologies identified as transformative in healthcare include fog computing within IoT, deep learning algorithms, and blockchain solutions. Additionally, the paper discusses the significant aspects and potential future implications of these technologies, employing methodologies that incorporate image processing, machine learning, and differential system modelling.

Kyrkou et.al [6] emphasizes the efficient classification of aerial images directly onboard UAVs for emergency response and monitoring applications. It introduces a specialized Aerial Image Database tailored for emergency scenarios and provides a comparative evaluation of existing classification methods. Based on this analysis, a lightweight convolutional neural network named Emergency-Net is proposed. The architecture utilizes atrous convolutions to process multi-resolution features effectively and is designed to operate on low-power embedded systems. Emergency-Net delivers up to 20× higher performance compared to existing models while maintaining minimal memory usage and incurring less than a 1% reduction in accuracy compared to state-of-the-art solutions.

Alamet.al [7] provides an in-depth exploration of the development and evolution of some of the most impactful deep learning models for intelligent speech and vision systems. It highlights large-scale industrial research and development efforts, shedding light on future trends and opportunities in these fields. Intelligent systems require robustness and efficiency, particularly in resource-constrained environments such as mobile devices, robotics, and automobiles, where low latency and high fidelity are critical. The survey reviews key challenges and recent advancements in deploying deep neural networks on hardware with limited memory, power, and processing capabilities. Additionally, it examines emerging applications of speech and vision technologies in areas such as affective computing, intelligent transportation, and precision medicine. To the best of our knowledge, this work offers one of the most comprehensive overviews of recent advancements in intelligent speech and vision systems, addressing both software and hardware perspectives. Many of these innovations, powered by deep neural networks, hold significant potential to drive future breakthroughs in speech and vision applications.

Hussain et.al [8] proposed the precise fire detection, we utilize deep multi-scale features from a backbone model combined with an attention mechanism. Intermediate layers capture spatial details such as object edges to identify fire regions, while the final layers extract global image representations. By fusing these features, the model effectively represents the image, and the fused features are further refined using multi-headed self-attention to emphasize critical fire regions. Preliminary experiments, as detailed in the repository here, demonstrate the proposed model's superior performance on a UAV fire detection dataset compared to existing approaches. This innovative use of multi-layer features offers a promising solution for accurate fire detection and highlights its potential applicability in smart city environments.

3 METHODOLOGY

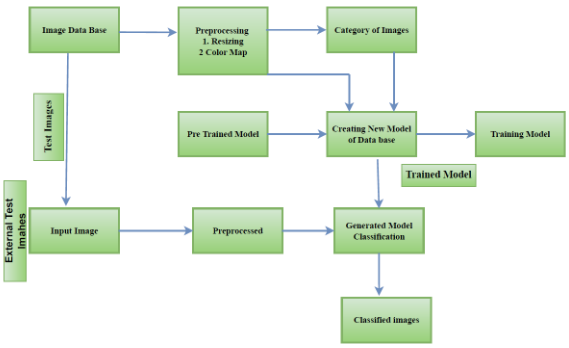

Fig 1 Workflow for Image Classification

The diagram represents a standard workflow for image classification, starting with an image database. Initially, the raw images undergo preprocessing, which typically involves resizing to uniform dimensions and applying appropriate colour mapping or normalization to standardize the data. This step ensures the images are in a format suitable for analysis. Once the images are pre-processed, they serve as input for model training. This model can either be a pre-trained model, which leverages prior knowledge, or a newly developed model designed specifically for the given dataset. After training, the model becomes capable of categorizing input images into specific classes based on learned patterns. The system can also handle external test images, which are fed into the trained model to evaluate its classification performance. This process helps assess the model's accuracy and generalization to unseen data, ultimately resulting in organized and categorized image outputs.

4. RESULTS

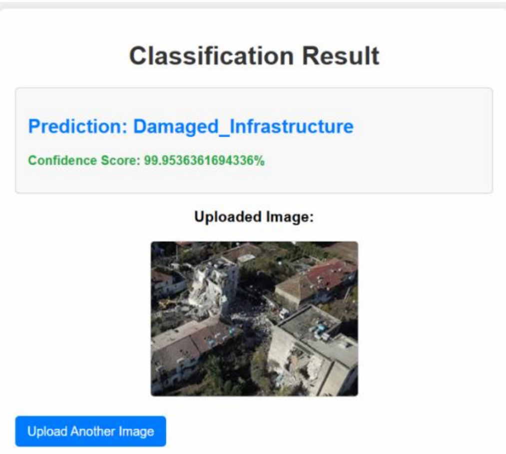

Fig 2 Damaged Infrastructure

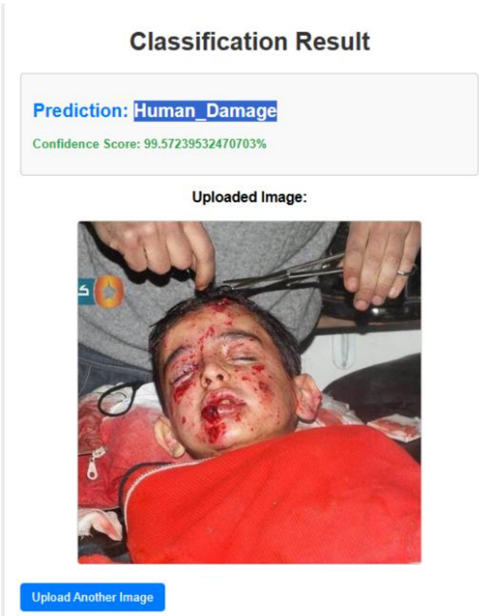

Fig 3 Human Damage

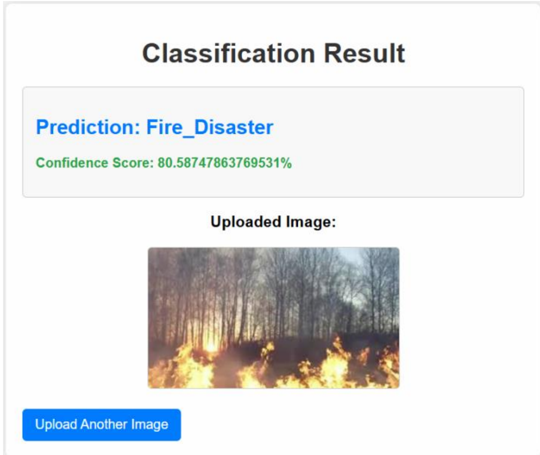

Fig 4 Fire Disaster

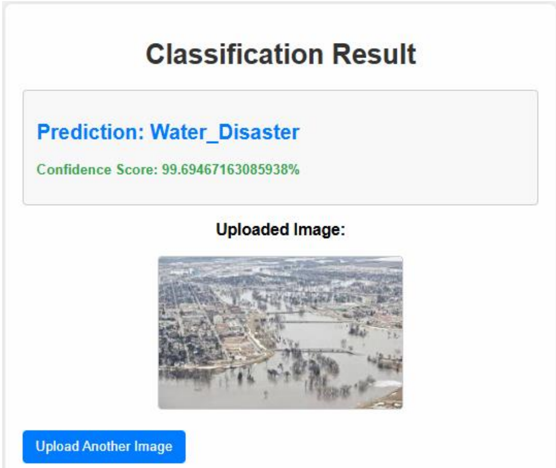

Fig 5 Water Disaster

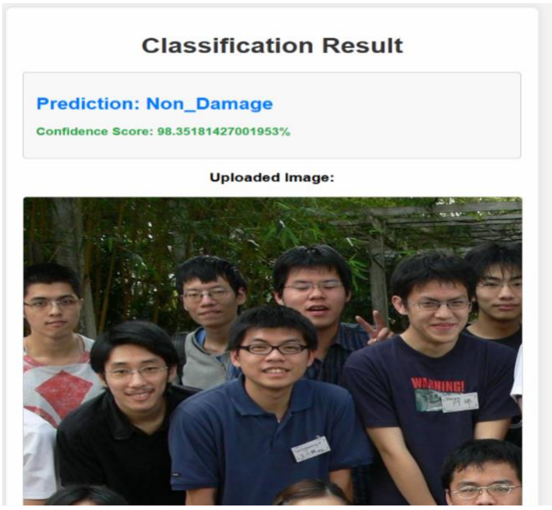

Fig 6 Non Damage

CONCLUSION

The proposed framework leveraging the Efficient-Net architecture demonstrates a highly effective approach to disaster classification from UAV imagery. By achieving a balance between computational efficiency and real-time performance, the system addresses critical challenges in disaster management, particularly in resource-constrained environments. The framework's superior accuracy and processing speed compared to existing models highlight its potential to significantly enhance disaster response and recovery efforts, paving the way for more scalable and efficient UAV-based monitoring systems.

FEATURE SCOPE

The proposed framework introduces a highly efficient disaster monitoring system that leverages a fine-tuned Efficient-Net model for classifying UAV-captured images into categories such as structural damage, fires, water-related incidents, human casualties, and non-critical conditions. It focuses on optimizing computational efficiency to support real-time performance, making it practical for use in resource-constrained environments. The system achieves notable improvements in accuracy and processing speed compared to existing methods, enabling rapid assessment of disaster zones. Additionally, its scalability and adaptability make it a promising solution for integrating UAV-based monitoring in diverse disaster management applications.

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