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Fire Smoke Detection Using Multi-Spectral Imagery from Multiple Satellites

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Introduction

Using satellite imagery with more spectral bands can improve the accuracy of Deep Learning (DL) models for fire smoke detection and using multiple satellites can increase the chance of fires being detected earlier [1]. However, the application faces many challenges: 1) Such imagery training data are rare and hard to collect, particularly for new sensors; 2) The DL models need to have good accuracy and be lightweight for timely onboard-satellite processing, while STOA models are usually too big, and often misclassify fire smoke to other aerosols, such as clouds; 3) DL models trained with imagery data from one sensor can hardly be directly used for another sensor due to differences in the spectral characteristics between the sensors. Our research aims to tackle these challenges.

Aims

- Construct multi-spectral imagery training datasets from multiple sensors.
- Develop a lightweight DL model that can achieve high accuracy for potential onboard-small-satellite applications.
- Design a framework to train and apply the model on multiple satellites, potentially allowing the application on newly launched satellites for early fire smoke detection.

Methods

Table 1. Imagery training datasets

Dataset	#Bands	Classes	#Images /Class	#Images Total
Landsat_smk2770	6	Clear	616	2770
		Other_aerosol	605	
		Smoke	615	
Sentinel-2_smk	7	Clear	112	351
		Other_aerosol	116	
		Smoke	123	

Table 2. Model performance based on Landsat_smk2770

Model	InAmp	#Params	Accuracy	Kappa	FN
ResNet50	No	23.60M	75.82%	63.68%	26.47%
	Yes	23.69M	80.43%	70.70%	29.41%
InceptionResnetV2	No	54.34M	83.97%	75.89%	24.77%
	Yes	54.35M	85.05%	77.52%	18.38%
MobileNetV2	No	2.263M	76.90%	65.11%	22.06%
	Yes	2.272M	78.80%	68.01%	21.32%
VIB_SD	No	1.676M	81.79%	72.61%	24.26%
	Yes	1.812M	85.33%	77.87%	13.97%

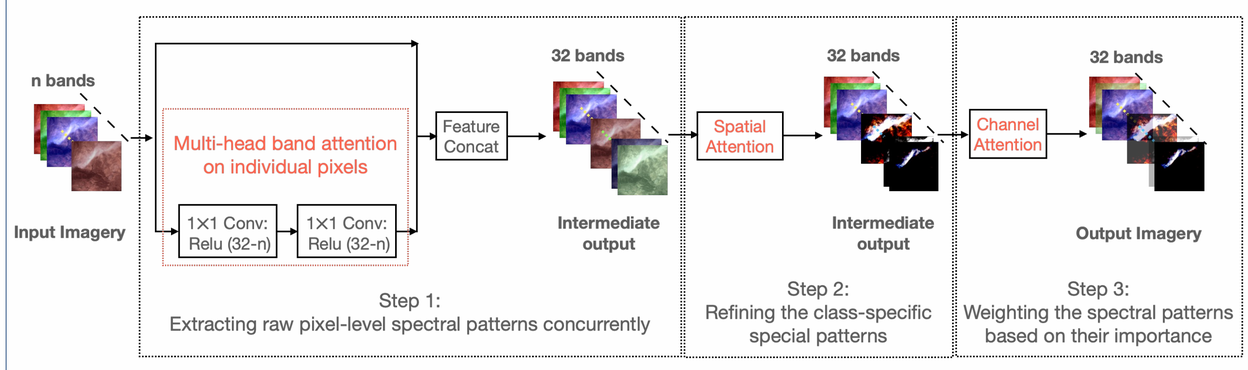

Figure 1. Structure of the InAmp module

Results

- We constructed two multi-spectral satellite imagery training datasets for fire smoke detection, namely Landsat_smk2770 and Sentinel2_smk, with six and seven spectral bands, respectively. See Table 1 for the details of the two datasets.
- We designed a lightweight CNN model VIB_SD_InAmp [2] which integrates the lightweight model VIB_SD [1] and a novel module InAmp [2] (See Figure 1.) that helps the model extract class-specific spectral patterns (See Figure 2 for the examples) to improve the accuracy. See Table 2 for the comparison of VIB_SD against some STOA CNN models when trained with/without InAmp using the Landsat_smk2770 dataset.
- We investigated and proposed a cross-sensor transfer learning scheme aided by the InAmp module accounting for variable spectral bands in the imagery data from different satellites. After being transferred and updated by using only a small portion of Sentinel2_smk data, the VIB_SD_InAmp model trained using the Landsat_smk2770 dataset achieved good accuracy. See Figure 3 for the performance of our proposed transfer learning scheme 'Init' [3] against other schemes and the benchmark model trained purely with the Sentinel2_smk data.

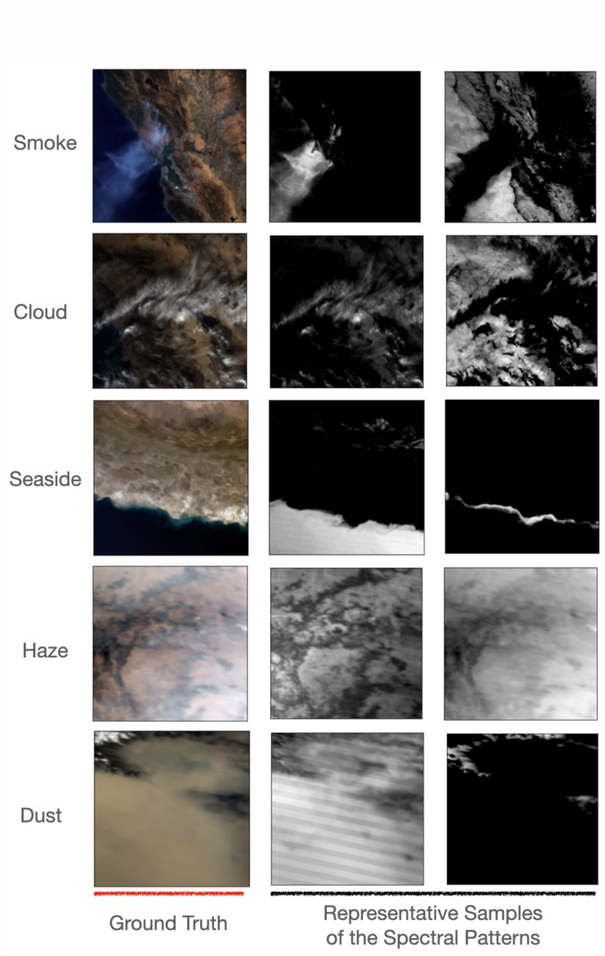

Figure 2. Examples of spectral patterns extracted by InAmp

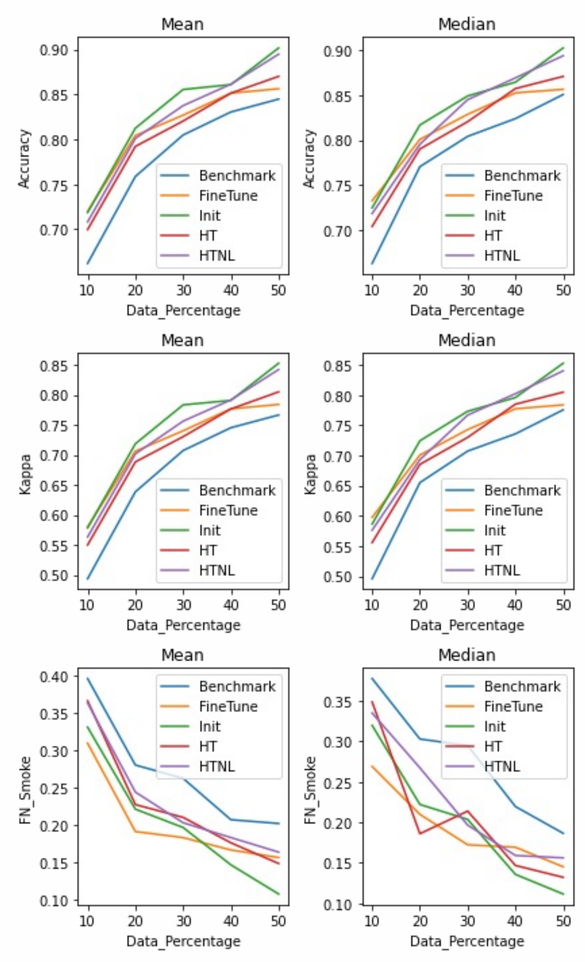

Figure 3. Transfer learning performance by mean (left) and median (right)

References

[1] Zhao, L.; Liu, J.; Peters, S.; Li, J.; Oliver, S.; Mueller, N. Investigating the Impact of Using IR Bands on Early Fire Smoke Detection from Landsat Imagery with a Lightweight CNN Model. Remote Sens. 2022, 14, 3047.

[2] Zhao, L.; Liu, J.; Peters, S.; Li, J.; Mueller, N; Oliver, S. "Learning Class-Specific Spectral Patterns to Improve Deep Learning Based Scene-Level Fire Smoke Detection from Multi-Spectral Satellite Imagery". Unpublished.

[3] Zhao, L.; Liu, J.; Peters, S.; Li, J.; Mueller, N; Oliver, S. Cross-Sensor Transfer Learning Aided with Spectral Pattern Extraction for Fire Smoke Detection Using Multi-spectral Satellite Imagery with Variable Bands". Unpublished.

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