Deep Learning Methods for Methane Detection in EMIT Hyperspectral Imagery

Reynaldo Souza de Carvalho, Carlos Roberto de Souza Filho. Universidade Estadual de Campinas.

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Abstract:

Methane (CH_4) is the most abundant hydrocarbon in the atmosphere and the second most significant greenhouse gas contributing approximately 20% to total radiative forcing and a Global Warming Potential that is over 86 times that of carbon dioxide (CO_2). Fossil methane emissions can occur naturally within sedimentary basins, where thermal degradation of organic matter generates methane and other hydrocarbon gases. These gases migrate through geological faults and fractures before being released into the atmosphere. Additionally, emissions from the oil and gas sectors such as leaks in pipelines, failures in storage tanks, and during oil extraction also contribute to the overall methane emissions.

These emissions typically exhibit a plume-like dispersion pattern, originating from discrete point sources and being transported over several kilometers by prevailing winds, with flow rates exceeding 100 kg/h. A primary challenge in segmenting and classifying these plumes is differentiating them from the background. Methane has two main spectral absorption features, located in the short-wave infrared region at 1620-1720 nm and 2150-2500 nm, with only the latter being of significant relevance. The strength of the methane signal is directly proportional to its absorption depth. Consequently, hyperspectral remote sensing instruments equipped to capture data at wavelengths associated with methane absorptions can effectively identify and quantify point sources of these emissions due to their high spectral resolution.

The hyperspectral sensor EMIT (Earth Surface Mineral Dust Source Investigation), originally developed with the mission of exploring mineral dust and aerosol impacts on biogeochemical models, has a spectral range spanning 381 nm to 2493 nm across 285 bands. Although not specifically designed to detect CH_4 emissions, it is an effective tool due to its broad spectral range. Current efforts by researchers involve calibrating EMIT data with various algorithms to detect methane signatures, however, these models often require manual intervention, leading to substantial amounts of noise, false positives and misinterpretations. Advances in deep learning have allowed the usage of Convolutional Neural Networks (CNN) to segment, detect and classify mineral and gas signatures in hyperspectral imagery, the latest and most efficient method being Hyperspectral Mask-RCNN (H-MRCNN).

The proposed method utilizes two datasets derived from EMIT hyperspectral imagery. The first dataset is a 4-band image comprising red, blue and green L1A radiance data and a fourth band comprising the EMIT L2B Methane Enhancement Data (EMITL2BCH4ENH). This dataset is used for evaluating and validating the proposed H-MRCNN model, as well as tuning the binary plume detector. Annotation data is generated to train the model and during this process, the ResNet-101 architecture builds a feature pyramid and a Region Proposal Network (RPN), along with proposals to generate mask bounding boxes for each instance of an object detected. The second dataset, a 285 band L1A reflectance image, is used for testing the model.

The proposed goal is testing different epoch and training rate combinations and evaluating which produce the best masks for the methane plumes. Once the method is designed and trained, statistical analysis using TensorBoard will be performed, allowing for a quantification of the model in question.

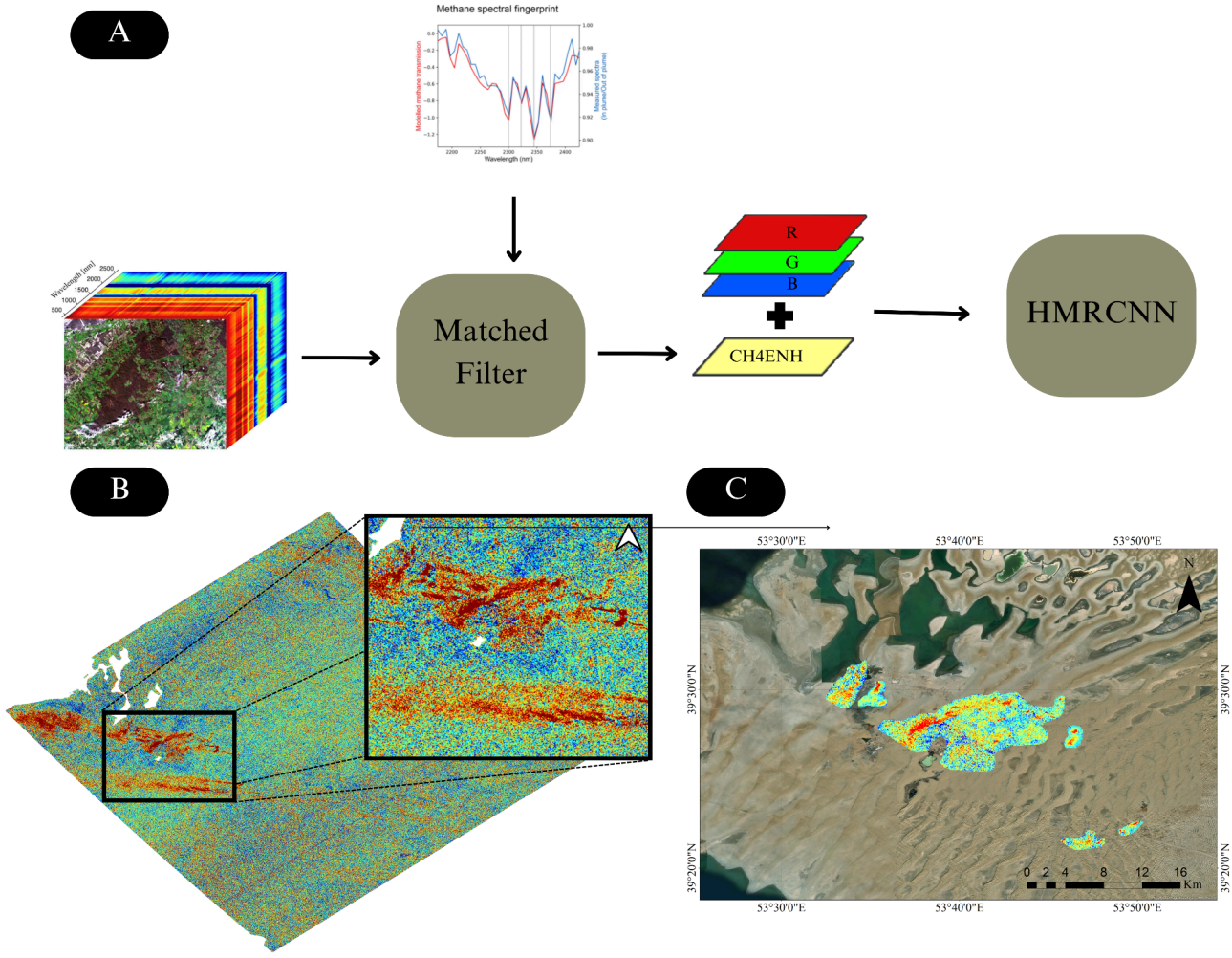

Figure 1. **A)** Processing pipeline for an EMIT Hyperspectral Image Cube **B)** Methane Enhancement Product (CH4ENH) from the test study area **C)** Methane plumes classified and segmented from the same image.