Early Detection of Underground Gas Leaks from Hyperspectral Imaging by Vegetation Indicators and Deep Learning

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Abstract

Early detection of underground natural gas release in pipeline transmission can not only reduce greenhouse effects but also prevent natural hazards. The timely identification of natural gas emissions remains difficult due to the limitations of current techniques. Vegetation indicators (VIs) based on hyperspectral imaging from remote sensing have been defined to monitor health deterioration to represent the stress occurrence due to natural gas leaks, but the sensitivity and separability of the VIs warrant further study. In this study, ground vegetation was used to sense underground methane emissions. Hyperspectral reflectance of vegetation was obtained weekly in two months of methane treatment. Modified Chlorophyll Absorption in Reflectance Index (MCARI) is most sensitive but with lower separability among physiology related VIs. Optimized Soil-Adjusted Vegetation Index (OSAVI) demonstrated both higher sensitivity and higher separability among natural gas specialized VIs. OSAVI discriminated vegetation stress after 21-day methane injection, which was confirmed by a deep neural network (DNN) at an accuracy of 98.4%. Spectra increase in VIS and decrease in NIR bands due to methane exposure.

Method

Four perforated PVC pipes were tested to simulate underground gas leakage and develop leak detection approaches. Two pipes in trenches, T1 and T2, were filled with methane at 50 liters per hour, 8 hours a day and 5 days a week. The methane concentration on the top of trenches ranged from 300-1200 ppm, mostly around 500-700 ppm. The ground covering the four pipes was scanned weekly to:

- Map VIs on the top of test trenches and surrounding areas, compare healthy with stressed vegetations, and quantify VIs difference between two groups of vegetations over time to detect the occurrence of stresses from gas treatments.
- Analyze hyperspectral images in time series through deep learning to distinguish the stressed from healthy plants through spectral changes due to gas leak influences.

Gas Leak Detection from VIs

The VIs studied are divided into two groups with representative OSAVI mapping of the test trenches w/wo gas treatments shown:

- Physiology related VIs (**MCARI**, mND705, PRI, WBI) based on the biochemical changes of plants when exposed to gas treatments.
- Gas specialized VIs (LIC, NGSI, **OSAVI**, VDMI) based on the most responsive VNIR bands to the natural gas treatments.

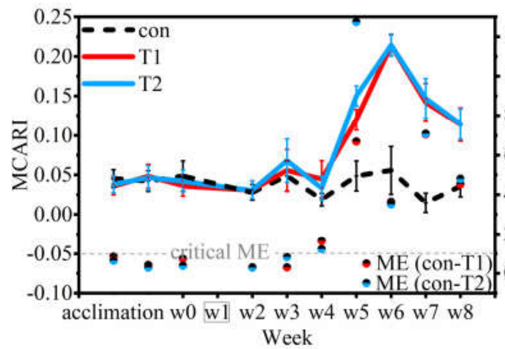


Fig. 1 Leak detection by physiology related VI - MCARI

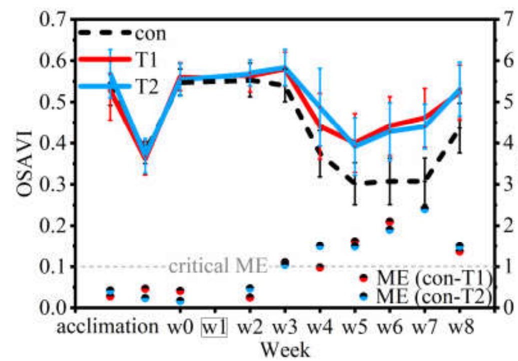
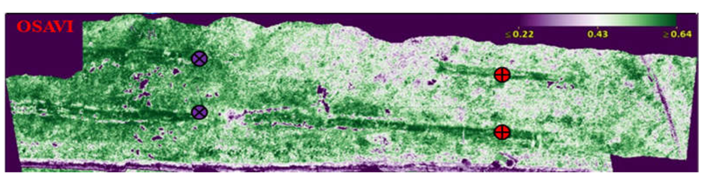


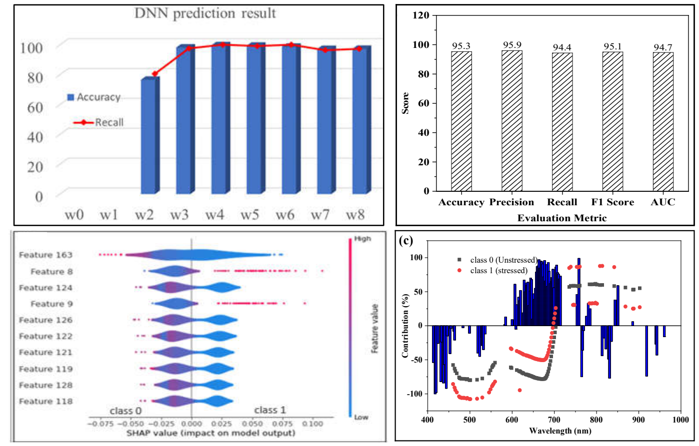
Fig. 2 Leak detection by gas specialized VI - OSAVI



Gas Leak Detection from DNN

A multilayer perceptron (MLP) DNN was developed:

- 8(weeks)×4(trenches)×2000(pixels) = 56,000 data points, 50% of which are for training and 50% for testing.
- 1 input and 5 hidden layer (512,1042, 2048,1024,512 neurons).
- Rectified Linear Unit (ReLU) activation in hidden layers and Sigmoid function for the last layer.



Conclusions

This study offered a method and tool to detect early gas leakage:

- OSAVI can determine gas leakage with high separability.
- DNN can identify gas leakage with a 98.4% accuracy after a 3-week gas treatment. Spectral reflectance of vegetations is more responsive to natural gas leaks in NIR and less in VIS.

Acknowledgement

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References

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