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RIVeR

Predictive Mapping of Spectral Signatures from RGB Imagery for Off-Road Terrain Analysis[1]

Sarvesh Prajapati, Ananya Trivedi, Bruce Maxwell, Taşkın Padır

Background

Estimating material and material properties has always been a challenging task in robotics. Using RGB image to predict these underlying properties is challenging and is mostly treated as a classification or segmentation problem which is good at learning representations but fails to capture physics-based information.

To tackle this problem, recent work uses different techniques like depth, haptics, spectroscopy, heat in conjunction with RGB, adding additional modality into the stack. In this work, we demonstrate the mapping of RGB images to Spectral Profiles of a given patch of material, which can be further utilized to estimate different material properties.

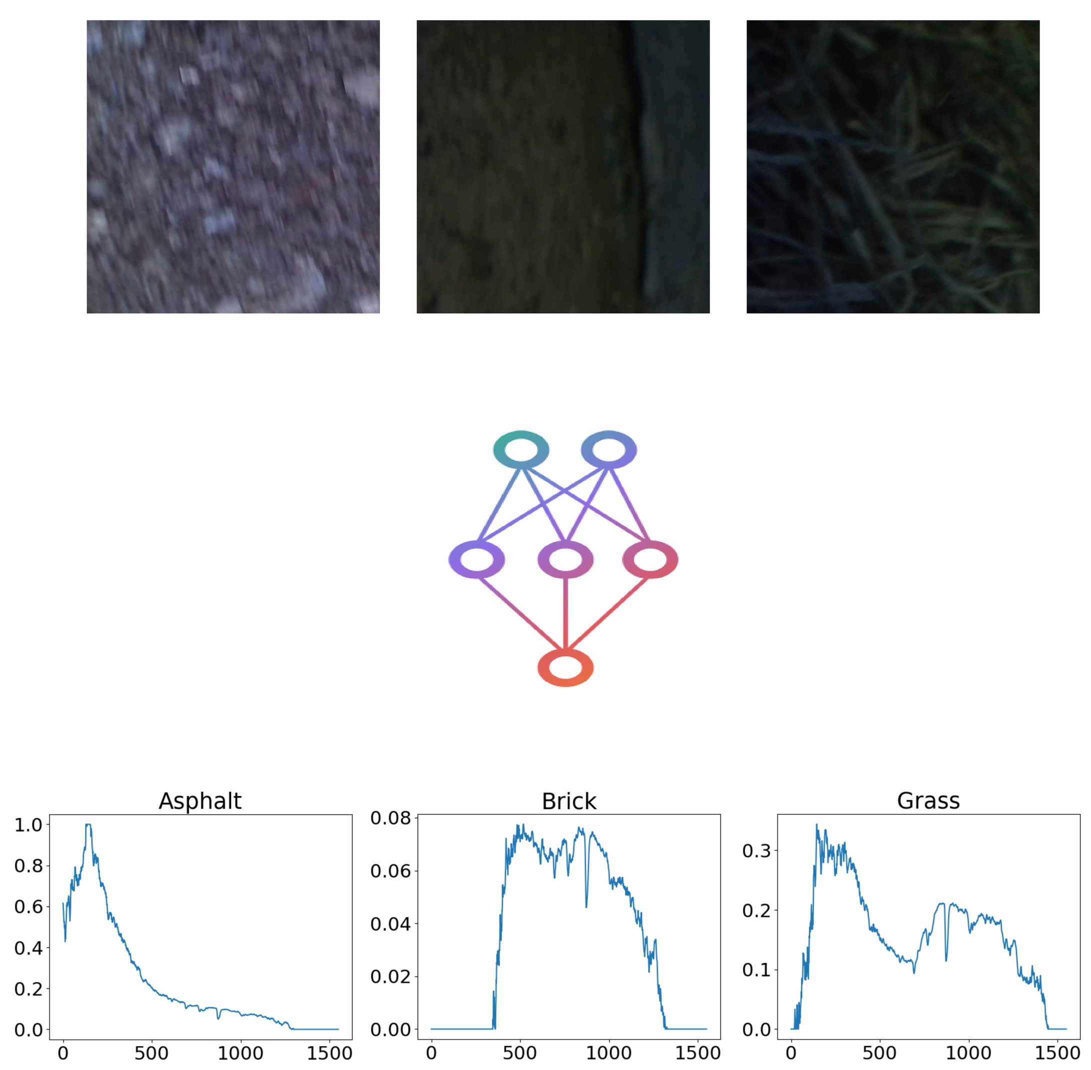

Fig. 1 Overall idea of the work, that maps RGB image to corresponding spectral profile

Methodology

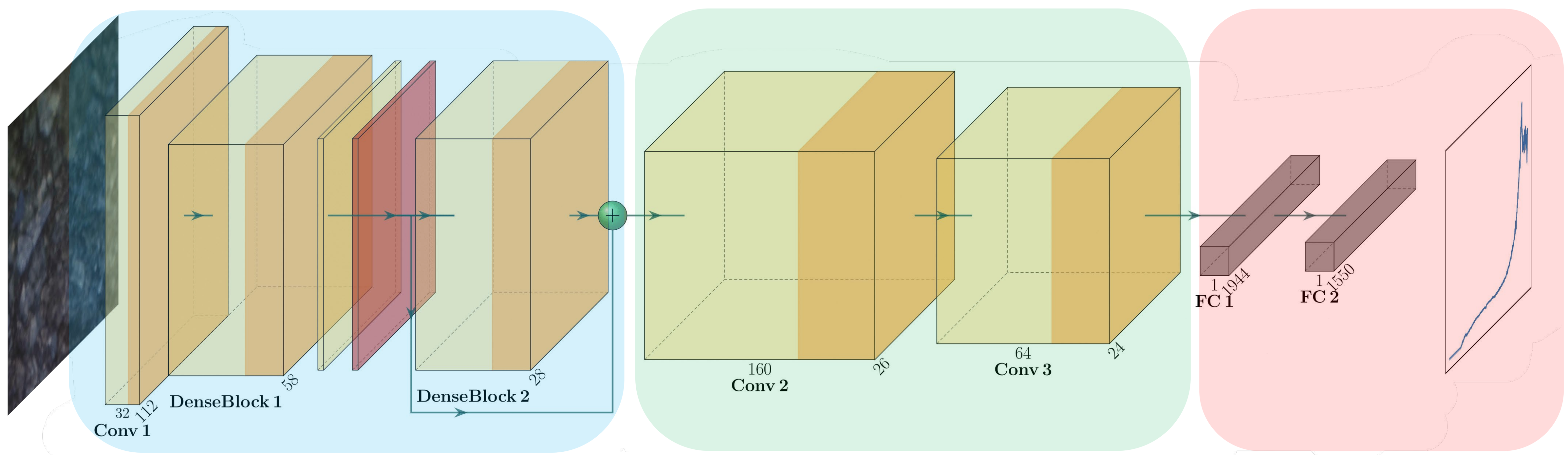

Fig. 2 RS-Net: End-to-End model for mapping RGB images to spectral profile. The input RGB image is passed through DenseNet's first and second dense block, output from first transitional layer is concatenated with output of second dense block, the feature maps are concatenated, passed through convolution and fully-connected layers for spectral mapping.

1. We propose RS-Net trained on VAST dataset [2] which comprises of RGB material patches with corresponding spectral profile.
2. The network consists of three parts, Feature Extraction, Channel-wise Convolution and Dimensionality Reduction.
3. The Feature Extraction extracts high-level features with fine-grain details, Channel-wise Convolution regularizes the representation and reduces dimensionality for efficiency. The Dimensionality Reduction layer predicts spectral profile based on regularized data.

Experiments

1. We train RS-Net on 6 out of 11 classes from the VAST dataset with MSE of 0.0015 Normalized Photon Count.
2. We pass predicted spectral profile to FCN for predicting terrain, Fig. 3 shows the result of classification.
3. Fig 4 shows output from RS-Net on grass, where x-axis is wavelength, and y-axis is normalized photon count.

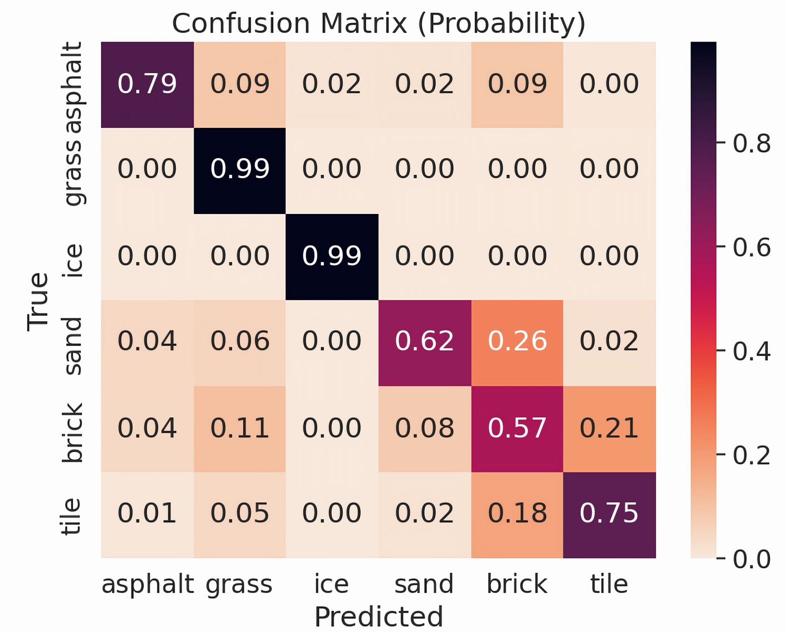

Fig. 3 Confusion matrix for terrain classification

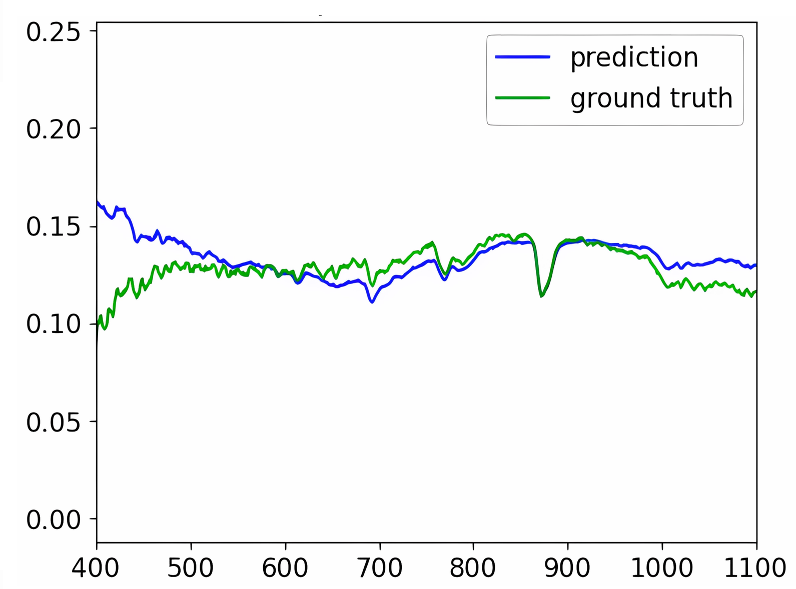

Fig. 4 Predicted v/s ground-truth for brick

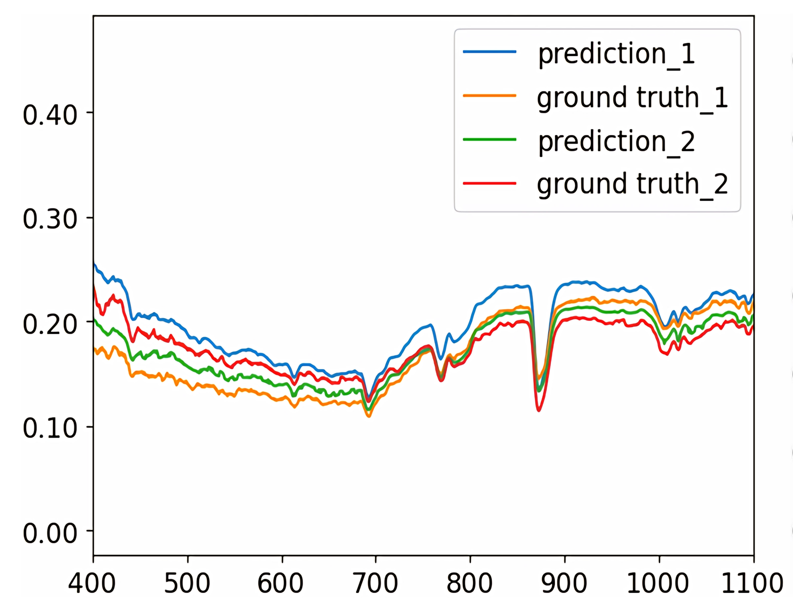

Fig. 5 Predicted v/s ground-truth for grass showing shift due to changes in environmental conditions.

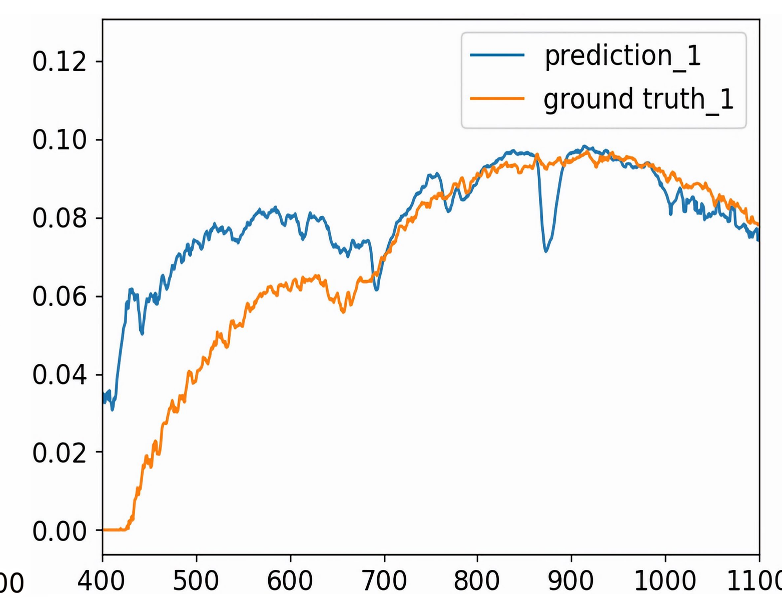

Fig. 6 Predicted v/s ground-truth for concrete which is not part of training data.

Findings

1. Environmental conditions affect physical properties of material, which can be seen in Spectral profiles (Fig 5).
2. RS-Net can learn representations for both seen and unseen data suggesting network is able to learn intrinsic parameters (Fig 6).

Future Work

1. Future work involves formulating a co-learning framework to learn physical properties based on spectral information like friction.
2. One of the disadvantages of spectral information is deployment challenges. Since the network's input is homogeneous material patch, deployment needs some sort of segmentation, therefore bottlenecking the potential of spectral data. To overcome this, we plan to use hyperspectral data instead.

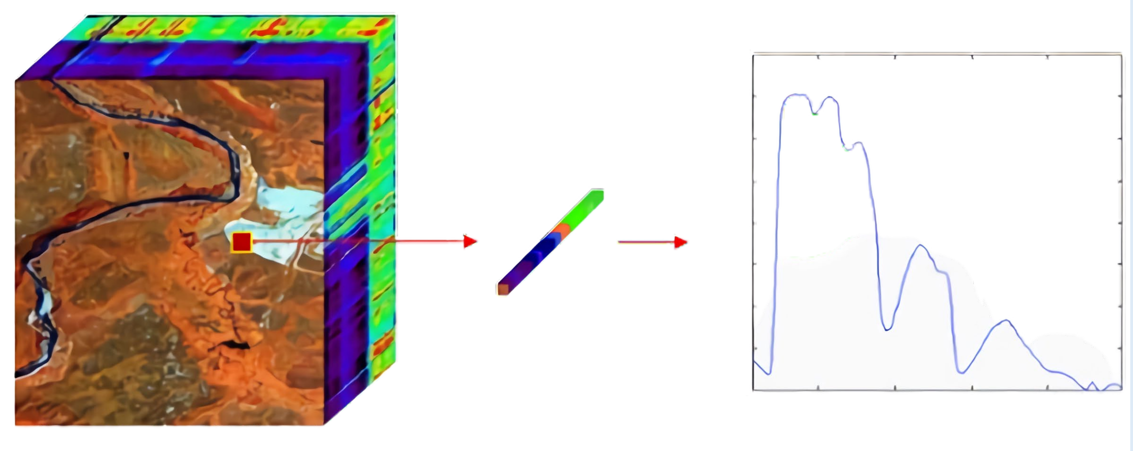

Fig. 7 Data cube of hyperspectral data, were each pixel contains spectral information along with RGB. Figure courtesy of [3].

References

[1] S. Prajapati, A. Trivedi, B. Maxwell, and T. Padir, Predictive Mapping of Spectral Signatures from RGB Imagery for Off-Road Terrain Analysis. 2024.

[2] N. Hanson, M. Shaham, D. Erdoğmuş and T. Padir, "VAST: Visual and Spectral Terrain Classification in Unstructured Multi-Class Environments," 2022 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Kyoto, Japan, 2022, pp. 3956-3963, doi: 10.1109/IROS47612.2022.9982078.

[3] https://udayton.edu/engineering/research/centers/vision_lab/research/was_data_analysis_and_processing/hyperspectral_data_processing.php