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Spatially Regularized Subspace-based Fusion for Multi-Sensor Image Features

Héctor Vargas(1), Juan M. Ramírez(2)
(1) Department of Electronic Engineering, Universidad Manuela Beltrán, Bogotá, 110231, Colombia e-mail: hector.vargas@docentes.umb.edu.co.
(2) IMDEA Networks Institute, Leganés, 28918, Spain e-mail: juan.ramirez@imdea.org.

Image fusion integrates complementary data from two or more images to synthesize a single composite representation with enhanced interpretative value, particularly in remote sensing applications [1]. Advances in satellite-based synthetic aperture radar (SAR) systems have enabled the capture of multisource geospatial data across diverse regions of the electromagnetic spectrum, including narrow and wide bands. These sensors produce heterogeneous yet synergistic information, such as high-resolution spectral, SAR, and RGB images, offering multifaceted perspectives of terrestrial scenes [2]. A comprehensive review of pixel-level fusion methodologies for merging SAR-derived features with RGB data is detailed in [3]. Among these modalities, hyperspectral imaging (HSI) systems acquire three-dimensional (3-D) datacubes, encoding rich spectral signatures of bidimensional (2-D) scenes. These signatures span the visible spectrum (VIS, 400-800 nm) to the near-infrared (NIR, 800-2400 nm), resolving hundreds of narrow contiguous bands via onboard spectrometers [4]. Unlike conventional RGB images, which prioritize spatial and color fidelity, HSI pixels encapsulate high-dimensional spectral profiles that reflect the intrinsic material properties of objects, thereby enabling precise scene classification. This discriminative capability has propelled the adoption of HSI in various domains, including precision agriculture and food quality assessment [5].

Prior research has predominantly focused on reconstructing high-spatial-resolution hyperspectral images (HSIs) through fusion of low-resolution HSI and high-resolution RGB data. Although such reconstruction-based methods aim to improve spatial fidelity, alternative approaches leveraging feature extraction, rather than direct recovery, have demonstrated potential to improve classifier accuracy while mitigating computational complexity. This work introduces a computational framework that directly extracts discriminative features from co-registered HSI and RGB sensor data, bypassing the conventional high-resolution HSI reconstruction step. The proposed method employs morphological operators in the RGB image to derive spatial structural features that are assumed to reside in a subspace distinct from the spectral signatures of the HSI. A subspace-based fusion model is formulated, where optimization parameters encode (i) the spatial features and (ii) the low-dimensional subspace matrices representing the HSI. These parameters are iteratively estimated via an alternating optimization (AO) strategy, alternating between updating the spatial features and refining the subspace representations. The optimization function incorporates a penalty term ensuring spatial smoothness while enhancing image edges. Then, the optimization function is solved efficiently using the alternating direction method of multipliers (ADMM).

- A mathematical model describes the feature fusion problem from data acquired by an HSI sensing system and an RGB sensor of the same scene. In particular, feature fusion becomes a constrained optimization problem whose loss function includes a regularization term inducing spatial smoothness while preserving image edges.
- A computational framework for the resultant constrained optimization problem, based on solving two optimization problems by combining AO and ADMM.
- A set of experiments on synthetic and real-world data sets including; Pavia University, Houston University 2013, and Houston University 2018 datasets, which show that the proposed method is empirically more effective than other state-of-the-art methods.

References

[1] L. Loncan, L. B. De Almeida, J. M. Bioucas-Dias, X. Briottet, J. Chanussot, N. Dobigeon, S. Fabre, W. Liao, G. A. Licciardi, M. Simoes *et al.*, “Hyperspectral pansharpening: A review,” *IEEE Geoscience and remote sensing magazine*, vol. 3, no. 3, pp. 27–46, 2015.

[2] P. Vouras, K. V. Mishra, A. Artusio-Glimpse, S. Pinilla, A. Xenaki, D. W. Griffith, and K. Egiazarian, “An overview of advances in signal processing techniques for classical and quantum wideband synthetic apertures,” *arXiv preprint arXiv:2205.05602*, 2022.

[3] S. C. Kulkarni and P. P. Rege, “Pixel level fusion techniques for sar and optical images: A review,” *Information Fusion*, vol. 59, pp. 13–29, 2020.

[4] J. M. Bioucas-Dias, A. Plaza, N. Dobigeon, M. Parente, Q. Du, P. Gader, and J. Chanussot, “Hyperspectral unmixing overview: Geometrical, statistical, and sparse regression-based approaches,” *IEEE journal of selected topics in applied earth observations and remote sensing*, vol. 5, no. 2, pp. 354–379, 2012.

[5] J. M. Bioucas-Dias, A. Plaza, G. Camps-Valls, P. Scheunders, N. Nasrabadi, and J. Chanussot, “Hyperspectral remote sensing data analysis and future challenges,” *IEEE Geoscience and remote sensing magazine*, vol. 1, no. 2, pp. 6–36, 2013.