# Special issue on *Multimodal data fusion for multidimensional signal processing*

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As one of the most important research topics, multidimensional signal processing is particularly emphasised for effective data analytics and interpretation. This has been successfully applied in a number of applications such as data compression, content extraction and retrieval, data mining, and classification, especially in video, hyperspectral imaging (HSI) and medical applications.

Recently, it has become a new trend to apply multimodal data fusion in multidimensional signal processing. This proves to be useful in not only effective feature extraction and data reduction but also data classification and decision making. Motivated by these strong interests, this Special Issue aims to report the progress in this research hotspot, where researchers can share their findings and exchange their approaches and results.

In this Special Issue, 11 papers are included which can be grouped into two thematic areas, i.e. fusion for denoising and enhancement of signal, and fusion for detection and classification as detailed below.

*Data fusion for denoising and enhancement of the signal*: In this group we have 5 papers, where the topics covered include pansharpening in multispectral and hyperspectral imagines, underwater video dehazing and compressed sensing for secure signal processing. By applying spatial-temporal and spatial-spectral fusion of multi-sourced data, the quality of the images is successfully improved.

The paper by Giorgio Licciardi, Gemine Vivone, Mauro Dalla Mura, Rocco Restaino and Jocelyn Chanussot presented an effective solution for pansharpening in hyperspectral imaging. By analyzing the drawbacks of two commonly used approaches, component substitution (CS) and multi-resolution analysis (MRA), a hybrid approach is proposed. A non-linear principal component analysis is also employed for dimensionality reduction. These have helped to improve the spatial resolution while preserving as much as possible of the original spectral information as well as reduction in the computational time.

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H. Hallabia, A. Kallel, A. Ben Hamida, and S. Le Hégarat-Mascle present a novel pansharpening method by using low-pass and high-pass filter banks for decomposition and reconstruction processing. The low-pass approximation of the pansharpened multispectral image is used to preserve the spectral quality whereas the high-pass filter facilitates obtaining the high-frequency panchromatic image details. Extensive experiments on Pléaides and GeoEye-1 data and comparisons with previous methods demonstrate the superiority of the proposed method.

In the paper from A. Mookambiga and V. Gomathi, a comprehensive review on fusion techniques for spatial information enhancement in hyperspectral imagery is presented. These have been categorized into two classes, i.e. hyperspectral pansharpening and hyperspectral image fusion with multispectral images. In addition to component substitution (CS) and multi-resolution analysis (MRA), matrix factorization and Bayesian approaches are also covered. Discussions on some available datasets and relevant measures for quantitative and qualitative assessment are also given. Some summarized challenges will also provide directions for future investigation.

Huimin Zhao, Wenguo Wei, Jun Cai, Fangyuan Lei, and Jianzhen Luo propose a novel integrated secure data processing framework for multi-sourced data fusion and processing. In the proposed framework, the distributed compressed sensing is adopted for outsourced data processing and recovering service. The generation of the pseudo-random sensing matrix can facilitate the data encryption in distributed compressed sensing, where joint recovery of multiparty data at legal users' side is achieved. Experimental results can demonstrate the proposed framework is effective and requires fewer measurements than other traditional methods. The proposed work can also be applied to other applications such as cloud-based collaborative secure signal processing and data mining.

In the paper proposed by Chunmei Qing, Feng Yu, Xiangmin Xu, Wenyou Huang and Jianxiu Jin, dehazing of underwater videos is focused to restore/enhance video degraded by medium scattering and light absorption. A spatial–temporal information fusion method is proposed, which include correlation based transmission estimation for color consistency and background light estimation to keep consistent atmospheric light values in a video. Comprehensive results have been demonstrated to validate its efficacy in terms of haze removing and color balancing capabilities.

*Data and feature fusion for improved detection and classification*: there are 6 papers contained in this group, where the topics covered include target detection and change detection in remote sensing, color image retrieval, image forgery detection, pedestrian detection and faked painting identification. In addition to conventional supervised learning such as support vector machine, new machine learning approaches such as deep learning, active learning and weakly supervised learning presented. Adaptive feature fusion is also introduced to avoid empirically parameter settings. These will provide useful insights for readers to further explore relevant techniques and applications.

The paper by Peicheng Zhou, Gong Cheng, Zhenbao Liu, Shuhui Bu and Xintao Hu proposed an inpainting-based depth-image-based rendering algorithm for virtual view synthesis. Simulation results show that the synthesized virtual images for the proposed DIBR system have better quality than those obtained using other works

(about 4–5 dB improvement). The parallel computation reduced runtime by 51 times and 25 times for generating nine and two views, respectively, compared to a single threaded approach. The method is realized on the compute unified device architecture parallel computing platform which runs on a graphics processing unit.

Y. Yan, J. Ren, Y. Li, J. Windmill, W. Ijomah and K.-M. Chao propose an adaptive fusion of color and spatial features for content-based retrieval of logo/trademark images. This is particularly important when these two features are combined in such applications, where weighting of these features can be optimized according to the image content. First, dominant colors are extracted via color quantization and k-means clustering. For each extracted dominant color, a component-based spatial descriptor is derived as local features. The significance of color features is used to measure the image quality and adaptive feature fusion. Experimental results have shown improved retrieval precision even with added Gaussian, salt and pepper, and speckle noise.

In the paper by Fei Gao, Wenchao Lv, Yaotian Zhang, Jinping Sun and Erfu Yang, a novel semisupervised support vector machine classifier is proposed to solve the problem of insufficient labeled samples, using active learning (AL) and context information. First, AL is employed to select unlabeled samples as semilabled samples, which are then relabelled by exploiting the context information. The relabelled samples are combined with labeled ones for training, along with a new query function to enhance the reliability of the classification and a fusion method to further enhance the robustness. Experimental results on change detection from real remote sensing images have shown significantly improved detection accuracy and efficiency.

J. Zheng, Y. Liu, J. Ren, T. Zhu, Y. Yan and H. Yang present a new approach for image forgery detection, using adaptive fusion of keypoint-based and block-based features. First, the image is segmented into non-overlapped regions, from which feature points are extracted using the scale invariant feature transform (SIFT). The ratio between the number of keypoints and the total number of pixels is used to classify a region into smooth or non-smooth (keypoints) regions. Accordingly, Zernike moments and SIFT features are respectively applied for effective forgery detection. Experimental results show that the proposed approach outperforms the keypoint-based method in reliability of detection and the block-based method in efficiency.

The paper by Jie Ren, Ming Xu, Jeremy Smith and Shi Cheng propose to apply multi-view and multi-plane data fusion for the robust detection of pedestrians in intelligent video surveillance. With the estimated homography, foreground regions are projected from multiple camera views to a reference view. The homographic transformations for a set of parallel planes, from the head plane to the ground, are applied to identify false-positive detections caused by foreground intersections of non-corresponding objects. Multiple features including occupancy information and color cues are also extracted from such planes for joint decision-making. Experimental results on real world sequences have validated the good performance of the proposed approach.

Zheng Wang, Dongying Lu, Dong Zhang, Meijun Sun, and Yan Zhou propose to leverage the hyperspectral image for identifying of fake Chinese paintings. Chinese paintings are scanned by a visual band hyperspectral camera with the spectral frequency ranging from 400nm to 900nm. Afterwards, the spectral and spatial features are extracted based on principal component analysis and convolution neural network, respectively. Finally, the extracted spectral features and spatial features are combined

to train a support vector machines for classification. Extensive evaluations can demonstrate the effectiveness of the proposed approach.