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Guest Editorial

Multi-dimensional image processing

1. Background and motivation

Multi-dimensional image processing is of paramount importance in areas such as multimedia, robotics, computer vision, graphics, biomedical engineering and industrial inspection. The growing interest in the development of multi-dimensional image processing techniques should be attributed primarily to the importance of color image and video processing and analysis. Practitioners and end-users deal with multi-dimensional data sets in emerging applications such as digital image indexing and archiving, web-based processing of color images and videos, virtual restoration of artworks, multimedia sequence mining and cDNA micro-array image processing. The surge of emerging applications and the proliferation of multimedia devices, as well as imaging-enabled consumer electronic devices suggest that the search for new, more efficient multi-dimensional image processing tools and solutions will continue.

During the last two decades, technological advances in hardware and software have allowed for replacement of the two-dimensional (2D) image processing techniques with their three-dimensional (3D) or higher order (multi-dimensional) counter parts. For example, in the past 2D processing of image sequences or motion videos used to rely on processing the individual frames separately. However, motion videos represent a true 3D image signal or a time sequence of 2D images which exhibits significant correlation in both the spatial and temporal domain. By omitting the essential temporal correlation of the visual data, 2D solutions generate output videos with noticeable motion artifacts. To avoid visual impairments, spatiotemporal techniques, such as various de-noising, enhancement and compression solutions, process the input video as a 3D image signal with emphasis on motion estimation and analysis. Coupled with feature extraction methods, multi-dimensional image processing concepts have been applied recently to video analysis, summarization, and retrieval with great success.

In parallel with the development of new, efficient and cost effective processing of motion videos, the need for high-quality image output has boosted research in the general area of color image processing, image analysis, and perceptual image evaluation. It is well known that a digital RGB color image can be viewed as a two-dimensional array of the three-dimensional, vectorial samples. In the early days of color image processing, many of the solutions originally developed for processing monochrome (gray-scale) images were used extensively for processing color visual data since each individual channel in the RGB color image can be considered a monochrome image. However, by ignoring the essential spectral correlation that exists amongst the three color channels, these so-called component-wise color processing techniques often generate images with color shifts and perceptual artifacts. This necessitates the use of vector processing of color images and video frames. Processing color pixels as vectors, vector-based solutions utilize the inherent correlation amongst the three color channels, thus reducing color artifacts and producing visually pleasing results. Given the excellent performance characteristics of vector-based solutions, they have been widely used in a variety of color image processing tasks, such as noise detection and removal, image enhancement, edge detection, image segmentation, image retrieval, and spatial interpolation.

This brief overview outlines image processing and computer vision applications which deal with multi-dimensional image data, and which require innovative imaging solutions to be developed or adapted to address particular tasks. In many of these applications, multi-dimensional imaging solutions must operate in real-time, a requirement with significant implications for both the development of cost effective imaging solutions as well as their integration in electronic devices. It should, therefore, come as no surprise that the Real Time Imaging Journal is the venue for presentation of the state-of-the-art solutions in multi-dimensional image processing.

2. Quick facts about the special issue

The idea of putting together the Special Issue on Multi-Dimensional Image Processing was suggested to the Editorial Board by the Guest Editors in late summer of 2004. By November 2004, the outline and schedule of the Special Issue were established by the Guest Editors, the Editor-in-Chief, and the Publisher Manager. The first call for papers was distributed through the Internet in November 2004. The announcement appeared, both on the journal web-site and in print in the journal issue in

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December 2004. Between March and June 2005, a total of 22 manuscripts were submitted for review and possible inclusion in the Special Issue. Each one of the submitted manuscripts was reviewed by three experts in the field of color image and video processing. Between May and August 2005, two rigorous review rounds were completed. It is our hope that the selected ten accepted papers illustrate relevant solutions to fundamental challenges in multi-dimensional image processing research and will prove useful to researchers and practitioners in the area.

3. Scanning the special issue

This Special Issue attempts to provide a comprehensive overview of the most recent trends in multi-dimensional image processing. The papers included in the issue focus on various topics central to developments in the field. Accepted papers cover both theoretical and practical aspects of the multi-dimensional imaging pipeline, ranging from image acquisition, to image and video coding, to color image processing and analysis, to color image encryption, and finally to 3D digital curves imaging.

The special issue opens with a paper authored by F. Tsalakanidou et al. entitled "*Real-Time Acquisition of Depth and Color Images Using Structured Light*." They propose a novel 3D color sensor to acquire both the range data and 2D color representation of the scene and to allow the combination of 2D and 3D processing of the acquired image data. The presented methods, used to encode and recognize the projected light, make the system practically independent of intrinsic object colors and minimize the influence of ambient light conditions. Face authentication is used to demonstrate the usefulness of the developed system, where 3D information is used for the normalization of the input images as well as for robust face detection, localization and 3D pose estimation.

L. Zhang et al. propose in their paper entitled "*Real-Time Lossless Compression of Mosaic Video Sequences*" a fast coding technique for lossless compression of video data captured using a single-sensor video camera. Since a color filter array is placed on top of the single image sensor, the captured video is in gray-scale mosaic-like format, imposing specific design constraints on the compression solution. The authors achieve the essential balance between codec throughput and compression performance by proposing a hybrid coding scheme. Frames with modest motion activity are processed using an inter-frame predictive coding approach, whereas intra-frame coding is used to process remaining frames of the captured video.

N. Sprljan et al. introduce a new implementation of wavelet packet decomposition to obtain a "*Modified SPIHT Algorithm for Wavelet Packet Image Coding*". Analysis of the problems arising from the application of zerotree quantization-based algorithms to wavelet packet transform coefficients is provided and generalized parent–child relationships for wavelet packets are established. The presented wavelet packet cost-function enables good energy compaction and results in excellent performance of the coding scheme for texture images. The developed algorithm is flexible and can accommodate various cost functions.

B. Smolka and A. Chydzinski propose an approach to "*Fast Detection and Impulsive Noise Removal in Color Images*". The proposed vector filter employs the peer group concept to switch between an identity operation and a robust nonlinear smoothing filter, resulting in the preservation of edges and fine details in the image while eliminating detected outliers. The filter is proven to be robust in suppressing both random and fixed-valued impulsive noise, and computationally simple making it attractive for various applications.

Z. Ma et al. introduce "*A Neighborhood Evaluated Adaptive Vector Filter for Suppression of Impulse Noise in Color Images*". Their method utilizes the strong correlation between the modified aggregated distances and local image distribution to form an adaptive switching rule which is essential in filtering of color images corrupted by impulsive noise. The two filter's parameters can be configured efficiently using online or offline optimization processes, keeping the computational complexity of the new filter at a level acceptable in practice.

S. Morillas et al. propose in their paper entitled "*A Fast Impulsive Noise Color Image Filter Using Fuzzy Metrics*" a new fuzzy metric for calculation of the aggregated distances between color pixels inside the filtering window. Building on the prior-art filtering concepts, the aggregated distances obtained using the developed fuzzy metric serve as an criterion to adaptively determine one of the input color vectors as the filter output. The proposed filter can achieve the balance between noise suppression and signal-detail preservation.

C. Doignon et al. address in their paper entitled "*Real-Time Segmentation of Surgical Instruments Inside the Abdominal Cavity Using a Joint Hue Saturation Color Feature*" an image processing approach suitable for robotized minimally invasive surgery. An automated color segmentation technique based on a discriminate color feature and an adaptive region growing with automated region seed detection and a model-based region classification are proposed for application in laparoscopy. The performance of the approach is evaluated using endoscopic image sequences to efficiently locate boundaries of a landmark-free needle-holder at half the video-rate.

N. Kim and N. Kehtarnavaz in their paper entitled "*DWT-Based Scene-Adaptive Color Quantization*" present an automated scene-adaptive color quantization method. The discrete wavelet transform is used to achieve a computationally efficient implementation of the multi-scale clustering algorithm in a 3D color space. In order to achieve higher color image compression rates for storage and transmission purposes, the proposed method reduces the number of representative colors in the image while keeping color distortion to an acceptable level.

R. Lukac and K.N. Plataniotis propose "*A Cost-Effective Encryption Scheme for Color Images*". Their scheme takes advantage of image secret sharing, pixel-based logical operations and bit-level-based processing concepts, and encrypts the secret color image into two color shares. The encryption procedure alters both the spatial and spectral characteristics of the input image and the produced shares, whereas the decryption procedure recovers the secret image with perfect reconstruction. Such a solution can secure transmission of color images over untrusted networks or it can serve as a private-key cryptosystem.

This Special Issue concludes with the paper by J. Glasa who proposes a method for "*Least-Squares Smoothing of 3D Digital Curves*". His method is described by linear operators which allow to perform the constrained, position invariant, least-squares smoothing of 3D digital curves. The approach minimizes the processing error and uses sparse symmetric circulant Toeplitz matrices with integer coefficients to represent various curve characteristics and invariants related to the original digitized curve.

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