SPECTRAL IMAGING FOR REAL-TIME IMAGING PRINCIPLES AND APPLICATIONS

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Guest Editorial

The journal of Real-Time Imaging has reported for a decade recent developments in real-time image processing in a very large range of applications. This demonstrates the maturity of the technology and its spread into many industrial fields.

"Classical Image Processing" grew mainly out of machine vision applications by exploiting the luminance information in industrial scenes, investigating either single shots of grey value images as still images, extracting additional stereo information from multiple camera positions, or grabbing continuously changing spatial luminance in image sequences. Colour was the supplementary dimension for simple discrimination via selective spectral features. Nowadays, many methods originally developed for grey value image processing are applied to multi-colour data arrays, although special considerations need to be taken into account for the sensors capturing data (e.g.

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single or multi-chip CCD or CMOS cameras), the illumination (by different colour temperature and spectral characteristics), and the colour system used (R G B, I H S, etc.) in which the colour spectrum is decomposed.

In particular, in cases where colour is used as the main discriminating feature, one has to see whether additional data introduced by colour is really useful or non-redundant information that the increase in data quantity is justifiable. Alternatively, one should see to what extent spectral bands beyond the visible range have the potential to contribute additional information that cannot be gathered otherwise from the visible range.

In the course of special issues of this journal, this is the second issue dedicated to the field of Spectral Imaging (SI). In principle, SI is an extension of grey-scale or colour imaging to the capturing and processing of spatially resolved spectral information within certain bands of the electromagnetic spectrum, (i.e. UV, visible, NIR, MIR, IR, etc.). Although some researchers working in the field of SI would like to adopt this definition, other colleagues feel that well hosted under this umbrella are those contributions still dealing with colour images which make use of only three spectral channels, e.g. RGB. These different views on the definition of SI are mirrored in the contributions made to this Special Issue on Spectral Imaging II.

Having achieved remarkable attention to the first Special Issue on Spectral Imaging [1], approximately two years later it seems that spectral imaging is progressing well and conquering various new application fields. It is proceeding to become mature allowing its real-time performance in industrial, agricultural and environmental applications where the ratio of price and user benefit defines the commercial margins for successful adoptions. This breakthrough has been mostly enabled by the improvements in computer technology and because of developments in novel optical equipment such as Specim's ImSpector* [2]. This dispersive optical component uses a prism-grating-prism (PGP) element that splits the light into its spectral bands. C-mounted between a lens and a CCD-camera, this set-up generates a spectrophotometer that delivers a new dimension in contact-free inspection techniques beyond simple visual analysis. In addition to spatial features including form, size, position, orientation or surface properties, such as texture, supplementary spectral data can be exploited for analyzing ingredients and chemical components, noting that spectral imaging captures both spatial and spectral properties within the specimen. Unfortunately, this leads to a considerable increase in the dimensionality or amount of data to be processed!

Recording image data by an aforementioned set-up involving a CCD-array camera as a detector, the optical lens projects object reflections as dispersed light via the PGP-device and the slit of the aperture onto the sensor grid. Spatial data parallel to the slit are registered along the x-axis of the detector array while the spectral bands of the dispersed light are recorded along the y-axis. Up to this stage of processing, the resulting sensor system could be denoted as a line camera providing full spectral information in each pixel of its line, delivering the spatial and spectral coincidence simultaneously. Moving either the object with respect to the spectral imaging system setup or a spectral imaging system setup with respect to the object perpendicular to the slit allows one to record the 2nd spatial dimension over time into a 3rd dimension of a data array (data cube). Data values represent spectral intensities as the 4th dimension in this representation, considerably increasing the volume of data as compared to conventional grey-value or colour-value image processing.

Spatial information plus spectral information greatly increases the amount of data and can easily overload commonly used computer memory and processing capabilities. Feature extraction but also

* ImSpector is a product of SPECIM, Spectral Imaging Oy Ltd., Oulu, Finland

reduction of the feature space by removal of redundant information as well as subsequent processing of data require adapting algorithms for material classification and measurement systems. Examples are online classification systems for material sorting or colour measurement.
Of course, camera objectives, illumination, and sensors have to be selected carefully for a particular spectral analysis and coherent calibration of the set-up. Furthermore, normalization of data demands particular adaptations to the task and environmental conditions. Classification of spectral data has to address the extra dimensional semantics of the feature space and has to deal with various problems dedicated to the physical character of the acquired data.

Beside this essential problem, on-going issues of illumination, calibration and particular imaging set-ups are still non-standard in SI with the difference to inspection tasks based on conventional imaging so that the complexity of appropriate solutions is usually much higher.

Application areas currently envisaged from different R&D groups within an incoherent arena are novel imaging, inspection and control for sorting and analysis systems for

i. Recycling and waste treatment
ii. Food industry, e.g. for food quality and safety control
iii. Agricultural industry, e.g. within the process of sorting fruits by a harvesting machine
iv. (Bio-) medical systems, e.g. for contact free in-vivo analysis and diagnosis systems
v. Chemical industry (colour measurements on industrial powders)
vi. Pharmaceutical industry (active agent distribution in pills)
vii. Cost-effective rapid analysis and authenticity control for industrial real-time and on-line quality control with inherent material classification

Currently, first solutions for sorting of polymer bottles in real-time or glass material and paper pulp for recycling purposes just touch the threshold of becoming commercially interesting and meet user needs, i.e. this is the actual front-end of technology! Unfortunately, the technology suffers from

- The great amount of hand-crafted engineering
- Limited spectral range of sensors and coherently reduced material and substance discrimination capabilities
- Bottle-neck to get appropriate components for reasonable prices
- Monopoly of few equipment providers with related prices that can be covered only by budgets for space and defence programs, i.e. not attractive for industrial applications

The state-of-the-art technology include investigations of recognition and discrimination of plastic, paper and glass for sorting in recycling but not yet solved as a standard application. First trials of experimental systems are installed. A breakthrough could be achieved by extending the IR-range from1700nm to 2400 and beyond demanding new sensor materials but also new developments of components and algorithms for the entire process and data processing chain enabling applications (ii) to (vii) on the above list in its full range. The interested reader will find further information in [3-5].

All the aforementioned aspects motivated the Authors of the Real-Time Imaging’s Special Issue on Spectral Imaging II to contribute some interesting articles dealing with particular approaches to solve problems ranging from agricultural applications to waste recycling. This special issue comprises eight papers dealing with image spectra in quite different ways that can be clustered due to applications and the spectral bands used either restricted on the visible range (VIS) of color images or beyond extending the range either to shorter (UV) or longer wavelengths in the NIR and data fusion of different kinds.

The first article is about early disease detection in remote sensing but ground based crop inspection making use of multi-sensorial data fusion with a neural network based classifier (SOM). The second article deals with a multi-spectral imaging system providing six bands that may be located in the VIS and NIR spectra for application fields of fruit quality assessment, agriculture, and environmental monitoring. The third paper discusses classification methods for cellulose based materials such as pulp, paper and cardboard as well as hardware requirements for industrial use of SI including adjustment and calibration techniques making use of a PGP element for spectral imaging.

The field of spectral imaging can also subsume classical colour image signal processing. Consequently, this issue also contains four articles where data recorded by conventional RGB cameras. This principle is extended in the fourth paper by adding more colours by additional cameras to increase the colour gamut but alignment of pictures is achieved virtually in software for synthesis and display to achieve real-time performance. The fifth article also presents a method for full spectral rendering making use of wavelet transform for a novel progressive refinement algorithm. The following two papers are focussed on processing of colour filter array (CFA) data for digital zooming and post processing for enhanced demosaiced camera images. The last paper again uses the wavelet transform for HDTV compression but not for broadcasting purposes but for three-band (R, G, B) remote sensing applications taking advantage of the high resolution and fast-capturing capabilities of HDTV compared to photographic alternatives.

These articles can only spot some aspects of this new and emerging field of spectral imaging for challenging real-time applications demonstrating the performance and the potential if additional information beyond the visual spectral range can be exploited for visual control and decision processes.

Particular thanks are given to both the Authors and the Referees, who all contributed to this special issue on spectral imaging. I would also like to acknowledge the valuable management done by the administrative office of Elsevier.

Looking forward to have this special issue as another step towards a breakthrough for SI technology in new applications and a higher level of quality of results fusing data of chemical characteristics taken from invisible bands of spectra and merge them with luminance and shape based features, I encourage other authors to submit papers to Real-Time Imaging focussing on the subject of spectral imaging as related to the scope of this journal.

Yours

Guest editor

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