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Snapshot hyperspectral imaging probe with principal component analysis and confidence ellipse for classification

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ABSTRACT

Hyperspectral imaging combines imaging and spectroscopy to provide detailed spectral information for each spatial point in the image. This gives a three-dimensional spatial-spatial-spectral datacube with hundreds of spectral images. Probe-based hyperspectral imaging systems have been developed so that they can be used in regions where conventional table-top platforms would find it difficult to access. A fiber bundle, which is made up of specially-arranged optical fibers, has recently been developed and integrated with a spectrograph-based hyperspectral imager. This forms a snapshot hyperspectral imaging probe, which is able to form a datacube using the information from each scan. Compared to the other configurations, which require sequential scanning to form a datacube, the snapshot configuration is preferred in real-time applications where motion artifacts and pixel misregistration can be minimized. Principal component analysis is a dimension-reducing technique that can be applied in hyperspectral imaging to convert the spectral information into uncorrelated variables known as principal components. A confidence ellipse can be used to define the region of each class in the principal component feature space and for classification. This paper demonstrates the use of the snapshot hyperspectral imaging probe to acquire data from samples of different colors. The spectral library of each sample was acquired and then analyzed using principal component analysis. Confidence ellipse was then applied to the principal components of each sample and used as the classification criteria. The results show that the applied analysis can be used to perform classification of the spectral data acquired using the snapshot hyperspectral imaging probe.

Keywords: Hyperspectral imaging, fiber bundle, snapshot, integral field spectroscopy, classification.

1. INTRODUCTION

Many optical systems and related instrumentations have been developed using the concepts of bulk optics and fiber optics for applications such as imaging,¹⁻⁵ communications^{6, 7} and lithography.⁸⁻¹¹ Hyperspectral imaging (HSI) is an imaging technique that provides spectroscopic information for each spatial point in the imaged scene.¹² Spectral information can be acquired from hundreds of wavelength bands¹³ and the data acquired can be arranged in a three-dimensional (3D) spatial-spatial-spectral datacube. HSI provides a wealth of information which can then be used for identification and quantification to reveal important information of the imaged scene,¹⁴ by applying data analysis techniques such as principal component analysis (PCA) and spectral unmixing.¹⁵ HSI has been used to predict beef tenderness,¹⁶ monitor chemical degradation of glass-fiber composites¹⁷ and measure oxygen saturation in the retina.¹⁸

The configurations of HSI systems can be broken down into three main categories, namely the spatial-scanning, spectral-scanning and snapshot imagers. These configurations differ in how the data is acquired in each scan. In a spatial-scanning hyperspectral (HS) imager, the spectrum is acquired from a limited part of the scene in each scan. The spectral information can be acquired from one point (whiskbroom) or one line across the scene (pushbroom).¹⁹ Repeated scanning is required so that the whole scene is imaged before the datacube can be formed. Spatial-scanning HS imagers usually use prism-grating-prism spectrograph for spectral dispersion before the light is detected by the sensor array of the camera.²⁰ A spectral-scanning HS imager captures the image of the entire scene in each scan, but only that of a narrow wavelength band. This is due to such imager using a tunable filter, whose spectral transmission can be electronically controlled.²¹ Repeated scanning of different wavelengths is required so that images of different wavelengths are acquired before the datacube can be formed. Snapshot HS imagers capture all the information required to form a datacube in a single integration period of the camera. Therefore, unlike the spatial- and spectral-scanning HS imagers, snapshot HS imager does not need to perform repeated scanning to build a datacube.²² Snapshot HS imager is preferred in real-time applications for fast-changing events such as missile plume phenomenology.²³

Diseases can occur within the body where table-top optical imaging systems cannot be used to investigate these sites. Therefore, HS endoscopes have been developed so that HSI can be performed on sites that are not accessible by table-top HSI systems. Endoscopic HSI systems have been developed using the spatial-scanning, spectral-scanning and snapshot configurations.^{1, 24, 25} Recently, an endoscopic snapshot HS imager has been developed, using the concept of integral field spectroscopy (IFS).²⁶ IFS uses a reformatter where the fiberlets are arranged in a two-dimensional (2D) array on one end, and rearranged to form a one-dimensional (1D) row on the other end.²⁷ When the image of the scene is captured by the 2D end and transferred to the 1D end, the number of spatial dimension of the image is reduced from two to one. This enables the HSI system to use the spatial (collapsed)-spectral image captured in a single integration period to form a datacube, after the remapping of the spectra collected from the 1D end of the fiber bundle to the corresponding positions on the 2D end.

The recently reported endoscopic snapshot HSI system using IFS uses a custom-fabricated 2D to 1D fiber bundle with 100 fiberlets.²⁸ These fiberlets are arranged in a 10×10 hexagonal array on the 2D end, and rearranged to form a row of 100 fiberlets on the 1D end. The fiber bundle is made flexible along its length with a distal end of a small profile so that it can also be used as an endoscope for probing.²⁶ This paper demonstrates the use of this endoscopic snapshot HS imager to acquire data from samples of different colors. The spectral library of each sample is acquired and analyzed using PCA, which is a dimension-reducing technique to convert the spectral information into uncorrelated variables known as principal components (PCs).²⁹ A 99% confidence ellipse (CE) is drawn around the PC scores of each sample and used as the classification criteria. The results show that the applied analysis can be used to perform classification of the spectral data.

2. METHODS

2.1 Experimental setup

The experimental setup is the same as earlier reported.²⁶ The system captures 756 wavelength bands within the spectral range from 400 nm to 1000 nm. Imaging was done in reflectance mode using a broadband light source (MI-150, Edmund Optics). The samples are tapes of different colors (green, grey, white and yellow) placed on glass slides (Figure 1). All the imaged objects were placed at ~0.5 mm away from the 2D end-face of the fiber bundle. Images were acquired at a rate of ~6.16 Hz.

Figure 1: Reference samples using tape of different colors on glass slides.

2.2 Data processing

Data processing was done offline using MATLAB®. In order to get the reflectance data, the sample data are corrected by white reference using a 99% reflectance standard (SRS-99-010, Labsphere) and dark reference.

The spectral library of each sample is built by collecting the spectra in 20 frames. The sample is moved using a mechanical stage during the capturing of the 20 frames, with each frame producing 99 spectra (99 active fiberlets out of 100 fiberlets). Therefore, 1980 spectra are used as the reference spectra of each class. The reference spectra of all classes are then compiled to form the spectral library.

PCA is performed on the spectral library using the “princomp” function in MATLAB®. The first and second PCs (PC1 and PC2) are considered and they explain ~99% of the variance in the spectral library. A score plot is acquired by plotting PC2 against PC1. The PC coefficients describe the relationship between the original variables (spectral bands) and the PCs, and are required in further analysis to convert spectral bands into PCs for classification.

A 99% CE is drawn around the PC scores of each class in the PC feature space. It is a statistical tool representing an area on the score plot with 99% probability that the PC score of the class lies within it. If the PC score of a spatial point falls within the CE, that spatial point will be classified under the same class.

In order to perform classification, each spectrum is converted into PC1 and PC2 using the PC coefficients of the spectral library found earlier. This is followed by the classification of the spectrum by checking if its PC score falls within the 99% CE of one class. If the result is positive, this spatial point is classified as that class. Otherwise, the PC score would be checked with the next class. If the spatial point is still not assigned to a known class, it will be classified as unknown class. This classification process was used for every spectrum. There may be a situation where there is a small overlap in the 99% CEs of the different classes. When the PC score of the spatial point falls within these overlapped areas, it is classified under the first class which gives a positive result, as there was no further classification for this spectrum.

3. RESULTS AND DISCUSSION

3.1 Spectral library

The mean and standard deviation of each set of 1980 spectra for all reference samples are shown in Figure 2. HSI can be used to acquire the detailed spectral characteristics of the imaged scene and it can be observed from Figure 2 that the mean reflectance spectra of the samples can be easily distinguished from each other.

Figure 2: Mean reflectance spectra (bold lines) with standard deviation (dotted lines) of samples in spectral library.

3.2 PCA and 99% CE

All the spectra in the spectral library are processed using PCA and this is followed by extracting PC1 and PC2 for all the spectra. The amount of variance explained by PC1 and PC2 are 87.16% and 11.85%, respectively. Based on the PC1 and PC2 from each reference sample, a 99% CE is drawn around the cluster of PC scores of each sample in the PC feature space, as shown in Figure 3. Although the clusters of PC scores of the green and grey reference samples can be differentiated, they are much closer to each other compared to other reference samples. This is due to their spectra having more similarities when compared to the other reference samples.

Figure 3: PCA score plot of spectral library with 99% CE of each reference sample.

3.3 Classification

As an initial study, another four samples of the same types as the reference samples are used as test samples. A frame is acquired from each test sample and the spectra from each frame are converted into PC1 and PC2 and plotted in the PC

feature space (Figure 4). If the PC score falls within a CE, the spectrum is classified as the same class as the CE. Otherwise, it will be classified as unknown. It can be observed from Figure 4(a) that the PC scores of some spectra from yellow test sample fall just outside the 99% CE of yellow reference samples, and will thus be classified as unknown. In Figure 4(b), the PC scores of the green and grey test samples fall within their respective CEs, and will thus be correctly classified. There is also a small overlap between the CEs of green and grey reference samples. In the event where the PC score to be classified falls within this overlapped area, it will be classified as green in this study.

Figure 4: PCA score plots showing the PC scores of reference and test samples. (a) Yellow and (b) green and grey samples.

After classification of each spectrum, the results are then mapped accordingly to also show the positions on the 2D end-face of the fiber bundle from which the spectra were collected. As shown in Figure 5, all the spectra from the green and grey test samples are correctly classified as the PC scores fall within the respective CEs [Figure 4(b)]. There are 9 spectra from white test sample and 19 spectra from yellow test sample that are classified as unknown. The PC scores of these spectra fall outside but lie very close to their respective CEs.

Figure 5: Classification mappings showing results from imaging (a) green, (b) grey, (c) white and (d) yellow test samples.

4. CONCLUSION

An endoscopic snapshot HS imager using the concept of IFS has been recently reported.²⁶ A custom-fabricated 2D to 1D fiber bundle is used as a reformatter to perform spatial transformation of the scene. The full data of the scene can be captured in one scan, making it a snapshot configuration. The fiber bundle is made to be flexible along its length with a distal end of a small profile so that it can be used as an endoscope. The paper demonstrated the use of the snapshot HSI probe to acquire data from reference samples of different colors. The spectral library of each sample was acquired and then analyzed using PCA. CE was then applied to the PC scores of each reference sample and used as the classification criteria. The results show that the applied analysis can be used to perform classification of the spectral data from test samples acquired using the snapshot HSI probe.

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REFERENCES

- [1] R. T. Kester *et al.*, "Real-time snapshot hyperspectral imaging endoscope," *J. Biomed. Opt.* 16(5), 056005 (2011).
- [2] V. K. Shinoj *et al.*, "Design, fabrication, and characterization of thermoplastic microlenses for fiber-optic probe imaging," *Appl. Opt.* 53(6), 1083-1088 (2014).
- [3] U. Dinish *et al.*, "Formulation and implementation of a phase-resolved fluorescence technique for latent-fingerprint imaging: theoretical and experimental analysis," *Appl. Opt.* 44(3), 297-304 (2005).
- [4] N. K. K. Mohan *et al.*, "Separation of the influence of in-plane displacement in multiaperture speckle shear interferometry," *Opt. Eng.* 33(6), 1973-1982 (1994).
- [5] A. Kishen *et al.*, "Analysis on the nature of thermally induced deformation in human dentine by electronic speckle pattern interferometry (ESPI)," *J. Dent.* 29(8), 531-537 (2001).
- [6] J. D. Bull *et al.*, "40-GHz electro-optic polarization modulator for fiber optic communications systems," *Proc. SPIE* 5577, 133-143 (2004).
- [7] P. Prabhathan *et al.*, "Discrete and fine wavelength tunable thermo-optic WSS for low power consumption C+L band tunability," *IEEE Photonics Technol. Lett.* 24(2), 152-154 (2012).
- [8] S. Shaoxin *et al.*, "Fabrication of large-scale photonic phased array using a holographic lithography system," *Opt. Eng.* 52(9), 095103 (2013).
- [9] K. V. Sreekanth, and V. M. Murukeshan, "Large-area maskless surface plasmon interference for one- and two-dimensional periodic nanoscale feature patterning," *J. Opt. Soc. Am. A-Opt. Image Sci. Vis.* 27(1), 95-99 (2010).
- [10] K. Sreekanth, V. Murukeshan, and J. Chua, "A planar layer configuration for surface plasmon interference nanoscale lithography," *Appl. Phys. Lett.* 93(9), 093103 (2008).
- [11] V. M. Murukeshan, and K. V. Sreekanth, "Excitation of gap modes in a metal particle-surface system for sub-30 nm plasmonic lithography," *Opt. Lett.* 34(6), 845-847 (2009).
- [12] D. Bannon, "Hyperspectral imaging: Cubes and slices," *Nat. Photonics* 3(11), 627-629 (2009).
- [13] V. Fresse, D. Houzet, and C. Gravier, "GPU architecture evaluation for multispectral and hyperspectral image analysis," *IEEE Conference on Design and Architectures for Signal and Image Processing*, 121-127 (2010).
- [14] A. M. Siddiqi *et al.*, "Use of hyperspectral imaging to distinguish normal, precancerous, and cancerous cells," *Cancer Cytopathol.* 114(1), 13-21 (2008).
- [15] G. Lu, and B. Fei, "Medical hyperspectral imaging: A review," *J. Biomed. Opt.* 19(1), 010901 (2014).
- [16] G. K. Naganathan *et al.*, "Visible/near-infrared hyperspectral imaging for beef tenderness prediction," *Comput. Electron. Agric.* 64(2), 225-233 (2008).
- [17] V. M. Papadakis *et al.*, "Monitoring chemical degradation of thermally cycled glass-fibre composites using hyperspectral imaging," *Proc. SPIE* 9804, 98040S (2016).
- [18] B. Khoobehi, A. Khoobehi, and P. Fournier, "Snapshot hyperspectral imaging to measure oxygen saturation in the retina using fiber bundle and multi-slit spectrometer," *Proc. SPIE* 8229, 82291E (2012).
- [19] J. Nieve *et al.*, "Imaging spaceborne and airborne sensor systems in the beginning of the next century," *Proc. SPIE* 3221, 581-592 (1997).
- [20] Q. Li *et al.*, "AOTF based molecular hyperspectral imaging system and its applications on nerve morphometry," *Appl. Opt.* 52(17), 3891-3901 (2013).
- [21] N. Gat, "Imaging spectroscopy using tunable filters: A review," *Proc. SPIE* 4056, 50-64 (2000).

- [22] N. Hagen *et al.*, "Snapshot advantage: a review of the light collection improvement for parallel high-dimensional measurement systems," *Opt. Eng.* 51(11), 111702 (2012).
- [23] N. Gat *et al.*, "Development of four-dimensional imaging spectrometers (4D-IS)," *Proc. SPIE* 6302, 63020M (2006).
- [24] H.-T. Lim, and V. M. Murukeshan, "Spatial-scanning hyperspectral imaging probe for bio-imaging applications," *Rev. Sci. Instrum.* 87(3), 033707 (2016).
- [25] M. E. Martin *et al.*, "Development of an advanced hyperspectral imaging (HSI) system with applications for cancer detection," *Ann. Biomed. Eng.* 34(6), 1061-1068 (2006).
- [26] H.-T. Lim, and V. M. Murukeshan, "A four-dimensional snapshot hyperspectral video-endoscope for bio-imaging applications," *Sci. Rep.* 6, 24044 (2016).
- [27] J. Kriesel *et al.*, "Snapshot hyperspectral fovea vision system (HyperVideo)," *Proc. SPIE* 8390, 83900T (2012).
- [28] H.-T. Lim, and V. M. Murukeshan, "Note: Design considerations and characterization of a flexible snapshot hyperspectral probe," *Rev. Sci. Instrum.* 88(3), 036107 (2017).
- [29] Y. Jiang, and C. Li, "Detection and discrimination of cotton foreign matter using push-broom based hyperspectral imaging: system design and capability," *PloS ONE* 10(3), 0121969 (2015).