Noise filtering of Hyperspectral Data of Oil Palms by Median Mean Projection Filtering

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Abstract

One of the many applications of hyperspectral imaging is in agriculture. However, hyperspectral data captured from airborne UAV sometimes contain speckle noise that make their spectral signatures different from those of field spectroscopy using similar wavelengths. Therefore, there exists a need to filter noisy hyperspectral data to improve their quality so that a strong correlation can be established between the airborne and field hyperspectral data for effective analysis. For oil palm hyperspectral data, an efficient and effective method is introduced to filter noise using median-mean projection filtering. This novel approach generates superior results compared to those produced by the conventional method of convolving the data with 2-D filters, in terms of output quality and signal to noise ratio. The resulting data also exhibit better luminosity and contrast. The proposed method was implemented using MATLAB R2021b running on Intel i7 processor and the average execution time was less than 10 seconds. The execution time can be further lessened if the codes are optimized and GPU is used. Overall, the proposed method removes the speckle noise and improves the luminosity and contrast of the data. This technique can be a useful tool to those working in the oil palm industry.

Keywords: Hyperspectral images, med-mean projection filtering, UAV, noise.

1. Introduction

Hyperspectral imaging has been used in many applications including agriculture, remote sensing, oil and gas exploration, quality control**,** forensic science, biotechnology, medicine and others [1][2]. Regular two dimensional (2-D) images captured by common cameras are either in color or grayscale. Usually, color images have three components, and they are red, green and blue. In terms of wavelengths (also known as bands or channels), the standard color space (sRGB) adopted by computer monitor manufacturers assigns red to 612nm, green to 549nm and blue to 464nm [3]. Airborne hyperspectral remote sensing provides data in the form of stacked 2-D images from the reflections of many bands of wavelengths captured by a hyperspectral camera. Each 2-D image corresponds to the reflection of a narrow channel or band of wavelength. Since all of the images are taken of the same spot (or location) using different bands of wavelength, it is expected that there will be overlaps of content among images. However, some images contain exclusive information not available in others. When collected and combined, this information becomes a powerful tool for data analysis. For example, in aerial hyperspectral data of oil palms, images of different bands are successfully used to detect diseases such as freckle, blast and Ganoderma infections [4][5].

Often, hyperspectral data obtained from long and short wavelengths contain more noise than those obtained using medium wavelengths. Noise contamination in the form of speckle noise (also known as salt and pepper noise) reduces the quality of the images. If the noise is severe, it must be filtered so that important information is not obscured or dampened. For instance, airborne hyperspectral data from the aerial view may contain noise that make them appear relatively different from the field spectroscopy data taken on the ground.

Consequently, it is hard to establish a clear correlation between them for ground truth verification. In this case, the noise in the airborne hyperspectral data must be removed so that spectral signatures in the data can be preserved, identified, and used for detection, identification, classification, and other forms of data analysis.

Normally, data that are badly affected by speckle noise are discarded. This is because, the values they contain are too volatile to be useful. Usually, only channels that are associated with very short or very long wavelengths are severely affected by speckle noise. That implies that most of the data are unaffected by speckle noise. In this study, we introduce a method to filter channels that are badly affected by speckle noise. This way, we can salvage noisy data associated with short and long wavelengths from being discarded.

2. Methodology

Noise in hyperspectral images mainly originate from changes in sun illumination intensity during the airborne image acquisition especially when part of the area is shaded by thick cloud. In addition, high amount of humidity in the field and air may absorb or scatter water-sensitive wavelengths used to capture the images. Furthermore, haze, floating particles, debris and strong reflectance from the background soil during sunny day may introduce noise or reduce contrast of the hyperspectral images [6]. Another factor that affects the quality of the hyperspectral data is the resolution of the image. It is the corresponding area on the ground represented by a single pixel in the image. The bigger the area, the lower the resolution is. Normally, the resolution is dictated by the quality of the camera used and the altitude of the UAV when the data is captured. Finally, the flight speed also has an impact on the data quality. Thus, it is important to maintain the altitude and speed of the UAV when capturing the hyperspectral data.

2.1. *Database*

The area under study is in Lekir, Perak, Malaysia. It is a flat coastal area which contains almost 20 thousand oil palms of Dura x Pisifera (DxP) species. The age of the oil palms is nearly ten years old by 2023. The area receives a good rainfall of approximately 2700 mm every year. The oil palms are free from any disease, stress or infestation except for *Ganoderma* infection that affects less than 2 percent of the oil palm population.

The hyperspectral camera used was Resonon Pika L (Resonon Inc., Bozemann, Montana, USA) mounted on

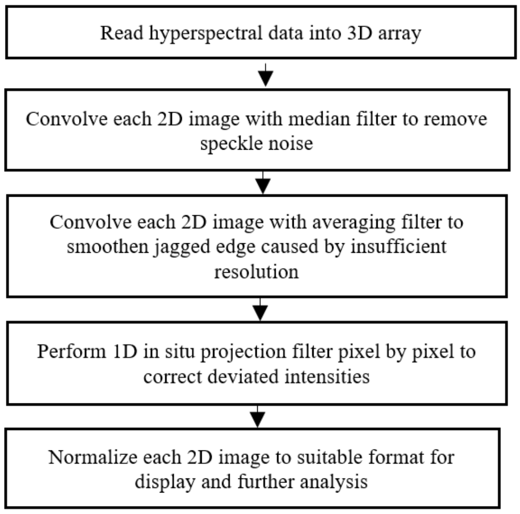

Fig. 1 Flowchart of steps in median-mean projection filtering.

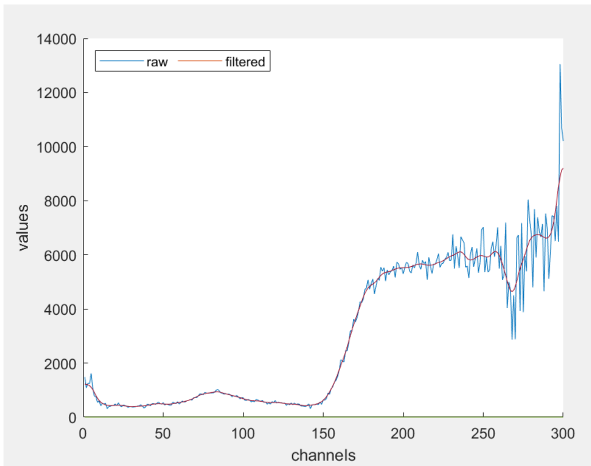

Fig. 2 The smoothing effect of applying the projection filter on 300 channels values of a sample pixel.

a DJI M600 Pro hexacopter drone. The camera captured a set of hyperspectral images with 300 spectral bands from 350 nm – 900 nm with ±2 nm spectral resolution. The hexacopter-type drone has a maximum payload of 6 kg and a flight duration of 15 – 20 minutes. A calibration tarpaulin was used as image white-calibration reference on the ground. Data recording activities were performed under clear sky during sunny days.

2.2. *Approach*

In this work, median-mean (med-μ) projection filtering is used to filter the noise. The main idea is the fact that a 2-D image obtained from a particular band shows an in situ positive correlation with images of neighboring bands of contiguous wavelengths. The flowchart of steps taken to filter noise from the hyperspectral data is shown in Fig. 1. The first step in the process is to read the hyperspectral data and store them into a 3D array. The size of the data is 1000x1000x300. Then each 2D image is filtered (convolved) with a median filter to remove speckle noise. In our work the size of the filter is limited to 3x3 since a larger median filter would eliminate thin leaves from the frond of the oil palms and take a longer time to execute.

Next, the image is subjected to average (or mean) filtering. Since the altitude of the UAV was 80m when the data were captured, the resolution of the images is good but not excellent. In fact, it is estimated that the best resolution attained is approximately 10 cm x 10 cm for each pixel. This makes some fronds of the canopy appear jagged. Average filtering smoothens the jagged edges caused by the insufficient resolution, but it also blurs sharp edges. Thus, the size of the averaging filter is also limited to 3x3 so that it doesn't reduce the contrast of the images too much.

Finally, the images undergo in-situ projection filtering, pixel by pixel, to capitalize on the strong correlation between contiguous bands (channels). The projection is performed one dimensionally from the middle band towards the low and high ends of the channels where pixel values become volatile as noise content increases. The projection filter employs Savitzky-Golay data smoothing technique to subdue volatility at the tail ends of the channels. In our experiments, we opted for Savitzky-Golay denoising filter of 3rd degree polynomial with 11 frame length. Fig. 2 shows the effect of performing projection filter on the values of 300 bands of one sample pixel. It is seen that the volatile values of the 300 bands are smoothened by projection filtering. It is especially obvious at the tail ends of the channels. The process is repeated for every pixel in the image so that the values of the pixels in bands that are severely affected by speckle noise can be replaced by the projected values from the filter. Finally, to display the data of each channel in the form of an image, they must be normalized so that their range will fall between 0 and 255. Then they can be displayed for further analysis.

3. Results and Discussion

The method is applied to hyperspectral data containing 300 spectral bands. The size of each band is 1000 x 1000 pixels. However, since there are 300 bands or images, each image is processed consecutively. The clarity of the images markedly improves after filtering as the noise is reduced. Fig. 3 shows the results of applying median filtering, projection filtering and the proposed method on a 400x400 area of one channel of the hyperspectral data that is affected by speckle noise. The size of the median filter used is 3x3. When the size of the median filter is increased to 5x5 or 7x7, it takes longer to implement. The bigger filter tends to remove the noise better but also blur the image more as it eliminates small objects that are bright or dark such as fronds and leaves. The mean filter is the moving average filter of 3x3. By itself the Savitzky-Golay projection filter is quite effective in filtering the speckles, but the best result is obtained from the combination of the median, mean and projection filters. The signal to noise ratios (SNR) and the average execution times of the filters are given in Table 1. As stated, the image becomes quite clean after filtering as the SNR value exceeds 40dB. Here SNR is estimated as the ratio of the standard deviation (sigma) of a reference image over the difference of the sigmas of a noisy image and the reference image. It is written mathematically as following Eq. (1)

$$\mathrm{SNR} = 10 \log_{10} (\sigma_r / (\sigma_n - \sigma_r)) \qquad (1)$$

where σ_r is the sigma of the reference image
σ_n is the sigma of the noisy image

This is based on the assumption that the strength of the signal in each band (image) is identical since they are normalized and the reference band is considered relatively free of noise. Normally, the reference image is one of the middle channels with the lowest speckle noise or the lowest standard deviation of uniform areas.

Furthermore, the standard deviation of each image is calculated only in selected areas that are considered of uniform intensity by manual inspection. Alternatively, the areas can be automatically identified as the ones with the lowest standard deviations in the reference channel. In our case, these areas are the dark spots between palm leaves. The proposed method was implemented on MATLAB platform running an Intel i7 multicore processor. The average execution time for processing a 400x400 subregion for one channel is approximately 0.5s as stated in Table 1. With further refinement of the codes and the use of parallel processing or GPU, the execution time can be decreased more.

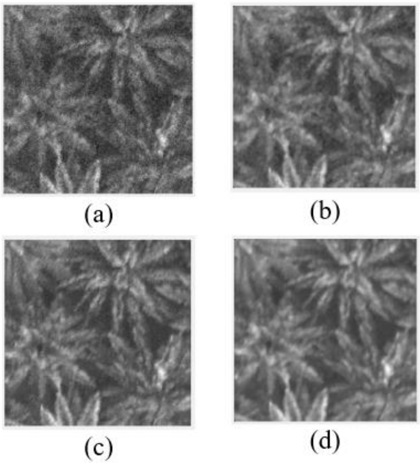

Fig. 3 A noisy subregion of an image a) Original subregion b) Filtered by median filter c) Filtered by projection filter d) Filtered by median and projection filters.

Table 1. The performances of the median, projection and proposed method.

Methods	Median	Projection	Proposed
SNR	21.4 dB	34.8 dB	40.5 dB
Time/image	0.1s	0.4s	0.5s

4. Conclusion

In this paper, a new method to filter speckle noise from hyperspectral images is proposed. The proposed method employs projection filter which capitalizes on the positive correlation among contiguous channels. It removes speckle noise from the images, improves their visual quality and increases the SNR values.

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