# Multidimensional median filtering of spectral images

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## Abstract

The use of spectral images in many practical applications is getting more and more common as the cost of computation power and of storage space gets smaller. But like ordinary color images, the spectral images also suffer from noise caused by transmission and manipulation errors. In this study different multidimensional median filtering methods are developed for noise removal from spectral images. First vector median filters are applied to spectral images. Then new three-dimensional median filters are introduced. In experiments we compared three-dimensional filters to common 2D median filters and found out that three-dimensional median filters on average were the best of all applied filters.

## Introduction

Spectral images suffer from the same problems as ordinary color images. They can be contaminated by different kinds of noise. Most common types of noise are Gaussian noise and impulse noise [4]. In this work we concentrate on removing impulse noise and more precisely bit noise from spectral images. Bit noise is the kind of noise where every bit in the image has certain probability of turning from zero to one or vice versa. Fortunately there are ways of removing noise. Well known methods include 1D and 2D median filters.

Median filter considers each pixel in the image in turn and looks it's neighbourhood in order to decide whether or not the pixel matches well it's neighbourhood. The median is calculated by first sorting all the pixel values into numerical order from the neighbourhood also known as filtering window. Then the pixel being filtered is replaced with the median pixel value within the filtering window. It is recommended that the filtering window's size $W$ is odd $W = (2k+1) \times (2k+1)$ for 2D-data, so that the median can be explicitly selected. In spectral image filtering, every band of the image is filtered similarly. This filtering method has it's drawbacks, e.g. edge jitter [1, 3].

Another way of filtering images is to use multistage median filters. They work just like the two-dimensional median filters that have window of size $W = (2k+1) \times (2k+1)$ except that they do the filtering in multiple stages, i.e. the median of medians is defined. This method gives some benefits compared to the regular 2D-dimensional median filtering. It is more flexible than the 2D-median filter and it also takes into account the temporal-order information better. The filter is also somewhat faster than the median filter. [2, p. 88]

## Vector and cubic filters

### Vector filters

Astola et al. [1] introduced a median filtering method for vector valued signals. The method is known as the vector median filtering. With spectral images it uses the spectral vector in the filtering process and thus the edges in the image do not move and yet the filter removes impulse noise very effectively. The definition of generalized vector median filter $GVM$ of vectors $\mathbf{x}_1, ..., \mathbf{x}_N$ is the vector $\mathbf{x}_{gvm}$ such that [1]

$$\mathbf{x}_{gvm} \in \{\mathbf{x}_i | i = 1, ..., N\} \quad (1)$$

and for all $j = 1, ..., N$

$$\sum_{i=1}^{N} dist(\mathbf{x}_{gvm}, \mathbf{x}_i) \leq \sum_{i=1}^{N} dist(\mathbf{x}_j, \mathbf{x}_i) \quad (2)$$

where $dist(\mathbf{x}, \mathbf{y})$ is the distance between the vectors $\mathbf{x}$ and $\mathbf{y}$.

### Cubic filters

Median filters and multistage median filters have been certified and tested extensively with gray-scale and color images. But their suitability for filtering spectral images is a far less studied problem. In this study a new method for filtering spectral images is proposed. In spectral images, especially in hyper spectral images, the bands next to each other correlate strongly. Therefore we filter the image with a cubic median filter or with a cubic multistage median filter. These filters work just like the median and multistage median filters except that the filtering window $W$ is not two-dimensional but instead it is three-dimensional of size

$$W = (2k+1) \times (2k+1) \times (2k+1) \tag{3}$$

This method has the same benefits as the 2D-median and multistage median filters, but it can also use the information of bands near each other to better filter the spectral image. Vector median filters fail to filter spectral images because spectral images have too many bands in comparison to the three component images like RGB images. Vector median filters fail to find "correct" spectral vectors, since they all contain errors more or less. After the spectral image has been filtered with a vector median filter, only the vectors with least errors are left, but still the image contains undesirable errors. A cubic filter avoids this because it uses only a part of spectral bands at a given time and thus it can easily find error free pixels among the bands. There are also limitations for the cubic filters. Spectral image should have plenty of bands, preferably over 100, so that the bands correlate strongly with each other. If there is no correlation between the spectral bands, then the filter performs poorly.

The actual median calculation in the cubic median filter is simple. The numbers inside the three-dimensional cube are arranged into numerical order and then the median of the numbers is chosen after which the center of the cube is replaced with the median.

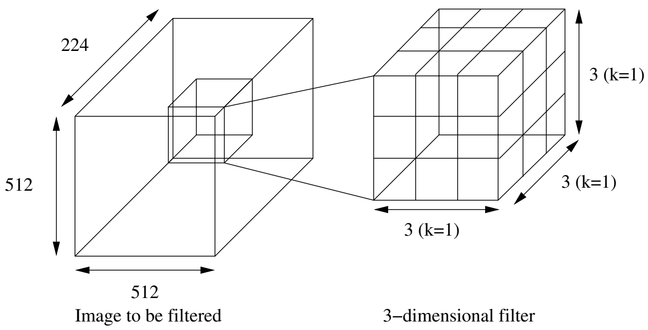


*Figure 1. Cubic filter of size* $3 \times 3 \times 3$. *Thus in Equation 3, k=1.)*

## Experimental Results

The methods presented were tested by using two test images. Images were from the airborne AVIRIS dataset [5]. They have 224 spectral bands in almost even intervals between 400 and 2500 nm. The first image (Moffet) contains a city near a mountain and the other image (Cuprite) contains more detailed data of a mountain. The spatial size of the image was 512 by 614 pixels. The images were corrupted with bit errors with 5% probability, i.e. on the average, every 20th bit was reversed. Figure 2(a) shows a part of the original image from band number 60. It was chosen because it contains a lot of visual details by human standards. Figure 2(b) shows the same image after the errors were introduced. It has to be noted that these images show only one band from the whole spectrum and thus the information content of the displayed images is very much questionable. One band can not possibly show all the dependencies between spectral bands [6]. They do give some visual feedback of the performance of the filters and help to evaluate the performance of the filters.

## Conclusions

This work introduces new multidimensional cubic filters for filtering spectral images. The filtering results of the cubic filters are comparable to ordinary 2D-median filtering results and they are better than the vector median filters. Figures 3(a)-3(c) show the filtering results of cubic filters and the well known vector median filter. As can be seen from the results in Table 1, the well known vector median filter did not perform very well. There was just too much noise in the image in order to vector median filter to work. It could not find suitable errorfree spectral vectors in the image anymore. With this many bands, it's reasonable to assume that every spectral vector has error at-least in one component and thus the vector median is only a vector that contains least errors. Cubic filters on the other hand avoid this problem because the neighboring spectral bands correlate strongly with each other. Unfortunately cubic filters also suffer from edge jitter and they are computationally heavy in comparison to other filters used in this work. Although every spectral vector has a very high probability of having errors in some bands, there are lots of bands that do not have errors in them, at least not in every pixel. The regular median filter works also well as can be expected, but it has it's well known problems with edges [1].

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## Biographies

Professor, Doctor of Technology Pekka Toivanen has graduated from Helsinki University of Technology in 1989. Since 1991 he has been working at the Lappeenranta University of Technology, at the Department of Information Technology. He is at the moment a head of the laboratory of Information Processing of the Department of Information Technology at Lappeenranta University of Technology. Pekka Toivanen is a member in SPIE and IEEE. His main research interests are multispectral image processing, color, and distance transforms.

Jarkko Vartiainen received his Masters degree in computer science from Lappeenranta University of Technology in 2003. Since then he has worked at the university at the Department of Information Technology. His current work is focused on image texture processing.

Arto Kaarna received his Master of Science degree in 1980 in Mechanical Engineering and Licenciate of Technology degree 1990 and Doctor of Technology degree in 2000 in computer science at Lappeenranta University of Technology (LUT), Finland. Currently he is working as a professor in media in networks with LUT. His main research interests are in color and spectral image processing and in imaging information in networks.

**Table 1. Results from filtering the noisy images. The images had bit errors with probability of 0.05. Best filtering method is highlighted.**

| | Moffet | | Cuprite | |
|---|---|---|---|---|
| **Filtering method** | **MAE** | **MSE** | **MAE** | **MSE** |
| noisy image | 391.27 | 2529000 | 173.72 | 580570 |
| 3x3 vector median | 319.73 | 1186300 | 143.67 | 260390 |
| 5x5 vector median | 307.8 | 902910 | 141.05 | 195530 |
| 7x7 vector median | 304.64 | 792340 | 141.19 | 170490 |
| 9x9 vector median | 303.4 | 737440 | 142.04 | 158060 |
| 3x3x3 cubic median | 71.378 | 21714 | 49.264 | 9772.1 |
| 5x5x5 cubic median | 108.13 | 45615 | 80.593 | 24544 |
| 7x7x7 cubic median | 134.74 | 67295 | 102.89 | 34182 |
| 9x9x9 cubic median | 163.66 | 98389 | 132.01 | 63697 |
| **3x3x3 multistage cubic median** | **66.535** | **20440** | **44.882** | **8838.9** |
| 5x5x5 multistage cubic median | 101.99 | 41993 | 76.542 | 25345 |
| 7x7x7 multistage cubic median | 126.84 | 60776 | 97.572 | 33455 |
| 9x9x9 multistage cubic median | 158.66 | 96972 | 125.83 | 64763 |
| 3x3x1 median filter | 67.356 | 33837 | 33.043 | 5268.7 |
| 5x5x1 median filter | 85.336 | 34841 | 46.179 | 8521.8 |
| 7x7x1 median filter | 100.88 | 49122 | 55.488 | 11984 |
| 9x9x1 median filter | 111.84 | 60921 | 62.257 | 14872 |

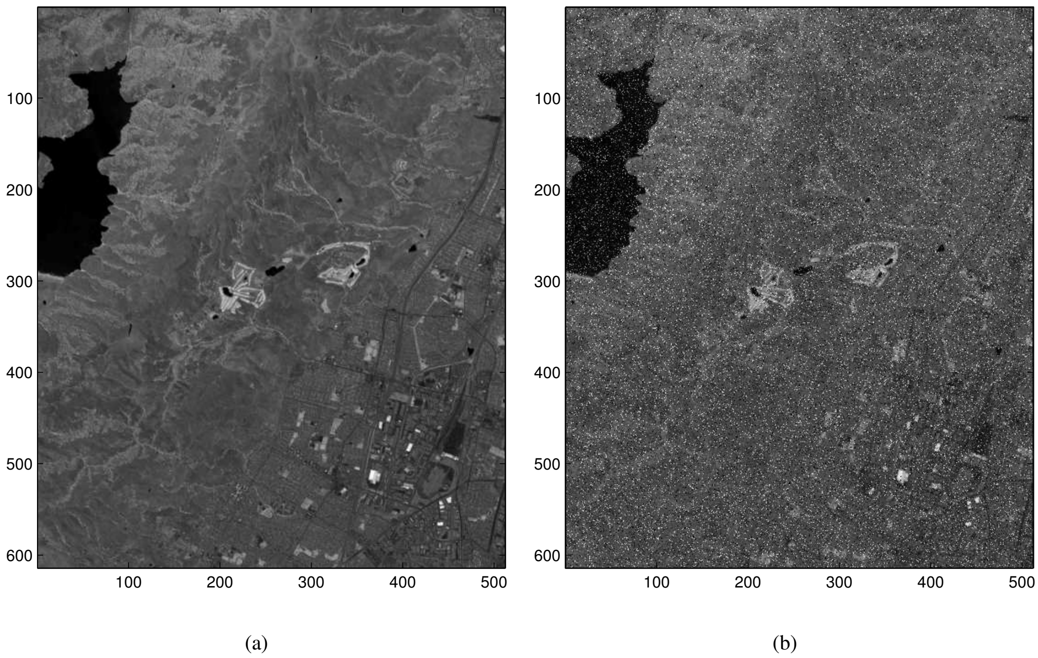
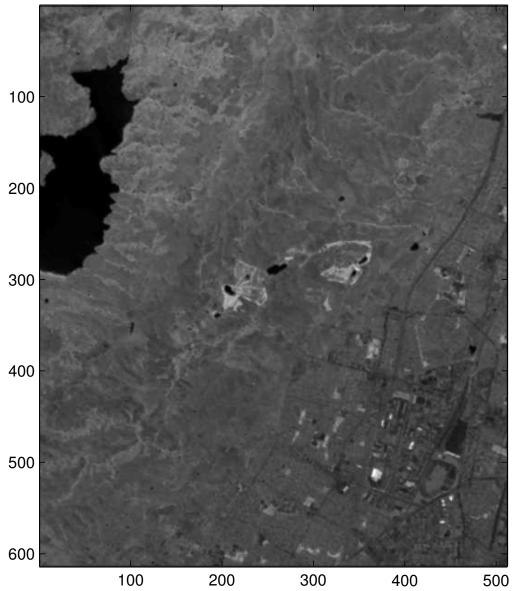
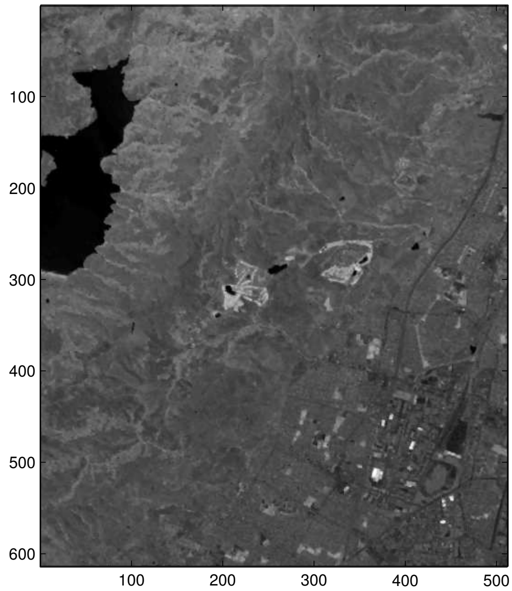


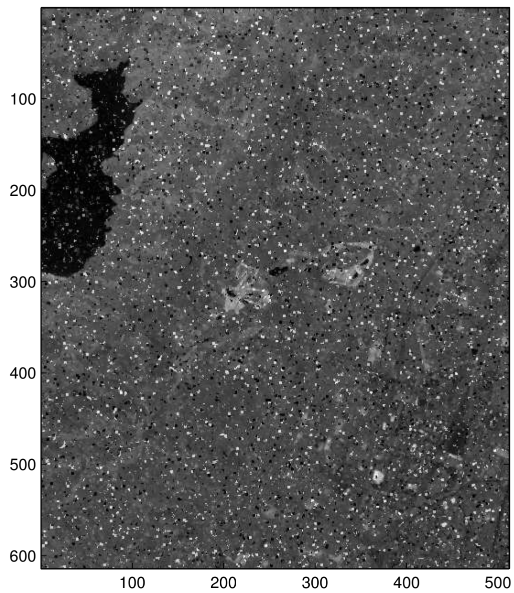

*Figure 2. (a) Band 60 from the original Moffet image. (b) Band 60 from the Moffet image with 5% bit-error noise added to it.*




(a)




(b)




(c)

*Figure 3. Band 60 from the Moffet image after it has been filtered with a (a) $3 \times 3 \times 3$ cubic filter, (b) $3 \times 3 \times 3$ multistage cubic filter, (c) vector median filter.*