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Fast GPU-based denoising filter using isoline levels

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Abstract In this study, we describe a GPU-based filter for image denoising, whose principle rests on Matheron's level sets theory first introduced in 1975 but rarely implemented because of its high computation cost. We use the fact that, within a natural image, significant contours of objects coincide with parts of the image level-lines. The presented algorithm assumes an *a priori* knowledge of the corrupting noise type and uses the polygonal level-line modeling constraint to estimate the gray-level of each pixel of the denoised image by local maximum likelihood optimization. Over the 512 × 512 pixel test images, the freely available implementation of the state-of-the-art BM3D algorithm achieves 9.56 dB and 36 % of mean improvement in 4.3 s, respectively, for peak signal to noise ratio and mean structural similarity index. Over the same images, our implementation features a high quality/runtime ratio, with a mean improvement of 7.14 dB and 30 % in 9 ms, which is 470 times as fast and potentially allows processing high-definition video images at 19 fps.

Keywords GPU · Denoising · Filter · Isoline · Level line

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1 Introduction

For the past few years, because of a fast growth in digital devices able to take pictures or make movies, digital processing has become more and more important. Moreover, the wide range of applications requiring noise removal makes it difficult to design a universal filter and the increase in pixel density of the CCD or CMOS sensors leads to higher noise levels and requires high data rates in the processing algorithms. In addition, it is difficult to quantify the quality of an image processing algorithm, as visual perception varies significantly from one person to another.

To date, many researchers have successfully sped up image processing algorithms by implementing them on GPUs. For example Mc Guire [14], Chen et al. [1] and Sanchez and Rodriguez [17] reported quite fast median filters. Sanchez's filter is able to output up to 300 million pixels per second, i.e., 150 fps of high definition video images. Bilateral filtering has also been successfully proposed by Yang [2].

However, most high quality algorithms, such as NL-means [3] or BM3D [4] make use of non-local similarities and/or frequency domain transforms, so the speedups achieved by their current GPU implementations (see NL-means [11]) do not come near those achieved by local methods such as Gaussian, median or neighborhood filters.

Considering that a *natural* image, i.e., any photograph of an outdoor or indoor scene taken by a standard camera, is of bounded variation and thus can be decomposed into a set of level-lines [5, 6], researchers have implemented algorithms that make use of level-lines properties, dedicated, in particular, to segmentation and classification [5, 7, 8, 9, 15].

Bertaux et al. described a method which significantly reduces speckle noise inside coherent images by using the properties of the level-lines in the image to constrain the

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