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Simultaneous image interpolation for stereo images

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ABSTRACT

Simultaneous interpolation of stereo images aims to use a pair of stereo images to reconstruct another pair of images with higher resolutions. To tackle this problem, a simultaneous approach is proposed in this paper. Since the prior image model is important for solving the ill-posed numerical issues encountered in the image interpolation computation, the proposed approach exploits a prior image model that considers both the spatial local smoothness constraint within each reconstructed high-resolution image and the disparity-compensated local smoothness constraint between the pair of reconstructed high-resolution images. The proposed approach requires the disparity to be known in advance or has been accurately estimated by the existing stereo matching algorithm. Experiments are conducted using both artificially generated images and real-life images to demonstrate the superior performance of the proposed approach.

1. Introduction

The objective of simultaneous stereo image interpolation is to reconstruct a pair of images from their low-resolution counterparts, in order to improve content recognition ability. This kind of image interpolation technique has potentials in overcoming hardware limitations of existing image acquisition systems such as robot navigation, vision-based driving and 3D TV.

This paper is focused on image interpolation for stereo images, as illustrated in Fig. 1, which is different with the conventional image resolution enhancement problem [1–5]. First, the conventional approaches produce a single higher-resolution image from either a single low-resolution image [1,2,4] or a set of similar images [3,5] that are acquired from the same scene using a single camera with multiple shots. However, in the context of this paper, only two stereo images are available and acquired using a stereo camera with a single shot. The resolutions of both these two images are enhanced. Certainly, more than one set of stereo images can be available using multiple shots. For that case, one needs to investigate how to register multiple sets of stereo images. That is out of the scope of this paper. Second, the challenge of conventional approaches is to exploit correlations of multiple images, which are different due to global geometric transformations such as translation, rotation or zooming. On the contrary, the challenge of the problem studied in this paper is to exploit correlation from two stereo images which are different due to disparity information.

Furthermore, it is important to note the significant difference between the proposed approach and our other work [6] in the following three aspects. First, this paper addresses the symmetrical stereoscopic images, while Tian et al. [6] addresses asymmetric stereoscopic images. More specifically, in this paper, both two observed images are degraded (i.e., downsampled and blurred) versions of the other set of two higher-resolution images. However, the objective of [6] is to enhance the resolution of an observed image from a higher-resolution image, which is

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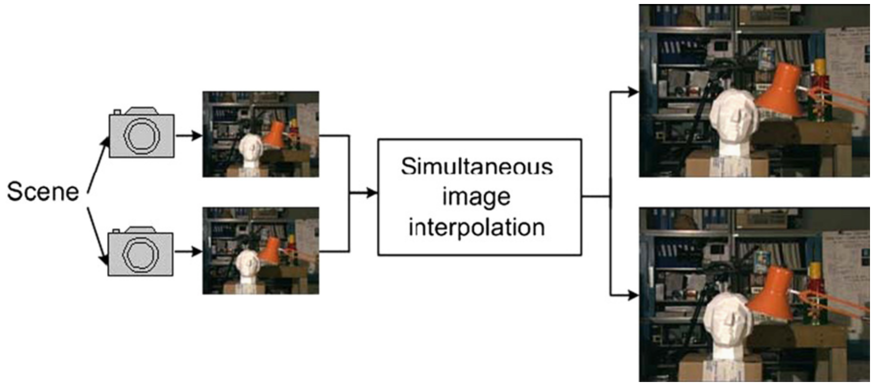

Fig. 1. A simultaneous image interpolation framework for stereo images.

available in the other view and is supposed to yield more detailed information of the scene. Second, the disparity estimation needs to be conducted on two images with same resolutions in this paper, while it is conducted using two images with different resolutions in [6]. The proposed approach requires the disparity to be known in advance or has been accurately estimated by the existing stereo matching algorithm. Third, a stochastic approach is proposed in this paper to reconstruct two high-resolution images, while a gradient-based approach is used in [6] to perform high-resolution image reconstruction.

There are not much research works tackling the image interpolation problem for stereo image in the literature. Kimura et al. [7] proposed a *maximum a posterior* (MAP) approach to use multiple pairs of stereo images to estimate both the higher-resolution disparity field and a single higher-resolution image. That is different with our paper, since we need to reconstruct a pair of higher-resolution images. Furthermore, Kimura et al.'s method imposed a same prior model for both the higher-resolution image and the higher-resolution disparity field. However, the disparity field should yield different prior image model with that of the reconstructed high-resolution image [8]. Mudenagudi et al. proposed a super-resolved view synthesis of a 3D scene with a set of calibrated images [9]. Bhavsar and Rajagopalan [10] proposed to exploit an *iterated conditional modes* (ICM) algorithm to reconstruct the higher-resolution images via estimating their MAP estimators. However, the ICM algorithm depends very much on the initial estimator, and it does not always converge to the global optimum [11]. Furthermore, the prior image model used in their approach neglects the constraints between the reconstructed pair of high-resolution images.

One challenge of the image interpolation is how to choose the prior image model, which is usually incorporated as a regularization strategy for solving the ill-posed numerical issues encountered in the image interpolation computation [12–15]. For that, a prior image model is proposed in this paper to exploit both the spatial local smoothness constraint within each reconstructed high-resolution image, and the disparity-compensated local smoothness constraint between two reconstructed high-resolution images. This is in contrast to that the conventional approaches treat each high-resolution image independently and neglect the smoothness constraint between the pair of desired high-resolution images.

The rest of this paper is organized as follows. Section 2 proposes two observation models to formulate the relationship among the observed low-resolution images and the desired high-resolution images. Then, a prior image model is proposed in Section 3 to conduct the image interpolation. Experiments are conducted in Section 4 to evaluate the performance of the proposed approach. Finally, Section 5 concludes the paper.

2. Observation model

In this section, the observation model that relates the unknown high-resolution images to the observed low-resolution images are developed. Suppose that a pair of images are used as the 'ground truth' of the high-resolution images to generate another pair of low-resolution images. Then a pair of high-resolution images can be reconstructed and compared with the ground truth for the purpose of conducting objective performance evaluation. Two $M_1 \times M_2$ high-resolution images and two $L_1 \times L_2$ low-resolution images are represented in lexicographic-ordered vector forms and denoted as $\mathbf{x}_l$,$\mathbf{x}_r$, and $\mathbf{y}_l$, $\mathbf{y}_r$, which have a size of $M_1M_2 \times 1$ and $L_1L_2 \times 1$, respectively. Note that, in the above notations, the subscript l represents the left-view images, while the subscript r represents the right-view images. With such establishment, the goal of image interpolation is to produce a pair of high-resolution images $\mathbf{x}_l$ and $\mathbf{x}_r$ based on a pair of low-resolution observations $\mathbf{y}_l$ and $\mathbf{y}_r$. Since the correlation between the unknown high-resolution image and its low-resolution counterparts, which are within same view and in the other view, respectively, is important to perform image interpolation, the following two observation models are proposed in this paper:

- *Intra-view observation model*. To generate a pair of low-resolution images (or observations) for simulation experiment, each ground-truth image is convolved with a *point spread function* (PSF), downsampled to a lower resolution, and finally added with a zero-mean white Gaussian noise. These operations can be mathematically expressed as

$$\mathbf{y}_l = \mathbf{H}_l\mathbf{x}_l + \mathbf{v}_{l,l}, \tag{1}$$