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Efficient Convex Optimization Approaches to Variational Image Fusion

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Abstract. Image fusion is an imaging technique to visualize information from multiple imaging sources in one single image, which is widely used in remote sensing, medical imaging etc. In this work, we study two variational approaches to image fusion which are closely related to the standard TV-L_2 and TV-L_1 image approximation methods. We investigate their convex optimization formulations, under the perspective of primal and dual, and propose their associated new image decomposition models. In addition, we consider the TV-L_1 based image fusion approach and study the specified problem of fusing two discrete-constrained images $f_1(x) \in \mathcal{L}_1$ and $f_2(x) \in \mathcal{L}_2$, where $\mathcal{L}_1$ and $\mathcal{L}_2$ are the sets of linearly-ordered discrete values. We prove that the TV-L_1 based image fusion actually gives rise to the exact convex relaxation to the corresponding nonconvex image fusion constrained by the discrete-valued set $u(x) \in \mathcal{L}_1 \cup \mathcal{L}_2$. This extends the results for the global optimization of the discrete-constrained TV-L_1 image approximation [8, 36] to the case of image fusion. As a big numerical advantage of the two proposed dual models, we show both of them directly lead to new fast and reliable algorithms, based on modern convex optimization techniques. Experiments with medical images, remote sensing images and multi-focus images visibly show the qualitative differences between the two studied variational models of image fusion. We also apply the new variational approaches to fusing 3D medical images.

AMS subject classifications: 68U10, 90Cxx

Key words: Convex optimization, primal-dual programming, combinatorial optimization, total-variation regularization, image fusion.

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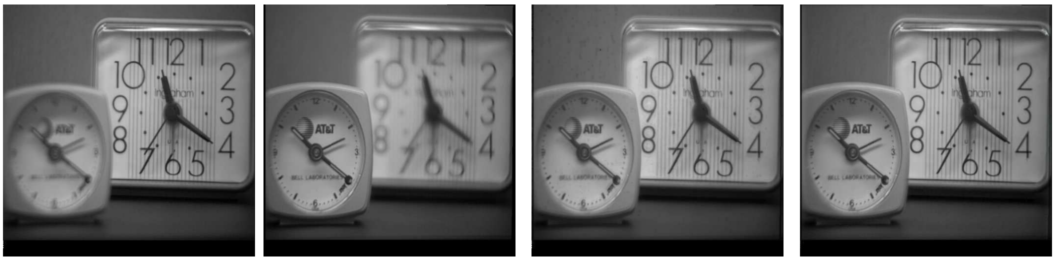
1. Introduction

Image fusion technologies have been developed to be an effective way to show different image information, acquired through various sources, in one single image. This is interesting in many areas, e.g. remote sensing [12, 30], medical imaging [28, 32] and synthesis of multi-focused images [19, 29]. More specifically, given two or more imaging data which are from different information sources and properly aligned, image fusion integrates all such data into one visualized image, mostly with higher spatial or spectral resolution. For example, two images may capture the same scene but with different focuses (see the left two images of Fig. 1), fusing these two images clearly gives a better visual result (see the right two fused images of Fig. 1). In remote sensing and satellite imaging, the fused image, which is merged from multispectral data, effectively carries much more visual information than any single image [27, 30]. In medical imaging, both Magnetic Resonance (MR) and Computed Tomography (CT) imaging are standard diagnostic tools providing complementary information. It is well-known that a CT scan will adequately highlight the bone structure details while soft tissue information is not clearly visible; on the other hand, a T2 weighted MR scan produces significantly better details for images of soft tissues. In this respect, it is highly desirable to have a combined view of CT and MR images, which illustrates significant details both from both CT and MR inputs and assists clinical diagnoses.



(a) (b) (c) (d)

Figure 1: **Multi-focus image fusion:** (a) and (b) give two images exposed with different focuses; (c) and (d) are the fused image computed by the proposed methods (2.1) and (2.3) in this work.

Parallel to the recent developments in image processing, many pixelwise image fusion methods have been proposed to tackle the issues of combining multiple images or informative data, e.g. the wavelet or contourlet based approaches [21, 23, 32], high-pass filtering method [1, 27] etc. In this paper, we concentrate on the variational approaches to image fusion, which were explored in [17, 24, 29]. Energy minimization and variational methods have been developed to be a standard way to effectively and reliably handle many practical topics of image processing and computer vision. Successful applications include image denoising and restoration [9, 22, 26, 31, 36], image decomposition [2, 20, 33] and image segmentation [9, 10, 34, 35] etc. With respect to this, the total-variational based image fusion methods [17, 29] provide an elegant ap-