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Fast restoration of star image under dynamic conditions via l_p regularized intensity prior

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Fast restoration of star image under dynamic conditions via l_p regularized intensity prior

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Abstract

This paper is an in-depth look at the problem of removing the blur from a complex motion-blurred star image. Accordingly, a simple yet effective $l_p(0 < p \leq 1)$-regularized deblurring method based on stars image intensity is proposed. The model builds on the principle that the intensity of clear star image is in accordance with Laplacian distribution or generalized p Gaussian distribution. Further, two algorithms are introduced to solve the ensuing non- smooth($p = 1$) or non-convex($p < 1$) constrained optimization problem. Simulations and actual star image restoration experiment are implemented to demonstrate that the centroids extraction accuracy of the proposed method is higher than 0.1 pixel, the running time is 3 to 5 times better than Richardson-Lucy filter or other methods based on image gradient constraint, and the peak signal to noise ratio(PSNR) of recovered star images excel results of several other image deconvolution methods.

Index Terms

star sensor; motion compensation; deconvolution; image restoration.

I. Introduction

Accuracy of star spots position underlies star identification and attitude determination of star sensor [1] in celestial navigation. During long exposure, star image generates motion blur because star sensor is affected by linear, angular, vibration motion of carrier, among others [2]–[5]. This process can be modeled as a convolution between a uniform motion blur kernel h,also called point spread function(PSF), and the clear star image irrespective of the motion around bore-sight [2], [6]–[8]. The blur kernel h can be constructed by measuring the carrier's movement via inertial sensors [2], [3] or estimating it according to isolated star spot [6]. Once the kernel is obtained, a number of fast non-blind deconvolution methods, such as Richardson-Lucy(RL) method or Wiener filter, are adopted to recover the blurred star image. However, the accuracy of star spots in the recovered star image is not satisfactory owing to the ring and the deblurred star spot equality [3], [5]. Some other deconvolution methods based on TV model [9]–[11] or the gradient of images complying with hyper-Laplacian distribution [12] could solve this problem effectively and the results are better than RL method or Wiener filter in terms of the quality of recovered images. In these methods, the gradient of star images and Fourier transform of gradient operator need to calculated, which is more time-consuming. Also, intensity of clear star images is zero in most pixels and only a handful of pixels contain star information in nature. The unique sparse structure could be used to save restoration time and improve performance of recovered star images. Jeffs [6] adopted star image sparsity as a constraint and achieved good results but time required was demanding.

In this paper, we deduce the intensity l_p regularized deconvolution model according to the MAP estimation, guided by the principle that intensity of clear star images is in accordance with Laplacian distribution or generalized $p(0 < p \leq 1)$ Gaussian distribution. The two types of distribution highlight the sparse structure of recovered star images and the results of the deconvolution model could be summarized as "finding the solution with the fewest nonzero pixels". The model adopts a uniform blur kernel h while ignoring the motion around the bore-sight (a tiny movement) according to [2], [6]–[8], which can ensure the relative position of star spots in little change, while the blur kernel varies in the three-axis motion of the star tracker in on-board environment. In this case, we can divide the image into M patches and each patch has one blur kernel based on locally-uniform assumption [13] which suggests that the proposed model is suitable for each patch. When $p = 1$, the deconvolution model is a non-smooth convex optimization problem which the split bregman method [14] is proposed to solve. When $0 < p < 1$, the optimization is a non-convex problem, approximation for l_p norm and fast iteratively reweighted least squares method [15] are introduced for an efficient solution.

The deconvolution model and its corresponding algorithms can guarantee the consistency of the recovered star images with the same weighting parameters. By virtue of the method presented in the study, the running time, extraction accuracy and PSNR of the recovered star image are superior to other common methods. Furthermore, a satisfactory solution could be obtained rapidly after several iterations, the background noise of blurred star image is sharply suppressed and the energy of the star spot is concentrated, which makes the submerged star spot in noise visible. The method overcomes the ring and noise that exists in the recovered star image using Wiener filter or RL method, which results in irregular shape and poor extraction accuracy of the recovered star spot.

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