Simulating Study on Observation of Space Point Target from a Shipborne Optoelectronic System

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Abstract. Richardson-Lucy (RL) algorithm is used to study the recovering of motion-blurred image of space point target, and the point spread function (PSF) of motion-blurred image is built up employing practical measuring data from a shipborne optoelectronic observing system. The influence of noise on the deblurring effect is analyzed, and the recovering results using RL algorithm with different denoise methods are discussed.

Introduction

Shipborne TT & C platform plays an irreplaceable role in space TT & C system since it has the advantages such as good motility and high flexibility of disposition. Moreover, measuring the positions of space point target (such as stars) via shipborne optoelectronic system (photoelectric theodolite and star sensor, for example) can be used to provide high precision course of the ship. Meanwhile, optoelectronic observing method is a significant and direct technique when the spacecraft is in its reentry blackout area. Furthermore, as the rapid development of shipborne optoelectronic observing technology, high precision optical measuring method becomes more and more important in space TT & C career.

However, shipborne platform experiences six-dimension motion, which causes complex relative motion between the target and the shipborne equipment. So the measuring precision of shipborne system is degraded due to the motion-blur of observed image. It is not very feasible to recover the image using blind deblurring method, since the relative motion is not just linear motion or central rotational motion [1-3]. As for high orbit target or dim target, the exposal time should be increased to some extent so as to enhance the ability and precision of observation. But the increase of exposal time makes the relative motion in this period more complex, and the collected image is blurrier.

One solution is to measure the ship posture data and the miss distance data employing the shipborne sensors while the optoelectronic system is observing the space target. The measured data can be used to construct the point spread function (PSF) of motion-blur, with which the motion-blurred image can be recovered employing methods such as Richardson-Lucy (RL) algorithm. RL algorithm is a nonlinear estimating method based on Bayesian theory [4-7]. In this paper, PSFs constructed by measured data from a shipborne optoelectronic system are employed to simulate the motion-blur of space point target’s image. Recovering of the blurred image is performed using RL algorithm, and the influence of noise on the deblurring effect is analyzed.

Theoretical Model

According to the theory of image processing, the blurred image can be described as the convolution of the original image and PSF. Considering the noise of image, the blurred image can be shown in Eq. 1:

\[ g(x, y) = h(x, y) * f(x, y) + n(x, y) \]  

(1)

where \( g(x, y) \) represents the blurred image, \( f(x, y) \) represents the original one, \( h(x, y) \) symbolizes PSF, and \( n(x, y) \) denotes noise.
The principle of RL algorithm is a process of estimating the original image via iteration based on maximum likelihood estimation theory:

\[
    f_{n+1}(x, y) = \left[ \frac{g(x, y)}{h(x, y) \ast f_n(x, y)} h^T(x, y) \right] f_n(x, y)
\]

where \( f_{n+1}(x, y) \) and \( f_n(x, y) \) are the estimated images after \( n+1 \) and \( n \) iterations. It is shown in Eq. 2 that the original image can be estimated via number of iterations as long as the PSF is known.

Usually, pitch and roll of the ship are the two main factors that introduce motion-blur when there is no servo applied on the optoelectronic equipment (e.g. star sensor). And miss distance is the key factor of motion-blur when servo is used (e.g. photoelectric theodolite). So the PSFs of motion-blur based on measuring data of ship posture and miss distance are both constructed, which are used in the simulated investigation and discussion of recovering effect employing RL algorithm.

**Results and Discussion**

Figure 1 depicts the PSFs based on practically measuring data and the corresponding simulated motion-blurred images. The pixels of images used in this paper are 512x512. The image in Fig. 1(a) is the original observing image without relative motion between the target and the optoelectronic system. The PSFs in Fig. 1(b) and Fig. 1(c) are constructed using ship posture data and miss distance data, respectively. In order to make it convenient for analysis and discussion, the PSFs are normalized and described within an area of 100x100 pixels, which does not influence the results of analysis essentially. In fact, the amplitude of miss distance data is much less than that of ship posture data. The interval of measuring data is 30 ms, and the number of data is 100, which means the whole exposal time of the observing image is 3 s. The exposal time is rather longer than usual values, which make the corresponding PSFs more complex so that we can verify the effect of recovering.

Figure 1. Simulation of space point target based on PSFs constructed by measuring data. (a) Original image without relative motion, (b) PSF based on ship posture data, (c) PSF based on miss distance, (d) motion-blurred image corresponding to the PSF in (b), (e) motion-blurred image corresponding to the PSF in (c).

It can be found out that the ship posture varies smoothly and continuously compared with miss distance, so the motion-blurred image is similar with the blurred image caused by linear motion, as shown in Fig. 1(d). The change of miss distance shows clear randomness and discreteness due to the impact of servo, and the corresponding motion-blurred image is more complex, as depicts in Fig. 1(e).
In order to make the study more representative, the PSF based on miss distance data is employed to perform the investigation below.

RL algorithm is employed to perform the recovering of motion-blurred image corresponding to the PSF in Fig. 1(c), and results are shown in Fig. 2. Noise is not considered in this part. The 100×100 pixels around the target are picked out and displayed for convenience of comparison. One can see that the recovering effect is rather clear after 5 iterations. The estimated image is nearly the same with the original one after 10 or more iterations.

Figure 2. Recovering of motion-blurred image using RL algorithm without noise.

Although noise of the image is not necessary to known when perform the recovering of motion-blurred image, it imposes important influence on the recovering effect, as shown in Fig. 3. The image noise is Gaussian noise with a variance of 0.0008. It is shown that the recovering process using RL algorithm is still effective, since the motion-blur is deblurred clearly. But the noise degrades the definition of the image badly, and RL algorithm does not remove the noise at all. On the contrary, RL algorithm enhances the image noise as the iterative number increases[8]. So the influence of noise on recovering of motion-blurred image should be investigated.

There are various methods to evaluate the effect of image recovering quantitatively. The correlation coefficient between the original and recovered image is an effect and intuitive method when the original image is known. The curves of recovering effect with different image noises are shown in Fig. 4. The variances are 0, 0.00008, 0.0003 and 0.0008, respectively. One can find out that RL algorithm is effective to recovering the motion blur when there is no noise, and the correlation coefficient tends to be convergent and stable after number of iterations. The trends of curves with other different noises are similar. The correlation coefficient reaches its maximum value after 4 iterations, then the coefficient decreases to a certain extent and tends to be stable, which results in a “bulge” on the curve. The main reason is that after 4 iterations the motion-blur is compensated effectively, but the noise is not eliminated or weakened. Furthermore, the image noise is enhanced as the iteration number increases [8]. So the effect of deblurring is degraded when the iteration number is
beyond 4. Apparently, it is necessary to perform image denoise before the deblurring using RL algorithm.

The popular image denoise methods includes mean filtering (MF) algorithm and Wiener filtering (WF) algorithm. The curves of deblurring effect using the denoise methods aforementioned are shown in Fig. 5. The initial Gaussian noise has a variance of 0.0003. The sample window of MF algorithm is 3×3, and those of WF are 3×3 and 8×8, respectively. It can be found out from Fig. 5 that the maximum value of coefficient is increased from 0.74 to 0.93 using MF algorithm, and the “bulge” shrinks clearly. The WF algorithm improves the maximum value of coefficient to 0.92 with sample window of 3×3, but the “bulge” is still apparent. When the sample window is 8×8, WF algorithm lifts the maximum value to 0.96 and eliminates the “bulge” to a large extent, which means the effect of denoise is the best among the above cases.

As for the observing of multi-target, RL algorithm in this paper can also be employed to recover the motion-blur, if the relative positions of the targets are static (such as constellation). The simulated results are depicted in Fig. 6. The whole sample time is increases to 9 s, and the variance of image Gaussian noise is 0.0003. From Fig. 6(c) one can see that noise and motion blurs the image and degrades the quality of image seriously, and the precise original positions of the targets can hardly be distinguished. WF algorithm with sample window of 8×8 is performed to denoise the image first, then RL algorithm is used to recover the motion-blur. The finally recovered image is shown in Fig. 6(d). It is apparent that the methods work well, and the recovered image is nearly the same with the original one.
Summary

In this paper, ship posture data and target miss distance data are employed to construct PSFs of motion-blur, which are used to perform the simulating investigation of deblurring of space point target’s image observed from a shipborne optoelectronic system. Recovering of motion-blurred images based on RL algorithm is studied, and the influence of noise is analyzed and discussed. The results show that it is effective to perform denoising first and then recover the blurred image using RL algorithm. The future work will focus on recovering of practically measured images using the methods in this text.

References


