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Satellite Multispectral Image Enhancement Based On Pan Sharpening Under NSCT Domain

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Abstract: In this pan-sharpening method based on the non-sub sampled contourlet transform (NSCT) is proposed. NSCT is very efficient in representing the directional information and capturing intrinsic geometrical structures of the objects. It has characteristics of shift-invariance, high resolution, and high directionality. In the propose method, a given number of decomposition levels are used for multispectral (MS) images and higher number of decomposition levels are used for Pan images. This decreases computation time and preserves both spectral and spatial qualities. Up sampling of MS images is performed after NSCT and not before. By applying upsampling after NSCT, structures and detail information of the MS images are more likely to be preserved and thus stay more distinguishable. Hence, we propose to exploit this property in pan-sharpening by fusing it with detail information provided by the Pan image at the same fine level. The proposed method is tested on WorldView-2 datasets. Both spectral and spatial qualities have been improved.

Keywords: Non-Subsampled Contourlet Transform (NSCT), Fusion Rule, Pan-Sharpening, Quality Assessment, Upsampling.

I. INTRODUCTION

Quality of images, provided by earth observation satellites systems, is directly linked to their spatial and spectral resolutions. Satellite sensors cannot give images with both high spatial and high spectral resolutions, the spectral and spatial resolutions have inverse relationship[1]. Consequently, these systems produce, on the one hand, panchromatic images (Pan) with high spatial resolution and low spectral resolution. On the other hand, they produce multispectral (MS) images with high spectral resolution and low spatial resolution. The addition of spatial information, extracted from the Pan image, into the MS image, provides an image with both high spatial resolution and high spectral resolution. This is known as pan-sharpening. Nowadays, the application of MS image pan-sharpening algorithms in remote sensing has become numerous due mainly to the growing number of satellite sensors. Till now, a large collection of pan-sharpening methods have been proposed to grow MS images to higher resolutions using spatial information of the Pan images. Among them, algorithms based on the widely used Intensity-Hue-Saturation (IHS) transform [2], they produce high spatial resolution MS images but with color distortion, specifically in vegetation areas. The proposed method in [3] utilizes the Normalized Difference Vegetation Index (NDVI) to correct pan-sharpened images. In [4], the authors have introduced a new high-resolution NDVI index based on which they proposed a method to reduce color distortion and to enhance the vegetation. The principal component analysis (PCA) is also used for pan-sharpening [5], however, like IHS, its main drawback is the distortion of the spectral information.

Recently, several pan-sharpening methods were proposed and are based on multi resolution approaches of the Laplacian pyramid, the wavelet transform, and the contourlet transforms (CTs). The wavelet transform is widely used in pan-sharpening due to its properties such as multi resolution, localization, critical sampling, and limited directionality (horizontal, vertical, and diagonal directions) [6]. However, it fails to capture the smoothness along the contours [1]. CT seems to overcome this drawback [7]. In fact, CT is a multi resolution transform that provides an efficient directional representation and takes into consideration wavelet properties. Thus, CT has been used for image fusion and pan-sharpening in [1] and [6]. The non-subsampled contourlet transform (NSCT) is a shift-invariant version of CT. In this paper, we will briefly describe the NSCT-based pan-sharpening algorithms in the standard form and then propose more efficient schemes improving the former. The first proposed method is similar to the standard method; however, the number of decomposition levels used for MS bands is lower than the number of decomposition levels for the Pan image. The second proposed method represents an improvement of the first one by using a more efficient upsampling algorithm and applying some rules to fuse the NSCT coefficients. It is shown that upsampling is very important in preserving edges in the pan-sharpened images [8]. The upsampling step is accomplished using an interpolation algorithm based on NSCT [9]. The second proposed method uses NSCT with an optimized number of decomposition levels and an efficient interpolation method.

II. NON-SUBSAMPLED CONTOURLET TRANSFORM

Generally, pan-sharpening is conducted using a multilevel decomposition to separate high and low frequencies. Pan sharpening techniques based on multi resolution analysis use multilevel decomposition methods to decompose MS and Pan images, and then inject spatial details extracted from Pan, but missing in MS, into MS images. Wavelet-based pan-sharpening methods are used to control the trade-off between spectral and spatial information delivered from an MS sensor and the Pan one, respectively. A large number of methods have been proposed based on the wavelet transform [10]. They provide satisfactory results but in [1], the authors have shown that CT is a better approach than the wavelet one for pan-sharpening. CT is able to capture and link the points of discontinuities to form a linear structure (contours). It is implemented by a multilevel transform followed by a local directional transform. The discontinuities at edge points and the multilevel transformation are obtained via the Laplacian pyramid. The local directional filter bank (DFB) is used to group these wavelet-like coefficients to obtain a smooth contour. CT is different from the other available multilevel and directional image representations, since it allows a different number of directions at each level. NSCT is a shift-invariant version of CT and has some excellent properties including multilevel and multi direction properties.

NSCT provides a better representation of the contours. CT employs the Laplacian pyramid for multi scale decomposition and the DFB for directional decomposition. To reduce the frequency aliasing of CT and to reach the shift invariance, NSCT eliminates the down samplers and the up samplers during the decomposition and the reconstruction of the image; it is built upon the non-subsampled pyramid filter banks (NSPFBs) and the non-subsampled DFBs (NSDFBs), as illustrated in Fig. 1. NSPFB, employed by NSCT, is a 2-D two channel non-subsampled filter bank (NFB). To achieve the multi scale decomposition, conceptually similar to the 1-D non-subsampled wavelet transform computed with the "à trous algorithm," the filters for the next stage are obtained by upsampling the filters of the previous stage with the sampling matrix [6]

$$D = 2I = \begin{bmatrix} 2 & 0 \\ 0 & 2 \end{bmatrix} \quad \textbf{(1)}$$

which gives the multi scale property without the need of additional filter design.

NSDFB, employed by NSCT, is a shift-invariant version of the critically sampled DFB in CT. DFB is constructed by combining critically sampled two-channel fan filter banks and resampling operations, which results in a tree-structured filter bank that splits the 2-D frequency plane into directional wedges [6]. NSDFB is constructed by eliminating the down samplers and upsamplers in DFB and as a result, NSDFB is also a two-channel NFB. To achieve multi direction decomposition, NSDFB is iteratively used. NSCT is obtained by combining NSPFB and NSDFB, as shown in Fig. 1.

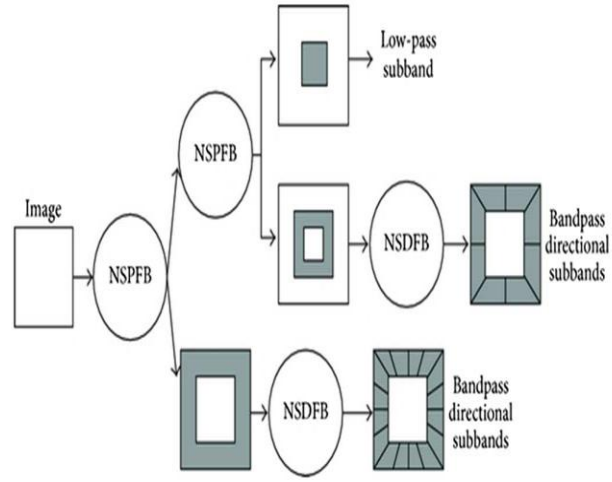

Fig. 1. NSFB structure that implements NSCT.

III. QUALITY INDICES

The quality assessment of the pan-sharpened MS images presents a problem since no reference image exists at the pan sharpened resolution. Even when reference MS images are available, the assessment of fidelity to the reference usually requires computation of a number of different indices. In this paper, we have selected the following widely used indices for assessing the quality of the obtained results.

- **The correlation coefficient (CC) [4]:** it is the most popular. It measures the similarity between the fused and original images.ACC value of +1 indicates that the two images are highly correlated or similar.
- **The correlation between high frequencies (sCCz) based on [4]:** a high-pass filter is applied to the fused bands and the Pan image. Then, the CC coefficient between the resulting images is computed.
- **The correlation between high frequencies (sCCo) based on [8]:** in this case, high-pass filtered versions of the pansharpened bands are compared with the high-pass filtered versions of the original MS bands.
- **The relative bias (BIAS):** it is the difference between the mean of the original image and that of the fused one, divided by the mean of the original image [4].
- **The relative variance (VAR):** it represents the difference in variance between the original and fused images, divided by the variance of the original image [4].
- **The standard deviation (SD) of the difference image in relation with the mean of the original image:** it indicates the level of the error at any pixel [4].
- **The Structural Similarity (SSIM) index:** it measures the similarity between two images. The SSIM index can be viewed as a quality measure of one of the images being compared, provided the other image is regarded as of perfect quality.
- **The universal objective image quality index (Q) [17]:** it models distortion as a combination of three different factors: loss of correlation, luminance distortion, and contrast distortion.
- **The relative average spectral error (RASE):** it is used to characterize the average performance of the pan

sharpening method in spectral bands [8]. The root-mean-square error (RMSE) [4].

- **The average spectral angle mapper (SAM):** it computes the change in angle of spectral vectors [9].
- **The relative dimensionless global error in synthesis (ERGAS):** it provides a single quantity synthesizing the quality of the fused dataset.
- **The QNR index:** it is used to assess fusion quality without requiring reference images. It is based on the universal quality index Q proposed in [7], and includes two indices, one for spectral distortion and the other for spatial distortion. In the QNR approach, it is assumed that the inter bands spectral quality of the pan-sharpened images is unchanged after the fusion process.

The best value for indices CC, sCCz, sCCo, SSIM, Q, and QNR is 1, whereas it is 0 for indices BIAS, VAR, SD, RASE, RMSE, SAM, and ERGAS.

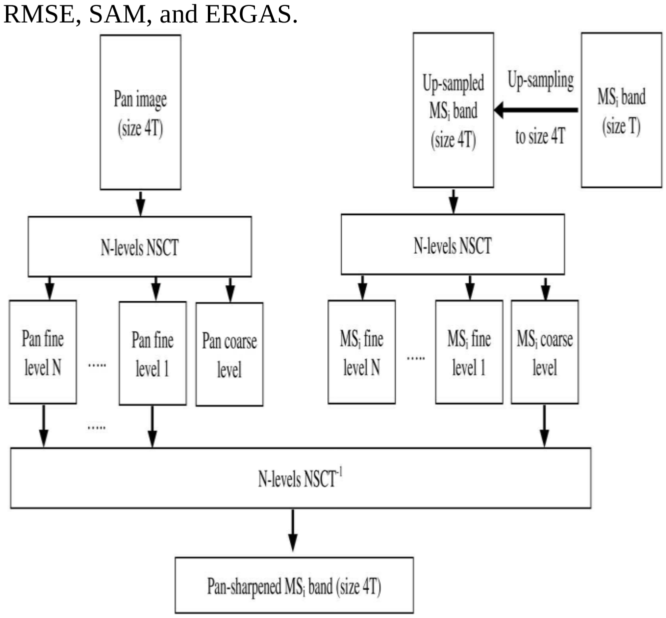

Fig. 2. Standard NSCT-based pan-sharpening method for i^{th} band (MS_i).

The protocol of Wald described in [2] is usually used to evaluate pan-sharpened images. It consists of three properties but only the first one can always be assessed since the two others need the reference. In order to apply the whole protocol, two approaches must be conducted. In the first approach, the pan sharpening is performed at the full scale. In this approach, the reference is not available; for this reason, it is possible to directly assess only the first property of Wald's protocol. The second and the third properties of Wald's protocol can be indirectly verified by using the QNR and sCCz indices. The second approach, instead, allows directly verifying also the second and the third properties. It consists of down sampling all the dataset (panchromatic and MS), making pan-sharpening at lower scale and using the original MS as reference [3]. This approach is used to compute indices sCCo, CC, Bias, VAR, SD, SSIM, Q, ERGAS, RASE, RMSE, and SAM. In this way, the protocol is entirely applied. In the first approach, the second and the third property of Wald's protocol are indirectly assessed by using the QNR and sCCz indices; while in the second approach the indices the CC, SSIM, Q, and sCCo indices verify the second property; and finally indices ERGAS and SAM verify the third property. In this paper, two fusions are conducted: one at full scale and the other at lower scale. All the pan-sharpened images reported in this paper are issued from the full-scale fusion process. This fusion is also used for computing the sCCz and QNR indices. The lower-scale fusion is used to compute the rest of the indices: sCCo, CC, Bias, VAR, SD, SSIM, Q, ERGAS, RASE, RMSE, and SAM.

IV. STANDARD NSCT-BASED PAN-SHARPENING

In general, all the multi resolution-based pan-sharpening methods adopt the following process [6].

- Forward transform the Pan and MS images using a sub-band and a directional decomposition such as the subsampled or non-subsampled wavelet or contourlet transform.
- Apply a fusion rule onto the transform coefficients.
- Generate the pan-sharpened image by performing the inverse transform.

A number of pan-sharpening methods using the contourlet transform have been proposed in [1]. Commonly, MS and Pan images are decomposed using the same number of decomposition levels, then appropriate rules are applied to fuse the obtained coefficients. The number of decomposition levels used is based on the dataset resolution ratio [24].For the IKONOS, Quick Bird, and Worldview-2 imagery, a two-scale decomposition level is sufficient to provide satisfactory results, whereas for the Landsat-7 EMT+ imagery, a one-scale decomposition level could be used [1]. Fig. 2 shows an example of an NSCT-based pan-sharpening method. For each MS band, the pan-sharpened NSCT coefficients are obtained from a combination of the coarse level coefficients of the corresponding MS band and the fine levels coefficients of the Pan image. Then the NSCT inverse transform is used to generate the corresponding pan-sharpened MS band.

V. PROPOSED METHODS FOR PAN-SHARPENING USING NSCT

NSCT-Based Pan-Sharpening With Different Numbers of Decomposition method used to fuse the images. The estimation of the number of decomposition levels for a wavelet-based multi resolution multisensory image fusion. They found that a lower number of decomposition levels preserve better the spectral quality, whereas a higher number of decomposition levels is recommended to maintain the spatial quality. Thus, the improvement of fused images may be achieved if an adequate number of decomposition levels are used. Consequently, we propose to use the NSCT based pan-sharpening with a different number of decomposition levels, where the number of decomposition levels for MS bands is lower than the number of decomposition levels for Pan images. For satellites, as WorldView-2, Quick Bird, and IKONOS, the resolution ratio between MS and Pan is 1:4. In subsampled CT analysis, in each level a decimation of 2 is applied. Thus, a decimation of four corresponds to two decomposition levels in subsampled CT. Therefore, if n decomposition levels are used for MS bands, then n+2 decomposition levels are used for Pan image. The two proposed methods are detailed in the following. The first one demonstrates the efficiency achieved when using a different number of decomposition levels; whereas the second one adds some improvement considering an upsampling method based on NSCT.

The conducted experiments show that a fixed value of 1 for the MS decomposition levels (n=1) is practical and provides good results. Three levels of the NSCT decomposition (n+2=3) are then applied to the Pan image. The coarse coefficients of the MS bands and the fine coefficients of Pan are merged to obtain the pan-sharpened image by taking the three-level inverse NSCT. Fig. 3 shows an example of the NSCT-based fusion. From left to right are shown the MS image, Pan image, fused image using the standard NSCT-based method and the proposed NSCT-based pan-sharpening with a different number of decomposition levels. Some indices, assessing the quality of the fused images, are computed and shown in Table I to demonstrate the efficiency of the proposed method. Spatial quality is measured by sCCz and sCCo, whereas spectral quality is evaluated using the rest of the indices. From Table I, it is clear that the proposed method (method1), based on different numbers of decomposition levels, gives better results, in terms of most of the indices, compared to the standard method based on a fixed number of decomposition levels for both the MS and the Pan images.

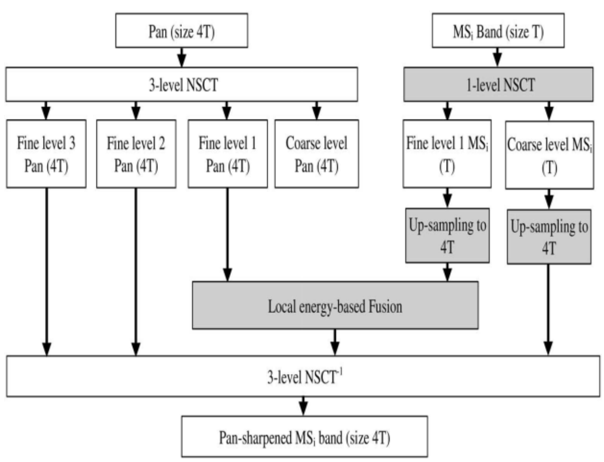

Fig .3. Proposed NSCT-based pan-sharpening method for an ith band (MS_i).

It is also important to note that the proposed method allows a gain in terms of execution-time, e.g., while 18 s are sufficient for executing the proposed method, 30 s are necessary for running the standard method; and hence, leading to a 35% time saving for our approach. This property can be important when real-time processing is considered. In our experiments, we used MATLABR2011b. In conclusion, the proposed method not only improves the spectral quality but operates with lower processing time compared to the standard method.

VI. EXPERIMENTAL RESULTS

In this section, the proposed method is evaluated and compared with the standard NSCT method and results as shown in Figs.4 to 10. The datasets used for this evaluation are those made available by DigitalGlobe, Astrium Services, and the United States Geological Survey (USGS), for the 2012 IEEE GRSS Data Fusion Contest. This contest has been annually organized by the Image Analysis and Data Fusion Technical Committee (IADFTC) of the IEEE GRSS since 2006. The image scenes cover a number of large buildings, skyscrapers, commercial, and industrial structures, a mixture of community parks and private housing, highways, and bridges. WorldView-2 Pan and MS images of (2048×2048) and (512×512) pixel sizes, respectively, over downtown San Francisco are selected for the demonstration purposes. Worldview-2 provides eight bands: coastal (C), blue (B), green (G), yellow (Y), red (R), red-edge (RE), and two near-infra-red bands (NIR1 and NIR2).

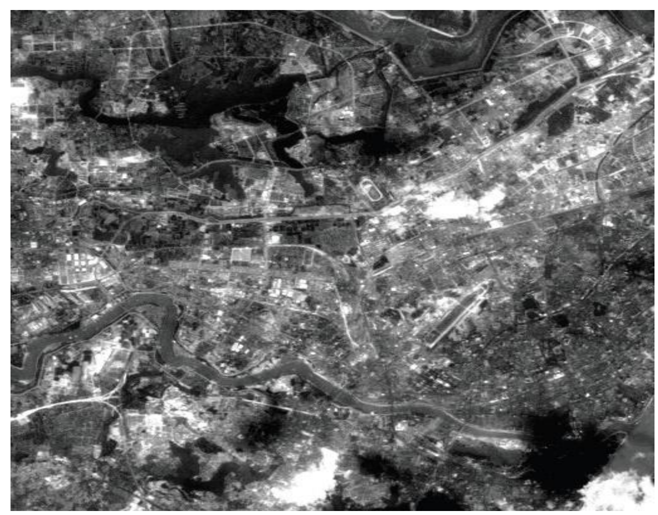

Fig.4. Input MS image and pan image.

Fig. 5. NSCT decomposed images.

Fig. 6. Fused image.

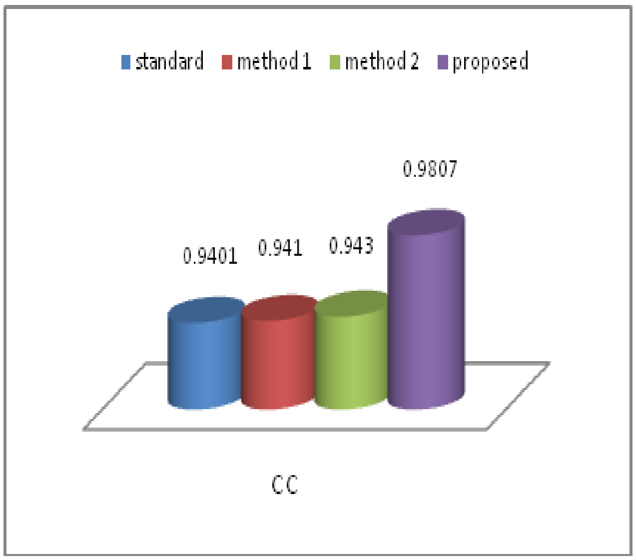

Fig .7. correlation coefficient.

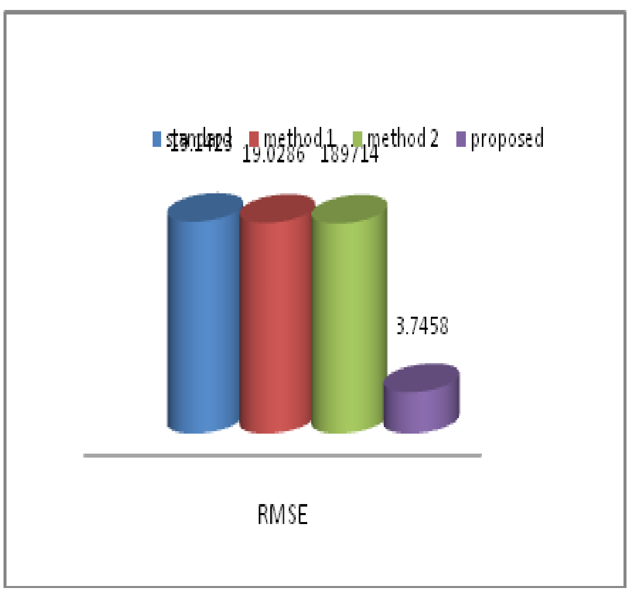

Fig .8. Root mean square error.

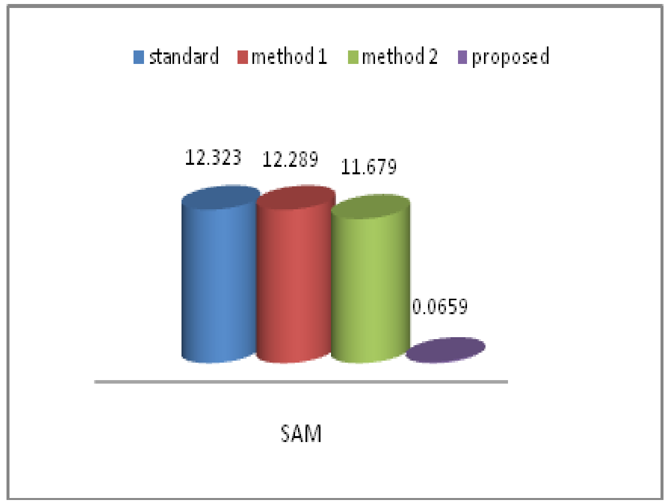

Fig .9. Spectral Angle Mapper.

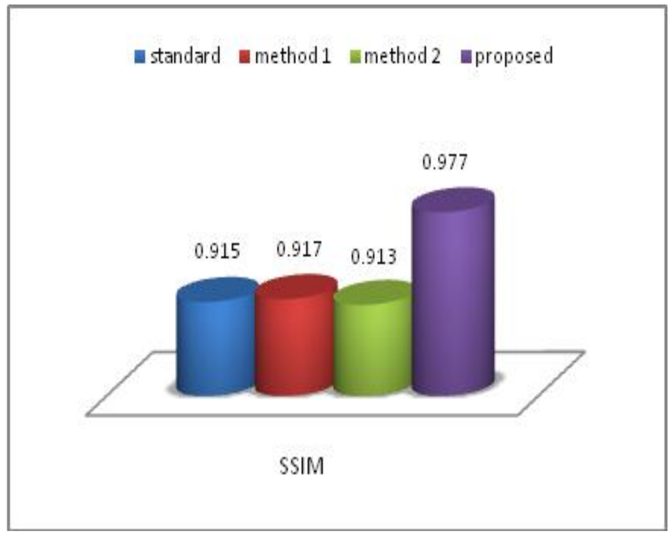

Fig .10. Structural similarity index.

VII. CONCLUSION & FUTURE SCOPE

The project presented that Multi spectral image enhancement using pan sharpening approach. Here, spatial details of pan chromatic image are fused effectively with multi spectral image based on NSCT and pixel level fusion. NSCT was helped to represent an image with better contour edges in different directions. Weighted average merging method based pixel level fusion was performed to fuse relevant details from low and high frequency with texture descriptor such as energy feature analysis. The fused image contains high spatial resolution and spectral resolution rather than input original image. It is used in the remote sensing imaging system for analysis of satellite images. The proposed technique has given better visual perception on processed MS image rather than prior approaches. The images can also be improved subjectively and objectively further. Further enhancement can be done in fusion technique while combining the MS image and NSCT images to obtain better results than the proposed method. The system can be further enhanced with better flexible algorithm to reduce the computational complexity.

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