Prototype Image Constraints Using Modified Inverse Filter for CBERS-2 Satellite Image Restoration

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Abstract. In POCS image restoration we consider the case where the prototype images are obtained from the observed image via a predetermined operator, which is the Modified Inverse Filter. A POCS algorithm using the proposed constraints and the limited amplitude constraint is applied to monochrome CBERS-2 satellite band 2 images.

1. Introduction

The amount of satellite imagery has widely increased with the new sophisticated imaging systems onboard. These sensors provide high quality data and allow a more accurate understanding of phenomena on ground. Among this new generation of satellites, the CBERS-2 (China-Brazil Earth Resources Satellite) was jointly developed by Brazil and China and its mission was designed to capture high-resolution images of Earth by using panchromatic and multispectral detectors [1].

However, images of digital sensors and aerial pictures need to be processed to better reflect the radiometric qualities of the data. A large number of image restoration methods has been developed for several applications, like Inverse and Wiener Filter, deterministic and statistical regularization techniques and POCS (Projections Onto Convex Sets) [2].

2. Image Restoration Through Modified Inverse Filter

The image restoration problem related here is to obtain an estimate of an image f from its degraded and noisy observation g which is the result of a linear imaging system modeled by

$$g = Hf + n , \tag{1}$$

where H is the convolutional degradation operator, and n denotes the additive observation noise [3]. Vectors g, f and n correspond to lexicographical ordering of the respective two-dimensional fields by rows, with dimension M, and columms, with dimension N. Consequently, these vectors have dimension $M*N$.

Equation (1) can be written in the Fourier domain as

$$G = HF + N , \tag{2}$$

where G, F and N are the Fourier Transform (FT) of the degraded image g, original image f and the additive noise n, respectively. Matrix H is the FT of the PSF (Point Spread Function), which model the limitations of the sensor. In the absence of noise, Equation (2) can be rewritten as

$$G = HF , \tag{2}$$

and an obvious choice for the Inverse Filter $\hat{I}$ is:.

$$\hat{I} = \frac{1}{H} \tag{3}$$

However, in the presence of noise Equation (3) is unstable. The instability arises from the location of the zeroes of H. The Modified Inverse Filter (MIF), also called Transfer Function Compensation, approximates the Inverse Filter and at the same time attempts to control the problems associated with it. The idea is to choose a desired function D as the response of the system that would alleviate the ill-conditioning effects [4]:

$$D = HW . \tag{4}$$

The function D should have a better behavior than the function H. A constant value for D yields the Inverse Filter. Once D is selected W can be estimated. Since we have a separable PSF for directions X and Y, also called across-track and along-track, respectively, W, D and H will be treated as 1-D functions. In that way, W can be written as

$$W(u) = \begin{cases} \frac{D(u)}{H(u)} & |u| \le u_c , \\ 0 & otherwise \end{cases} \tag{5}$$

where u is the frequency and u_c is the system cut-off frquency. The desired response $D(u)$ used in this work is given by Equation (6), where u_w is the frequency for which the Modulation Transfer Function is 0.5 [4].

$$D(u)=\begin{cases}0 & 0\le u\le u_c\\ 0.5\left(1+\cos\left[\pi(u-u_w)\big/(u_c-u_w)\right]\right) & u_w\le u\le u_c\end{cases} \quad (6)$$

3. POCS Technique

The POCS method can be used to find a common point *f* which satisfies a set of constraints, each of which forms a convex set. This common point *f* lies in the intersection of all the convex sets [3]

$$f\in C=\bigcap_{i=1}^{i=m} C_i \quad (2)$$

where the *i*th closed convex set C_i denotes the *i*th constraint on *f*. The common point can be found by alternatively projecting onto the convex sets C_i via the corresponding projecting operator P_{C_i} as

$$f^{(k+1)}=P_{C_m}P_{C_{m-1}}\ldots P_{C_1}f^{(k)}=P_C f \quad (3)$$

In this work we used two convex sets: limited amplitude restriction set and prototype image restriction set, whose equations are given by:

$$P_{C_{LA}}x(k,l)=\begin{cases}\alpha, & if\ \ x(k,l)<\alpha\\ x(k,l), & if\ \ \alpha\le x(k,l)\le\beta\\ \beta, & if\ \ x(k,l)>\beta\end{cases} \quad (7)$$

$$P_{C_{PI}}=\begin{cases}WG-\sqrt{\delta}\,\dfrac{\Delta}{|\Delta|} & if\,|\Delta|^2>\delta\\ Q\ otherwise\end{cases} \quad (8)$$

where $P_{C_{LA}}$ and $P_{C_{PI}}$ are, respectively, the limited amplitude and prototype image projections operators.

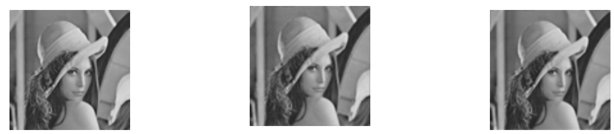
4. Experimental Results

In our experiments we used a monochrome image, the well-kown Lena image, shown in Figure 1(a). This picture is a 256x256, 8 bits/pixel. The degraded and noisy image was obtained by blurring the original image by a 3x3 Gaussian PSF corresponding to band 2 of CBERS-2, and by adding zero mean Gaussian noise with variance equal to 0.9, which[i] is shown in Figure 1(b).

The degraded images were restored using the POCS algorithm below:

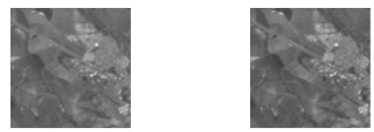
$$f^{(k+1)}=P_{C_{LA}}P_{C_{PI}}f^{(k)},(16)$$

where $P_{C_{PI}}$ and $P_{C_{LA}}$ are the projections onto the prototype image and limited amplitude constraints sets respectively. Figure 1(c) displays the restored image using the algorithm described above, which was evaluated using the ISNR. We obtained, for this experiments, $ISNR=1.521$. Figure 2 shows the CBERS-2 satellite image: 2(a) original and degraded image, 2(b) image restored using the POCS algorithm.



(a) (b) (c)

Figure 1 (a) Original image, (b) degraded image and (c) restored image.



(a) (b)

Figure 2 (a) Original image, (b) restored image.

5. Conclusion

We concluded that the images obtained by Modified Inverse Filter and our POCS algorithm are very close, which demonstrates the reliability of the algorithm.

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