SUBPIXEL HIGH ACCURACY IMAGE REGISTRATION FOR RADAR INTERFEROMETRY PROCESSES

Yitzhak August, Dan G. Blumberg, Stanley R. Rotman.

The unit of Electro-Optics Engineering and the Department of Geography and Environmental Development.
The Earth and Planetary Image Facility Lab (EPIF)
Ben-Gurion University of the Negev
Beer Sheva, 84105 Israel
augusty@bgu.ac.il, blumberg@bgu.ac.il, srotman@ee.bgu.ac.il
www.epif.bgu.ac.il

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ABSTRACT:

Image registration is one of the important steps in processing remote sensing data. In the process of SAR interferometry (InSAR) there is use of multiple data sets from different times or different look angles. Generally, data registration processes contain two steps; the first step is estimation of the transformation of coordinates from the reference image to all other images in the data set. The second step is resampling (interpolation) of the images to the reference grid. This work presents a new algorithm for the estimation of local shift in SAR detected images. The algorithm uses a Fast Fourier transform (FFT) and a cross power spectrum of the two images. From the cross power spectrum parameters and some empiric fix parameters are calculated for the translation vector up to a fraction of a pixel. The proposed algorithm is invariant to the image gain (or uncelebrated images and change in dynamic ranges) and also to bias change, another benefit from the local shift estimation is the low influence by small area of image corruption. It also shows that our method is minimally influenced by noise and clutter that are inherent in detected SAR images. In this work we present both simulated and real data results and compare the algorithm to other methods of registration.

1 INTRODUCTION

Image registration is a mathematical process of overlaying image or data (matrix or other data array) according to some reference grid. In some cases an image is aligned according to some geographic grid. In other cases the used reference is a float or a relative reference grid. If a data set contains a number of images of the same scene, the common way is to align all the images according to one of the images (master set) in the data set and align the final process data results according to the geographic grid. The registration process is used to align images of different acquisition times, different image geometries or different radiation properties[DB1] i.e. (wave length or wave polarization). These changes in the properties of the images and the inherent noises are the sources of the difficulty of image registration. In order to be able to align one image to another, some of the areas must contain the same information or the same structure. This restriction is hard to achieve when the images are spanned over long time periods or over areas that high temporal changes. In general, there are two types of registration. One is pixel registration (or few pixels) and the other is sub pixel registration (fine registration). The difference between these two types of registration is on the scale of the registration errors. For some remote sensing applications and works, the pixel registration is good enough. In other remote sensing studies the restriction of misalignment is about $1/10$ or even less of the pixel size. The registration process has two parts. The first part of the process is to find and estimate the transformation between the reference coordinates and the image local coordinates. This step can be done globally or on small sub areas of the image i.e. this process is a parametric estimation of the transformation model. The second step is to interpolate the image according to the transformation found in the first step. The transformation and interpolation can be simple or more complex according to the model of registration (translation, rotation, or other), the geometry distortions, and other restrictions. In this work we will present a new method for sub pixel registration of Synthetic Aperture Radar (SAR) detected images. This method is highly accurate in detection of translated vectors for the registration process. It is assumed that the previous step of pixel registration has already been done and the maximum components of the translation vector are less than 0.5 of the pixel size.

2 THEORETICAL BACKGROUND

We start by considering two discrete signals $f_{1d}(x, y), f_{2d}(y, y)$. These two signals present the same information (we assume periodic signals $f_{1d}(x, y) = f_{2d}(x + t_1, y + t_2)$ (which t_1 and t_2 are the signal periodic interval) but on a slightly different grid i.e. the signal shift is less than one sample interval. To describe this fraction of interval sample shift we describe the signals as a downsampled version of higher density signals (Kim and Su, 1993, Shekarforoush et al., 1996, Foroosh et al., 2002). We write the signal f_1 and it is shifted version f_2

$$f_2(x, y) = f_1(x + \triangle_x, y + \triangle_y) \quad (1)$$

The translation vector components $(\triangle_x, \triangle_y)$ are an integer displacement vector. Another way to represent these signals is in the frequency domain. Where $F_i(\omega_x, \omega_y) = \mathrm{DFT}\{f_i(x, y)\}$, The DFT is the symbol for the discrete Fourier transform. Using the properties of the DFT transformation we can represent the shift as a multiplication of the signal in the Fourier domain by a linear complex phase; equation (2) describes the relation between the two signals.

$$F_2(\omega_x, \omega_y) = F_1(\omega_x, \omega_y) \cdot \exp(j\triangle_x\omega_x + j\triangle_y\omega_y) \quad (2)$$

As we assumed before, our signals are down samples of the high resolution signals. Let's assume that the original signals were down sampled by a factor of m, n in the x, y axes (Vetterli and Kovacevic, 1995). We define new frequency variables $\omega'_x = (\omega_x + 2\pi m)/M$ and $\omega'_y = (\omega_y + 2\pi n)/N$ where $n \in \{0...N-1\}$ and $m \in \{0...M-1\}$, in the frequency domain the two down sample signals presented as (3) and (4). The original signal

$$F_{1d}(\omega_x, \omega_y) = \frac{1}{NM} \sum_{n=0}^{N-1} \sum_{m=0}^{M-1} F_i(\omega'_x, \omega'_y) \qquad (3)$$

The shifted signal:

$$F_{2d}(\omega_x, \omega_y) = \frac{1}{NM} \sum_{n=0}^{N-1} \sum_{m=0}^{M-1} F_i(\omega'_x, \omega'_y) \cdot \exp(j\omega'_x \triangle_x + j\omega'_y \triangle_y) \qquad (4)$$

Now we present the cross power spectrum of the down sample signals (also known as phase correlation)

$$C(\omega_x, \omega_y) = \sum_{n=0}^{N} \sum_{m=0}^{M} H_{nm}(\omega'_x, \omega'_y) \exp(j\triangle_x \omega'_x + j\triangle_y \omega'_y) \qquad (5)$$

Where $H_{nm}(\omega'_x, \omega'_y)$ is defined in the next equation

$$H_{nm}(\omega'_x, \omega'_y) = \frac{F(\omega'_x, \omega'_y)}{\sum_{n=0}^{N} \sum_{m=0}^{M} F(\omega'_x, \omega'_y)} \qquad (6)$$

To estimate the translation shift, in the first step we assume a near linear surface (Stone et al., 2001). In our proposed algorithm we estimate the slope of the surface along the ω_x and ω_y i.e. we take only the two vectors along the x and y direction.

$$D_x = \frac{1}{\sum_{s_x=0}^{S_x-1} \alpha_{sx} \omega_{sx}} \cdot \sum_{s_x=0}^{S_x-1} \frac{\alpha_{sx} \angle C(\omega_{sx})}{\omega_{sx}}$$

$$D_y = \frac{1}{\sum_{s_y=0}^{S_y-1} \beta_{sy} \omega_{sy}} \cdot \sum_{s_x=0}^{S_y-1} \frac{\beta_{sy} \angle C(\omega_{sy})}{\omega_{sy}} \qquad (7)$$

D_x and D_y represent the component of the translation vector. S_x and S_x represent the size of the observed signal in x and y.In summation α_{sx} and β_{sx} represent the relative high absolute value component of the signal in the first quarter of the spectrum, where the signal contains power and these variables get the value of 1 elsewhere these values are equal zero. In most cases the signal contains more energy in the low or in the medium region of the spectrum, so it is common to take the α_{sx} and β_{sx} to equal to one in the $[0, ..., 0.6]\pi$ region. In other cases of spectrum power distribution, it is possible to set a threshold for the selecting of only the high power spectrum components. Because of some nonlinearity in this method and the discrete nature of the signals we present some mechanisms to get a more accurate estimation. We add anti symmetric polynomial as a fixing function.

$$\angle C(\omega_x, \omega_y) = (\triangle_x \omega_x + \triangle_y \omega_y) + O(\triangle_x, \triangle_y) \qquad (8)$$

The fixing function represented in a parametric way.

$$O(\omega_i) = \sum_{z=0}^{Z} \gamma_{(2z+1)} \cdot \triangle_i^{(2z+1)} \qquad (9)$$

Z can be up to about 2 or 3. The final translation vector is represented as

$$D_i = d_i + O(d_i) \qquad (10)$$

Another approach that does not use the fixing function is an iterative way. In this way we find the translation vector and resample the signal according to the translation vector and redo it again. In this way we converge to the final results.

2.1 assumption and approximation

In this work we are assuming four major assumptions. The first assumption is that the signals are a translation version of one another. This can be the situation where the signals are periodic signals. The next two assumptions are that once there is some shift between the signals the angle of the components in the Fourier domain is represented as ramp function and the slope of this ramp is nearly constant for different shift. We will see in the next section that these two last assumptions are very close to the simulation we did. The last assumption is that the signals are similar and the most power is distributed in the same way in the furrier domain.

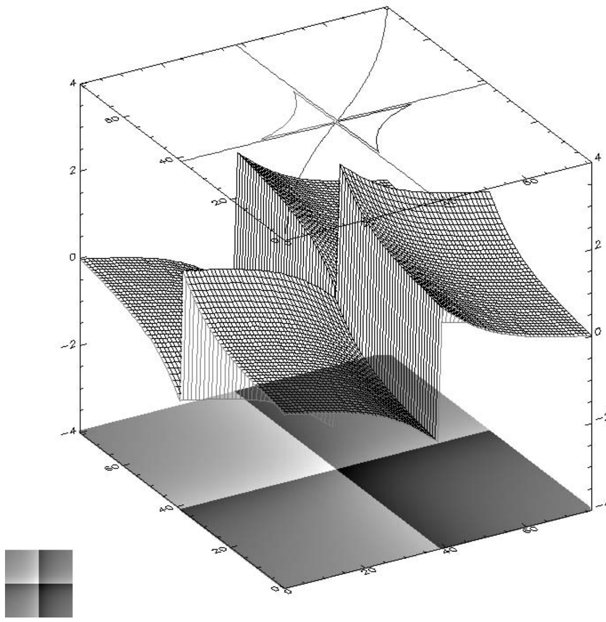

Figure 1: the angle surface of the phase correlation for two sub pixel shifted Gaussians; we can see that in the first quarter the phase angle as close to linear surface

3 REGISTRATION PROCESS

The registration process is assumed to run on signals that the relative shift between the reference image and all other images is about one or two pixel in each axes. This can be done by applying coregistration process or any other pixel registration process (Zitov and Flusser, 2003, Brown, 1992). First the SAR data matrix must be detected and converted to a SAR image; next step is denoising, in our work we use low pass filters that are implemented by two dimensional convolution operators with a suitable kernel (we used a two dimensional circular Gaussians). An alternative way is to use the bilateral LPF method (Tomasi and Manduchi, 1998, Durand and Dorsey, 2002). The bilateral filter is a nonlinear filter that smoothes a signal while preserving strong edges. In this stage both images are divided into new grid i.e. the images split to sub areas. The splitting process allows us to select and use only the similar sub areas i.e. the small areas that remain similar or do not change in time. The selection of similar areas is base on the correlation coefficient. We select only areas that have correlation coefficient values. Between any pairs of sub image part the translation vector is estimated. But because of the "window" effect we check tree kinds of windows a rectangular simple window, blackman window and Blackman-Harris window (Harris, 1978, Stone et al., 2001). The final step is to estimate the shift from the phase correlation as show in the previous section. After the pair sub area shift estimation, we assume a ridge image shift and for averaging translation vector to get the image final translation vector.

4 RESULTS AND DISCUSSION

The using of this method was first applied on simulated signals. We started by synthesizing two signals of Gaussian shifted and find the fixing function parameters $\gamma_{(2z+1)}$. We find out that the Blackman-Harris window had the best results. The signal shift was between -0.5 and $+0.5$. We compared the estimated shift and the real known simulated shift. The results are showen in the next figure.

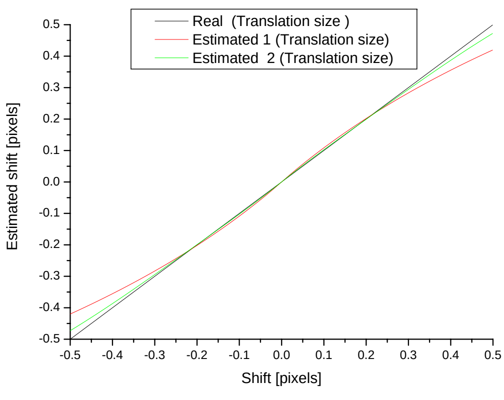

Figure 2: real shift and estimated shift

As we can see, the accuracy of the estimation is rising as the shift getting low values. In the graph we can see the estimation of the shift by adding the fixing function. The difference between the estimation process and the real shift are present next. The fixing function is base on estimation the best fit for this function. We find that the parameters for the fixing function (in the case of Gaussian like functions distribution) are $\gamma_{(1)} \approx -0.07 \pm 0.00082$, $\gamma_{(3)} \approx +1.70 \pm 0.01$,$\gamma_{(5)} \approx -3.14 \pm 0.05$ all the even factor as are equal to zero.

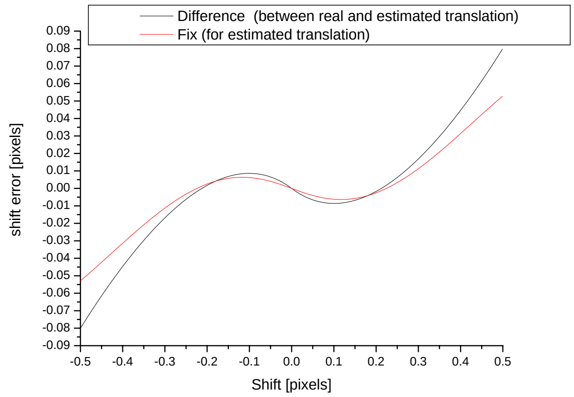

Figure 3: the error and the fix function for the translation estimation

After the simulation part, we use the registration method on a set of ERS SAR images. We used two regions, one of the regions contains a bright manmade object and the other contains only natural morphologies such as dunes. We tried to estimate the accuracy of the shift estimation in two ways; the first way is by trying to make from the register images an interferogram, which fringes can be view were the shift error in less than 0.1 pixels. The other way, is to search a close translation vector which after resampling the signals bring the correlation coefficient to rise into a maximum. According to this method we get an error shift of about 0.05 and 0.1 pixels for signals that also contain changes beside the shift.

5 CONCLUSIONS AND FUTURE WORK

Our conclusion is that this presented method is suitable for SAR image registration and is also suitable for the process of SAR interferometry. We did not use this method for images in the visible or infra red spectrum, but this can be done in future research. It is also important to find a way for the fixing function parametric estimation.

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