ITERATIVE APPROACH FOR HIGH RESOLUTION INSAR SUBSURFACE FOCUSING AND COREGISTRATION IN ARID REGIONS

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1. INTRODUCTION

Subsurface sensing and determination of subsurface topography is encountered in a number important applications ranging from oil exploration in arid regions to geology, archaeology, glaciology, and planetary explorations. There are also a number of important military applications which includes detection of landmines and underground facilities. The current technology for many of the aforementioned problems is based on ground penetrating radars (GPRs) [1]. However, mapping large areas using GPRs is extremely time consuming and labor intesive. To circumvent the problems with GPR, we recently developed the concept of a two-frequency (Ka and VHF) subsurface mapping InSAR to see through sand and map the sand layer thickness [2]. The proposed system consists of two InSAR subsystems: (1) a Ka InSAR responsible for mapping the top interface topography and (2) a VHF InSAR tasked for obtaining information about the subsurface targets and interfaces. The Ka-band system receives its signal from the top surface backscatter since the propagation through the top layer is limited by the absorption and volume scattering losses. On the other hand at low frequencies, the waves can penetrate the top layer with minimal attenuation and scatter from the bottom interface giving information about its topography. The subsurface height is then obtained using a fast physics-based iterative inversion algorithm that can efficiently correct for the propagation effects through the top layer using both the Ka and VHF InSARs data. The proposed technique was experimentally verified using scaled model measurements in the lab and the measurement results showed good agreement with the simulation results [3].

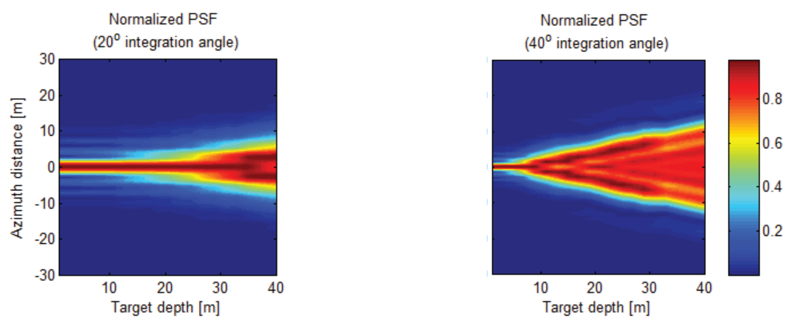
However, conventional focusing and coregistration techniques significantly limited the resulting azimuth and range resolutions for achieving accurate elevation data. This is mainly due to the large number of pixel averaging on the interferogram to overcome the defocusing and co-registration errors [4]. Degrading resolution is detrimental in some applications that require high resolution such as mine detection. To overcome these limitations, we present an iterative approach for subsurface focusing that can iteratively correct for the refraction and propagation effects through the top layer. This provides a significant improvement in maintaining the resolution while keeping high elevation accuracy in addition to correcting for the image deformation due to the refraction through the top surface. The result is verified experimentally where improved coherence is shown which indicates better focusing and coregistration.

3. DEFOCUSING AND DISTORTION EFFECTS IN SUBSURFACE SAR

Conventional SAR processing assumes that the wave path between the radar and the target is a straight line with a propagation constant equal to that of free space. For subsurface targets with top surface undulations, this results in two types of image artifacts: defocusing and geometrical distortion. In this section, we present these effects on two sample scenarios. In the following simulations, the center frequency is 150 MHz, the bandwidth is 60MHz and the platform height is 5 Km.

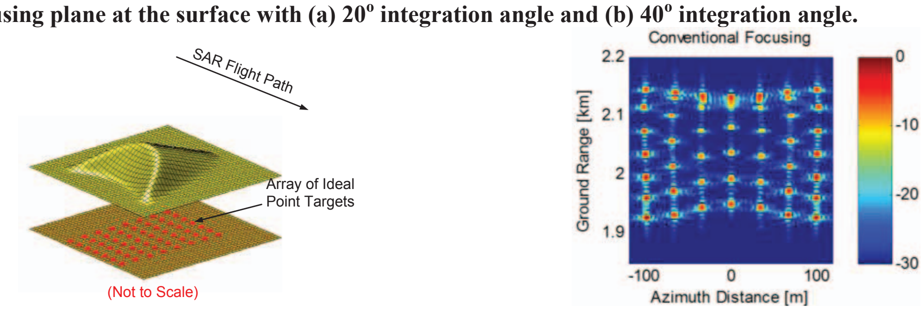
The first problem with subsurface SAR images are defocusing effects which can be separated into range defocusing and azimuth defocusing. Simulation results shows that range defocusing, which is due to sand dispersion, is much less significant than azimuth defocusing since dry sand dispersion is very small for the frequency range and bandwidth considered for this application. However, azimuth defocusing is very significant and poses significant limitation on the achievable azimuth resolution. An example is shown in Fig. 1 where a target was placed under a sand layer with flat interface at a depth of Z_t that is varied from 0 - 40m, and ground range of 2 Km. The target image was generated using conventional back-projection with focusing plane at the surface. Figure 1 (a) shows that for small synthetic aperture (small integration angles), the azimuth target point spread function (APSF) maintains its form up to a depth of approximately 20m (corresponding to large depth of focus) but is relatively wide (poorground resolution). However, for larger integration angles, the APSF is much narrower (good ground resolution) when the target is near the surface (Z_t <5m). The resolution degrades quickly as the target depth is increased. Since for VHF SAR even larger integration angles are typically required to achieve reasonable ground resolution (e.g. 120^o is used in [5]), accurate focusing is extremely important.

The second issue with conventional focusing method is geometric distortion due to refraction effects through the top surface topography. A sample scenario is shown in Fig. 2 (a) , where an array of 49 point targets arranged uniformly over an azimuth range of 200m and ground range of 200m centered at (0, 2Km) is placed at a depth of 5 m under a *barchan* sand dune with crest height of 30m and length of 200m. The integration angle was limited to 10^o to avoid defocusing. We can see that the point target locations is shifted due to the refraction through the top layer. This limits the use of the subsurface InSAR in some applications such as mine detection and also affects the image coregistration accuracy. An interesting phenomena is the geometric distortion near (0, 2.12km) where the refracted rays made two targets appear at the same range. This is very similar to foreshortening and layover in conventional SAR imaging when two targets share the same range bin due to surface topography. Unfortunately, this can only be fixed by increasing the bandwidth or adjusting the radar look angle and cannot be fixed by refocusing.



(a) (b)

Fig. 1: Azimuth Point Spread Function (APSF) of a point target vs. the target depth when using conventional focusing with focusing plane at the surface with (a) 20° integration angle and (b) 40° integration angle.



(a) (b)

Fig. 2: Sample scenario to illustrate geometric distortion in subsurface SAR images due to top layer propagation effects, (a) the simulation scenario and (b) the conventionally focused SAR image.

3. ITERATIVE APPROACH

The flowchart for the proposed iterative approach is illustrated in Fig. 3. First, we start by a very coarse resolution SAR image using a limited azimuth integration angle. This gives reasonable focusing at the expense of reduced resolution as shown in the previous section. Next, the subsurface inversion algorithm is used to obtain an initial estimate of the subsurface topography according to [2]. Knowing the subsurface topography, the Doppler history of the subsurface is generated by the subsurface SAR simulator. Then, the subsurface back-projection focusing can be performed with a larger integration angle. The procedure is repeated until the desired ground resolution is achieved. The proposed iterative focusing approach was applied to the scenario shown in Fig. 2. The results are shown in Fig. 4 (a) and (b). In Fig. 4 (a), the image is focused using conventional back-projection with 40^o integration angle where we can see the two types of errors. The defocusing, which is noticeable for shallow targets (e.g. the target at (-100, 1.93km)), and it becomes is very pronounced for deeper targets (e.g. the target at (0, 2.05km) under the crest) As shown in Fig. 2(b) the resulting image is very poor in quality. Applying the proposed iterative approach and refocusing the data through the sand layer, we can see significant improvement in the azimuth response of the point targets as well as the correction for image geometric distortion effects (Fig. 4 (b)). For instance, the azimuth resolution of the target at (0, 2.1Km) in Fig. 4 (a) is reduced from about 20m to 2m.

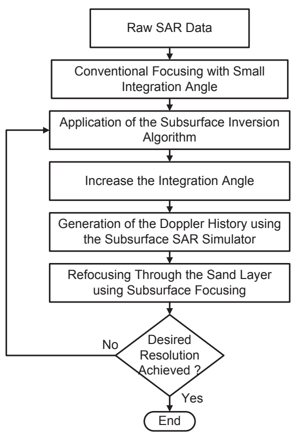


Fig. 3: The proposed iterative scheme.

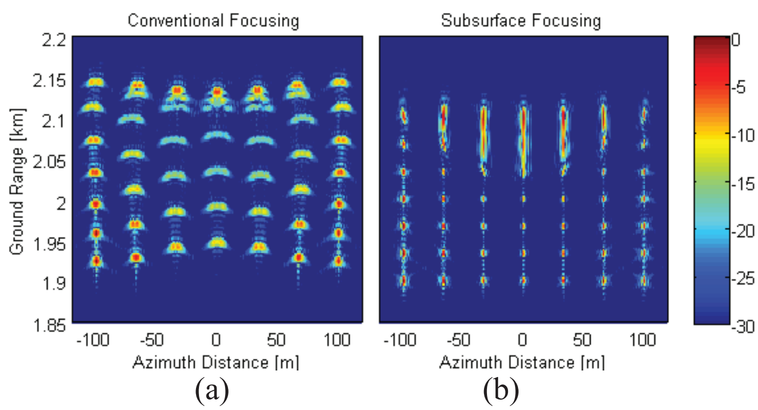


Fig. 4: Results of applying the refocusing algorithm for the scenario in Fig. 3, (a) conventional focusing and (b) with the subsurface focusing (3rd iteration). The integration angle is 40^o in both cases.

11. REFERENCES

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