TOPOGRAPHY OF SAND COVERED BEDROCK USING A TWO-FREQUENCY AIRBORNE INTERFEROMETRIC SAR MEASUREMENTS

Adel Elsherbini and Kamal Sarabandi

Radiation Laboratory,
Department of Electrical Engineering and Computer Science,
The University of Michigan, Ann Arbor
saraband@umich.edu

1. INTRODUCTION

Due to the increasing need for energy and the fact that fossil fuel is still the most commonly used energy source, the search for new oil fields is becoming increasingly important. One of the popular techniques of oil exploration is using seismic explosions, where the reflected seismic waves are measured and used to find the geological structure of the region. Some of these measurements are done in the deserts where the bedrock is covered with a sand layer of variable thickness. This sand layer dissipates a large portion of the seismic explosion power and thus many experiments have to be repeated with their associated cost and setup time. Knowing the sand layer thickness in such regions can be of great aid to the selection of the seismic experiments' sites and minimizing their cost and time. The most common techniques are ground based, such as ground penetrating radars (GPR). However, they are extremely inefficient in mapping the sand layer thickness over a large region.

As an alternative technique, we present the use of a dual frequency (Ka and VHF) airborne Interferometric Synthetic Aperture Radar (InSAR) for estimating the sand layer thickness in deserts as shown in Fig. 2. The Ka-InSAR will be responsible for mapping the height of the sand surface since at such high frequencies, the scattering phase center will be very close to the air-sand interface due to the strong volume scattering at such frequencies. Thus, conventional InSAR processing [1] can be used to estimate the sand height. On the other hand, at VHF frequencies, the surface scattering at the air-sand interface and the volume scattering are very small due to the large operating wavelength. Thus, the waves can penetrate the sand layer and then scatter back from the sand-bedrock interface. By applying a modified InSAR algorithm presented in this paper to the measured data, the sand layer thickness can then be extracted.

The bedrock-mapping VHF-InSAR system design differs from that of conventional InSAR systems in several key issues. First, the operating frequency should be sufficiently low to allow for sufficient penetration through the sand. However, the frequency cannot be chosen to be very low in order to make the design of the antennas feasible and allow for sufficient backscattering from the bedrock to achieve a suitable receiver signal-to-noise ratio. Second, the system bandwidth have to be carefully selected according to the desired cross range resolution but it is also limited by dispersion of the pulse as it propagates through the sand layer. Due to the losses in the sand which causes increased pulse distortion with the bandwidth, the width of the pulse after compression does not have the same inverse relation with the bandwidth as is the case for conventional SAR systems. Third, in the power budget design, the reduction of the clutter from the sand surface has to be taken into consideration in addition to maximizing the backscattering from the bedrock. This will depend on the surface roughness of the sand and the bedrock as well as the dielectric constant of the sand and the choice of the incidence angles.

In addition, due to the refraction of the incident waves at the air-sand interface, the conventional InSAR processing cannot be used. Thus, we developed a new inversion algorithm to solve for the bedrock height. The algorithm is based on geometrical optics as shown in Fig. 2. Given the sand height and slope from the Ka-InSAR data, the measured phase difference between the received signals at the two antennas and the dielectric constant of the sand, the set of nonlinear equations describing the model can be efficiently solved using the proposed iterative algorithm shown in Fig. 1. First, the Ka InSAR is operated to obtain the sand height map. The algorithm is then applied at each pixel in the VHF map to estimate the bedrock height. An initial approximation of the radar look angle, θ, is estimated from the measured phase difference between the two antennas $\delta\varphi$ using the conventional InSAR equation [1]. The look angle is then used in the sand map to obtain the incidence point on the sand. After that, the bedrock height, h, that gives the correct pixel range is calculated using geometrical optics. The initial guess of h is then updated using an update rate μ which is added to ensure the stability of the iterative scheme. Next, using the calculated h, a new estimation of the radar look angle is used and the process is repeated until the difference in height between two consecutive passes is less than a specified error tolerance Δ. The proposed algorithm was found to give sufficient accuracy within a reasonable number of iterations. A sample scene for linear sand dunes [2] is shown in Fig. 3 and the estimated bedrock height using the algorithm is shown in Fig. 4.

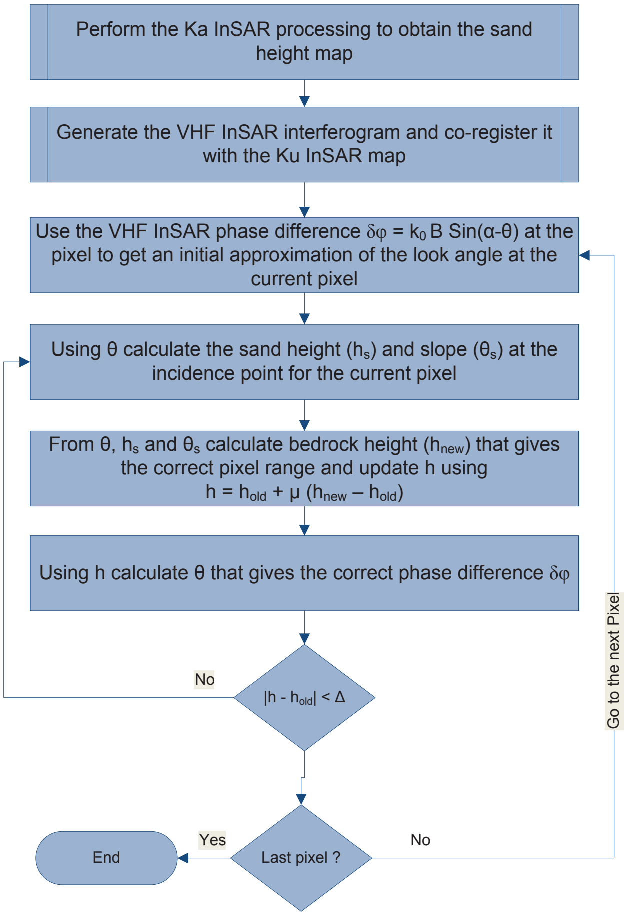

Figure 1: The Inversion Algorithm.

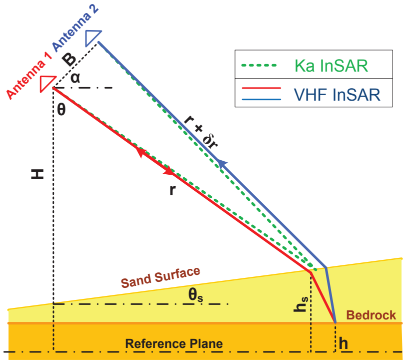

Figure 2: The system operation.

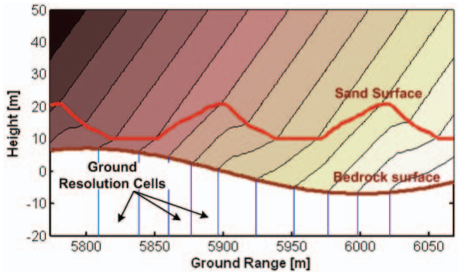

Figure 3: Sample scene of a sand covered bedrock.

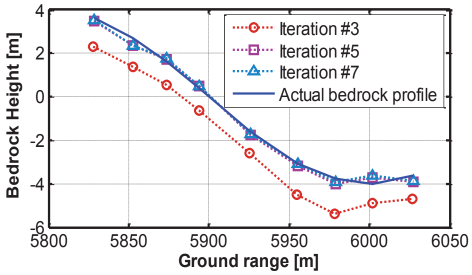

Figure 4: Bedrock height estimation using the inversion algorithm.

2. REFERENCES

[1] R. Gen and J. L. Van Genderen, "Review Article SAR interferometry - issues, techniques, applications," International Journal of Remote Sensing, pp. 1803 – 1835, 1996.

[2] C. S Bristow, S. D Bailey and N Lancaster, "The sedimentary structure of linear sand dunes", Nature, pp. 56-59, July 2000.