Forest canopy height estimation using particle swarm optimization and TerraSAR data

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ABSTRACT

Forest canopy structure is very important to measure forest change and forest coverage. And TerraSAR-X data are well suited for inversion applications at tree height. Based on the Random Volume over Ground model, the three-stage algorithm and its PSO improvement are studied in this paper. Taking the TerraSAR-X data of Mengla County in Yunnan Province China as the data source, the forest height inversion algorithm were compared in the experiment part. Finally, the results are verified with the field measured data. The results show that the precision of forest height inversion based on the PSO intelligent algorithm is better than the traditional three-stage algorithm, and the correlation coefficient is improved by more than 20%.

Keywords: Particle swarm optimization, TerraSAR, height estimation

1. INTRODUCTION

Forest canopy height, as an attribute of forest vertical structure, is an important parameter used to estimate stand stock, stand productivity and biomass[1]. Polarized Interferometric Synthetic Aperture Radar (PolInSAR) is a new remote sensing technique that has the properties of both polarized SAR sensitive to the direction and canopy of the vegetation scatters and PolInSAR sensitive to the height and distribution of the vegetation bodies, which can not only improve the accuracy of topographic measurements but also obtain the relevant physical parameters of scattering mechanisms, especially for tree height[2]. It is of great significance in forestry resource management and forestry investigation and research, especially the forest parameters provide the possibility of high precision inversion of tree height and various other parameters of ground features[3].

The forest height estimation methods can be divided into two types: high-dimensional data nonlinear optimization[4] and polarization mechanisms-based algorithm[5]. The disadvantages for high-dimensional data nonlinear optimization methods are also obvious: firstly, the computational effort is huge; secondly, the dependence of the algorithm performance on the initial value of the iteration is too great, which is easy to fall into the trap of local optimal solutions[6]. Then there are problems such as inaccurate estimation of polarization parameters for those polarization mechanisms-based algorithm[7]. Therefore, in this paper, a PSO-improved algorithm based on the Cloude three-stage strategy, is introduced to improve its coherent region estimation process to improve the accuracy of forest height inversion. The experimental results are partially carried out using TerraSAR-X data for the inversion experiments and combined with the field measured heights for statistical analysis.

2. BASIC THEORY

Random Volume over Ground (RVoG) model is one of the most widely used models in polarization interference. The model contains two layers of scatter and ground structures, and the model describes a randomly distributed forest cover model with a thickness of HV polarization in a two-layer medium model[8]. Under the RVoG model, the forest height can be understood as the thickness of the random body. The relevant equation in the RVoG model is as follows.

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$$\begin{cases} \gamma_c(\vec{w}) = e^{i\Phi_0}\left(\gamma_v + \frac{m(\vec{w})}{1+(\vec{w})}(1-\gamma_v)\right) \\ \gamma_c = \frac{1}{l_0} \neq \gamma_v(\omega) \begin{cases} I = \int_0^{h_v} \exp(ik_z z^*) \exp\left(\frac{2\sigma z^*}{cos\theta_0}\right) dz^* \\ I_0 = \int_0^{h_v} \exp\left(\frac{2\sigma z^*}{cos\theta_0}\right) dz^* \end{cases} \\ k_z = m\frac{2\pi}{\lambda}\frac{\triangle\theta}{sin\theta} \end{cases} \tag{1}$$

where $\gamma_c(\vec{w})$ is the total complex coherence of the random body scatterer-surface diatom; Φ_0 is the ground interference phase; $m(w)$ represents the ground body amplitude ratio, which denotes the attenuation caused by electromagnetic waves passing through the vegetation body layer, which can be considered as a function of the thickness of the random body and the attenuation coefficient; γ_v is the coherence for body scattering; h_v represents the height of the forest; then θ is the angle of incidence of the radar wave; σ is the extinction coefficient; k_z is the vertical effective beam. $\Delta\theta$ is the difference of the incident angle between the two observations, λ is the wavelength of electromagnetic wave. Where the known quantities are θ, k_z, λ, $\Delta\theta$, $\gamma_c(\vec{w})$ can be estimated from the basic formula, the unknown quantity are h_v and σ.

The three-stage forest height inversion algorithm is a classical forest height inversion algorithm proposed by Cloude[8], which is completed by three steps: linear fitting, surface phase solving, and forest height inversion. As shown in Figure 1, the observations of the six polarization channels can be arranged in the complex plane, according to the variational form of the RVoG model. The line represents the phase of the surface reflection when the complex coherence coefficient varies between 0 and 1. Therefore, the farthest intersection point in the complex plane can be consider is the complex coherence of the ground layer Φ_0. After estimating the line of the complex coherence coefficient, the feature can be used to complete the forest height inversion that the complex coherence coefficient γ_v is determinated by both the forest height h_v and the extinction coefficient σ[5].

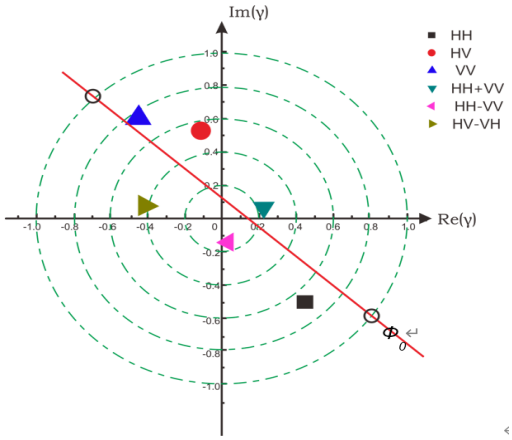


Figure 1. Three-stage forest height inversion algorithm.

3. FOREST HEIGHT INVERSION ALGORITHM IMPORVED BY PSO FOR POLINSAR DATA

Due to the existence of temporal decorrelation and some other unfavorable conditions, the inaccurate estimation of the "pure body decorrelation coefficient" is the biggest problem faced by the three-phase method[9]. Therefore, to improve the accuracy of the surface phase, the maximum coherence magnitude difference criterion and the maximum interference phase difference criterion are introduced in this paper, i.e., the polarization state corresponding to the maximum coherence magnitude difference is selected as the optimal polarization state, as in equation (2):

$$\Delta r_{fit} = \max \left| |\gamma(\omega_i)| - |\gamma(\omega_j)| \right| \tag{2}$$

where $|\gamma(\omega_i)|$, $|\gamma(\omega_j)|$are the amplitude of the corresponding complex coherence coefficient of polarized interference vectors ω_i, ω_j respectively.

Meanwhile, to improve the efficiency of parameter estimation, the PSO algorithm was introduced to the coherent region estimation process in this paper[10]. By integrating equations (1) and (2), the objective function could be designed for the particles which is called "fitness". And the solution element which is named "position" in the feature space was combined with the coherence coefficient γ_v, extinction coefficient σ and the forest height h_v[11]. The flow of the PSO-improved forest height inversion method is as follows:

(1) The master and salve images are registered and filtered;

(2) Polarized interferometric scattering matrix is generated;

(3) The parameters of the line for phase of surface reflection are estimated and the swarm is initialized;

(4) The objective function values of every particle are computed according to equations (1) and (2);

(5) The global best record and every individual optimal record are updated according to the fitness values;

(6) New velocities are calculated and the positions of all particles are updated according to Reference[10];

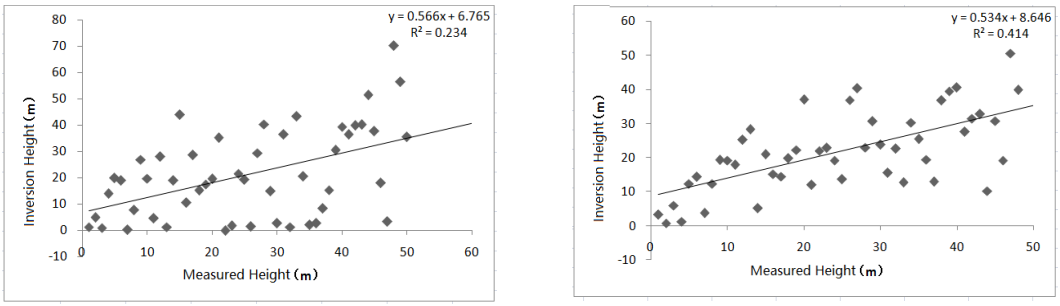
(7) Once a termination condition was accomplished, the global optimal record is saved as the optimization result, otherwise, we return to Step (4).

4. EXPERIMENT RESULT

In order to verify the performance of the forest height inversion algorithm on the real data, the dual-star fully PolInSAR images of TerraSAR-X were used for the experiment which provided by the German Aerospace Center (DLR). The Pauli color composites of the master and salve images were generated after reading the single-view complex data of the primary and secondary images separately as shown in Figure 2.

(a) master image (b) salve image (c) field sample plot

Figure 2. Pauli-basis composite image of master and salve image.



(a) three-stage algorithm (b) PSO improved algorithm

Figure 3. Scatter plot of height invertion.

The forest height inversion results of the three-stage algorithm and the PSO improved algorithm were compared with the measured data. After removing the outliers, tree height inversion scatter plots were produced and the following results were obtained as shown in Figure 3.

The statistical analysis of the height inversion results of the two methods is shown in Table 1.

Table 1. The precision of inversion result.

Inversion method	Mean (m)	Standard deviation	Correlation coefficient *R*	RMSE
The three-stage algorithm	10.904	14.275	0.483	7.38
The PSO improved algorithm	10.858	14.928	0.643	5.53

As shown by the tree height inversion scatter plot and the accuracy table of inversion results. Compared to the three-stage algorithm, the PSO-improved algorithm has a strong correlation with a correlation coefficient *R* of 0.643 and a root mean square error (RMSE) of 5.53, which has a significant improvement.

5. CONCLUSION

A novel intelligent algorithm for the forest height inversion problems with PolInSAR data was proposed in this paper, which effectively combines the RVoG model of PolInSAR data and the advantages of the PSO algorithm. In this method, the initial positions of the particles are calculated by estimating the line that represents the phase of the surface reflection with six polarization channels. Then the height inversion results are optimized with the PSO processing, to improve the correlation coefficient. The experimental results show that the method is effective in forest canopy height inversion with PolInSAR data.

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