Research on Phase Unwrapping Based on Improved Ant Colony Algorithm

Xiaomao Chen, Zheyu Chen, Yiwei Fan, Chunfei Liu
Guangxi Key Laboratory of Precision Navigation Technology and Application, Guilin University of Electronic Technology, Guilin 541004.

Abstract. Phase unwrapping is a key step in data processing of interferometric SAR. The key to the traditional entanglement method is the establishment of branch tangents. The shorter the length of the tangential line, the better the untangling effect. Under the idea that the business travel problem (TSP) solves the shortest path, the ant colony algorithm and the particle swarm algorithm are proposed. Based on the two algorithms, the cluster analysis method can be introduced to establish a shorter branch tangent than the traditional unwrapping method, to avoid the "island effect" in the process of untangling. The feasibility and effectiveness of the method are verified by simulation.

1. Introduction
Interferometric Synthetic Aperture Radar (SAR) is a remote sensing technology developed on the basis of Synthetic Aperture Radar [1]. It is a combination of synthetic aperture imaging technology and interference technology. InSAR uses two antennas with a certain difference in viewing angle to image and acquire two complex image data. The interference phase difference between the two images is obtained through interference processing, and then the target area is inverted. Digital elevation model. The phase of the interference obtained in the actual interference processing is lost. $2n\pi$ The phase information, ie phase wrap [2], requires the recovery of the true interferometric phase from the phase of the winding, ie phase unwrapping [3].

The algorithm for two-dimensional phase unwrapping can be roughly divided into three large blocks. These include the path-integration-based phase unwrapping algorithm[4] proposed by Goldstein in 1988, the least square method [5] proposed by Ghiglia and Romero in 1994, and the algorithm proposed by Costantini in 1996 to solve the phase unwrapping problem using network planning algorithms [6].The basic idea of the path tracking phase unwrapping algorithm is based on the phase information of the adjacent region, by identifying the discontinuous points (residual points) in the interferogram and connecting the branch tangent [7] between the residual points, and selecting the appropriate points when integrating The path bypasses the tangent to achieve phase unwrapping. The advantage of this method is that the error in the unwrapping process can be controlled as much as possible in the noise region, thereby avoiding the global transmission of local phase errors, but in areas with more local residual points, The branch line is easy to cross and loop, so that the area cannot be unwrapped to form an "island"[8]. Path tracking method is a kind of local method. The least squares rule is based on global considerations. The minimum of unwrapped phase gradient and winding phase
gradient deviation is converted into the extreme value problem for solving the minimum norm, because the least squares method is global. The method solves the near-real expansion phase, but its error easily spreads into the entire image [9]. The network flow rule is more like a combination of local method and global method. The main idea is to minimize the deviation between the unfolded phase gradient and the winding phase gradient, and transform the minimization problem into the network optimization problem on the minimum cost flow [10].

2. Improved ant colony algorithm theory and phase unwrapping of particle swarm optimization

2.1. Improved Ant Colony Algorithm Theory
Because the Goldstein branching method is prone to generate a large area of closed loop area when the local residual point is large, and the total length of the branch tangent is too long, this paper introduces the ant colony algorithm [11] to optimize the branch tangent to make the branch tangent the overall length is shortened, reducing the loop enclosed area. Different from the traditional ant colony algorithm, this paper attempts to use the cluster analysis method [12] to first segment the phase map, and then use the ant colony algorithm to solve the shortest connection path of the residual points for the segmented phase map. The specific steps in this section are as follows:

a) The entire interferogram is scanned, and the polarity of the residual point is determined by the adjacent 4-point loop integration and the position is marked to generate a distribution map of the residual points.

b) The residual point distribution map is divided into 4 blocks, and the ant colony algorithm is used to connect the residual points with opposite polarities to keep the polarity of each distribution map balanced. If there is a residual point of charge unbalance, it is defined as a "far point" residual point.

c) Scan the entire residual point distribution map, and use the ant colony algorithm to separately process the remaining "far point" residual points that do not reach the charge balance and establish the branch tangent.

The shortest path problem can be considered an optimization problem. It is used to find the shortest path connecting all the residual points in the coherent image, and "ant selection shortest path" corresponds to "set the shortest path in phase unwrapping" [13]. According to the distance between the residual points and the number of ants passing through the path, the probability of connecting the residual points to other residual points is calculated and connected with the residual point with the highest probability. Then, starting from the connected residual point, the probability of connecting the residual point to the remaining residual point is continuously determined, and is connected to the residual point with the highest probability. Cycle through them until the residual point of the complete part is connected.

In the process of selecting the shortest path, the probability that the kth ant connects the residual point from the residual point in the tth cycle $P_{i,j}^k(t)$ for.

$$P_{i,j}^k(t) = \begin{cases} \frac{\tau_{i,j}(t)^\alpha \eta_{i,j}(t)^\beta}{\sum_{k \in \phi_k} \tau_{i,k}(t)^\alpha \eta_{i,k}(t)^\beta} & j \in \phi_k \\ 0 & \text{others} \end{cases}$$  

(1)

among them $\tau_{i,j}(t)$ The intensity of the pheromone of the path between the residual point i and the residual point of the t-th cycle. In this paper, the initial pheromone intensity on each path takes a smaller identical value. $\eta_{i,j}(t)$ Is the distance between the residual point i and the residual point. $\alpha$ and $\beta$ are empirical weight parameters.
The pheromone strength of the path between the residual points \(i\) and \(j\) after the \(t\)th cycle \(\tau_{i,j}(t)\) Updates are as follows:

\[
\tau_{i,j}(t+1) = \rho \cdot \tau_{i,j}(t) + \Delta \tau_{i,j} \quad \rho \in (0,1)
\]  

among them \(\rho\) For the pheromone volatilization coefficient, \(\Delta \tau_{i,j} = \sum_{k=1}^{m} \Delta \tau_{i,j}^k\), \(m\) is the number of ants.

2.2. Phase Unwrapping of Particle Swarm Optimization Theory

The particle swarm optimization algorithm [14] is a stochastic algorithm for simulating the foraging behavior of birds. Each particle searches for the optimal solution of the problem according to the optimal solution of itself and the particle population, and finally finds the target of the optimal solution of the problem [15]. Let the \(i\)th position and the flight speed vector be: \(X_i = (x_{i1}, x_{i2}, x_{i3}, \ldots, x_{i4})\), \(V_i = (v_{i1}, v_{i2}, v_{i3}, \ldots, v_{i4})\), its best position in history is \(P_{best}(i) = (P_{i1}, P_{i2}, P_{i3}, \ldots, P_{i4})\) The best position of the history of particle swarms is \(g_{best}(i) = (g_{i1}, g_{i2}, g_{i3}, \ldots, g_{in})\) The speed and position of each particle is updated as follows:

\[
V_i = \omega \cdot V_i + c_1 \cdot r_1 \cdot (P_{best}(i) - X_i) + c_2 \cdot r_2 \cdot (g_{best}(i) - X_i) \quad (3)
\]

\[
X_i = X_i + V_i \quad (4)
\]

In the middle \(\omega\) For inertia weight; \(c_1, c_2\) Learning factor \(r_1\) with \(r_2\) Is a random number.

The phase unwrapping step of the particle swarm algorithm is as follows:

a) The entire interferogram is scanned, and the polarity of the residual point is determined by the adjacent 4-point loop integration and the position is marked to generate a distribution map of the residual points. The residual points of the negative charge are sorted.

b) Calculate the fitness of the particles.

c) Sort all particles and set \(P_{best}\) with \(g_{best}\) The best position for the individual's current and population.

d) Update position and velocity, generate new particle swarms, and design fitness values for each particle swarm and sort them.

e) Update \(P_{best}\) with \(g_{best}\) Best location.

f) If the stop condition is met, the search is stopped, otherwise it returns to step (4).

g) According to \(g_{best}\) A sequence of optimal negative residual points is obtained, and then a tangent to the sequence of positive residual points is established.

3. Results and analysis

In order to test the performance of the ant colony algorithm and the particle swarm algorithm, the peaks function in the Matlab software of the phase surface to be processed is generated. The original phase map and residual points are as follows:
The results of the Goldstein branching method and the branch tangent simulation of the proposed algorithm are shown in Figure 3. The length of the branch tangent established by the Goldstein branching method is significantly longer than the length of the tangential line of the ant colony algorithm and the particle swarm algorithm, and multiple loops appear in the area where the residual points are dense, that is, the probability of the closed area is relatively large.

Figure 3. Analog data branch tangent

Figure 3 (a), (b) and (c) are simulated phase development diagrams of the Goldstein branching method, the ant colony algorithm and the particle swarm algorithm, respectively. From the figure, the effect of the Goldstein branching method is obviously worse than the other two in this paper. It is mainly due to the local optimal solution obtained by the Goldstein branching method, which has a bad influence on the phase unwrapping result. The algorithm establishes a good branch tangent to obtain a better unwrapping result.

Figure 4. Analog data phase expansion diagram

Figure 4(b) and (c) are the ant colony algorithm and the particle swarm algorithm respectively. The shortest distances of the two algorithms are 180 and 200 respectively, due to the tangential distance of
the ant colony algorithm. The algorithm has a short tangent distance and its phase unwrapping effect is better than the particle swarm algorithm.

![Path optimization result of residual point](a)Ant colony algorithm branch ![Average distance and shortest distance](b) particle swarm optimization

**Figure 5.** Simulation data tangent optimization map

4. **Conclusion**

Aiming at the shortcomings of traditional two-dimensional phase unwrapping method, based on the advantages of clustering analysis principle, this paper optimizes the traditional ant colony algorithm and particle swarm optimization algorithm, and uses simulation experiments to test its performance. The experimental results show that the proposed method overcomes the shortcomings of the traditional unwrapping algorithm and solves the problem of the Goldstein method. It not only improves the quality of phase unwrapping, but also speeds up the phase unwrapping. The Goldstein method is an effective and reliable method of phase unwrapping.

**Acknowledgements**

Project supported by Guangxi Key Laboratory of Precision Navigation Technology and Application, Guilin University of Electronic Technology.

**References**

[1] Wang Chao, Zhang Hong, Liu Zhi, et al. Interferometric Measurement of Spaceborne Synthetic Aperture Radar [m]. Beijing: Science Press, 2002, 107-137.

[2] Bioucas-Dias J M, Valadao G. Phase unwrapping via graph cuts[J]. IEEE Trans on Image Processing, 2007, 16 (3): 698-709.

[3] Xu W, Cumming LA region-growing algorithm for InSAR phase unwrapping [J]. Geoscience and Remote Sensing, IEEE Transactions on, 1999, 37 (1): 124-134.

[4] Golstein R M, Zebker H A, Werner CL. Satellite radar interferometry: two dimensional phase unwrapping [J]. Radio Science, 1988, 23 (4): 713-720.

[5] D.C.Ghiglia and L.A.Romero. Robust two-dimensional weighted and unweighted phase unwrapping that uses fast transforms and iterative methods [J]. Optoc. Am.

[6] Costantini M A novel phase unwrapping method based on network programming[J]. IEEE Transactions on Geoscience & Remote Sensing, 1998, 36 (3): 813-821.

[7] Zhao Ming, Huang Lei, Zhang Qi Can, et al. Quality guided phase unwrapping technique: comparison of quality maps and guiding strategies [J]. Applied Optics, 2011, 50 (33): 6214-6224.

[8] Zhong He Ping, Tang Jin Song, Zhang Sen. An improved quality-guided phase unwrapping algorithm based on priority queue [J]. IEEE Geo-science And Remote Sensing
[10] Cui Hai Hua, Liao Wen He, Dai Ning, et al. Reliability guided phase-unwrapping algorithm for the measurement of discontinuous three-dimensional objects [J]. Optical Engineering, 2011, 50 (6): 63-66.

[11] Hibig M, Suchandt s. Adam N. A class of soluition-variant transformations of coat functions for Mainun cot fow pase unwrapping [J]. Journal of the opvical Society of Ameica A Ovis Image Science & Vision, 2004, 21 (10): 1975-87.

[12] WEI Zhi-qiang, JIN Ya-qiu. InSAR Phase Unwrapping Algorithm Based on Ant Colony Algorithm [J]. Journal of Electronics & Information Technology, 2008, 30 (3): 518-523.

[13] Yu H W, Li Z F, Bao Z. A cluster-analysis-based efficient multibaseline phase-unwrapping algorithm [J]. IEEE Transactions on Geoscience and Remote Sensing, 2011, 49 (1): 478-487.

[14] Shi Chao, Tian Linya. Application of Ant Colony Algorithm in Phase Unwrapping of InSAR [J]. Surveying Engineering, 2016, (12): 75-80.

[15] Zhang Wei, Feng Dazheng, Qu Xiaoning. Two-dimensional phase unwrapping method based on improved particle swarm optimization algorithm [J]. Chinese Journal of Radio Science, 2012, 27 (6): 1116-1123.

[16] Zhou Li, Zheng Rui. Two-dimensional phase unwrapping combined with optical optimization algorithm and particle swarm optimization algorithm. [J] Laser Magazine, 2015, 36 (9): 68-71.