Edge Preserved Extrapolation Method for Full Polarimetric RPM Imaging with UWB Radars

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Abstract - **Ultra-wideband (UWB) radar system has a great advantage as short range 3-dimentional(3-D) sensor with high range resolution being suitable, for target recognition in optically blurred situation. As one of the most efficient 3-D imaging approaches, the range point migration(RPM) method has been developed, which specifies target boundary extraction using measured ranges. The RPM method stills suffers from insufficient imaging area along cross-range direction, and this incurs the difficulty for target recognition using the reconstructed 3-D image, which is an essential problem in radar imaging. To tackle with this problem, an ellipsoidal aggregation based image extrapolation method, incorporating full polarimetric datasets and RPM imaging, have been already proposed. While this method retains an accurate extrapolation for smooth surface target, it suffers from inaccuracy for target shape with edge. Thus, this paper introduces an edge preserved algorithm based on eigenvector decomposition for quasi Hessian matrix obtained by RPM image. The results from finite-difference time-domain (FDTD) based simulations demonstrate that our method effectively expands a target image without sacrificing an accuracy around edge area.**

Index Terms — **UWB sensor, Range points migration (RPM), Image extrapolation, Full polarimetric data, Machine learning.**

1. Introduction

UWB radar has a great potential to become an innovative short-range 3-D imaging sensor with considerably higher range resolution at the order of cm and favorable penetration ability of dielectric objects such as walls or human body. In particular, this radar system is promising indoor sensing application, such as robotic sensors in disaster rescue situations or private watch sensors for independently living elderly or disabled persons with alleviating privacy issue. Various radar imaging methods based on delay-and-sum (DAS) approaches have been developed such as space time beamforming algorithm[1], time-reversal algorithms[2], aiming at providing more accurate and higher resolution image with low computational cost. As more accurate and time efficient imaging method, the range points migration (RPM) method has been introduced[3]. This method extracts a reflection point on target boundary for each sensor location, using batch conversion from range points (a set of antenna and measured range) to reflection points by assessing the accumulation degree of focused points determined by other range points. It should be noted that the RPM completely resolves an inherent paring problem between range and direction of arrival (DOA) using stochastic approach based on Gaussian kernel estimation. However, a reconstructed area along cross-range direction is limited in a narrowed aperture case that a sensor scanning is blocked by obstacles such as rubble. To avoid this problem, the image extrapolation method using multiple partial ellipsoids based extrapolation with full polarimetric dataset through neural network based learning, has been proposed [4]. However, this method does not still address with a naturally awaken problem that a partial ellipsoid would mismatch the discontinuous boundary area.

To address with the above problem, this paper proposes an edge-preserved extrapolation method by exploiting the unique feature that the spatial shift of reflection point on boundary along antenna scanning can be directly related by using one-to-one correspondence between range point and target point. Focusing on this feature, this method can introduce a quasi Hessian matrix for estimating the curvature on target boundary. Using eigenvalue decomposition of this matrices, the extrapolating area would be adaptively changed according to target boundary curvature. The results from numerical simulation demonstrates that the proposed method significantly improves an accuracy in the 3-D imaging compared with that obtained by the original extrapolation method.

2. System Model

Figure 1 shows the system model. A set of transmitting and receiving antenna is scanned on the $x-y$ plane, and its location is expressed as $(X,Y,0)$. The center wave-length of transmitted signal is λ. It assumes the multiple liner polarizations for the x and y directions in trans-mitting and receiving, respectively. $s_{i,j}(X,Y,R)$ is output of the Wiener filter of electric field observed at the location $(X,Y,0)$, where R = c/t with t defined as the delay time and c the speed of radio wave and the transmitting and receiving polarization are along the i(x or y) axis and j(x or y) axis, respectively. The range point extracted from the local maximum of $s_{x,x}(X,Y,R)$ is denoted $\boldsymbol{q}_k=(X_k,Y_k,R_k)$.

3. Proposed Method

As mentioned in Sec. I, we have already proposed an image extrapolation method incorporating RPM image and full polarimetric data set learning. To be suitable for more elaborate shaped target, especially having edge, this paper introduces area restriction algorithm. Such idea is realized by changing an extrapolation degree corresponding to curvature on target surface. To assess such Hessian related value, we introduce the following matrix;

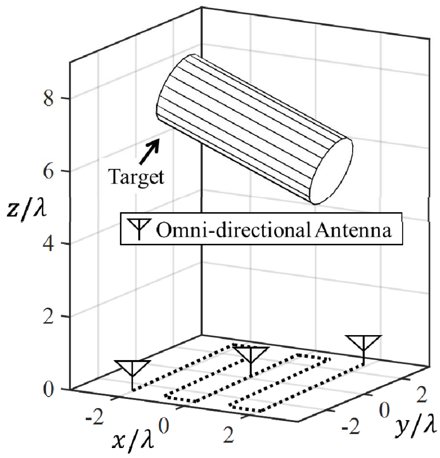

Fig. 1. System model

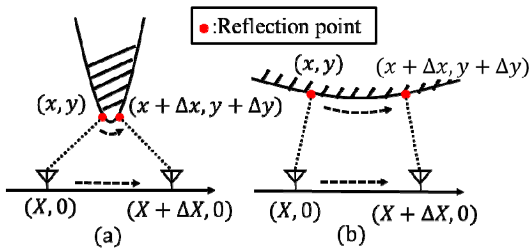

Fig. 2. Relationship between $\Delta x_k / \Delta X_k$ and curvature on target surface.

$$\boldsymbol{S}_k = \begin{bmatrix} \frac{\partial x_k}{\partial X_k} & \frac{\partial y_k}{\partial X_k} \\ \frac{\partial x_k}{\partial Y_k} & \frac{\partial y_k}{\partial Y_k} \end{bmatrix} \simeq \begin{bmatrix} \frac{\Delta x_k}{\Delta X_k} & \frac{\Delta y_k}{\Delta X_k} \\ \frac{\Delta x_k}{\Delta Y_k} & \frac{\Delta y_k}{\Delta Y_k} \end{bmatrix}, \quad (1)$$

where (x_k, y_k, z_k) denotes the target boundary point estimated by RPM corresponding to $\boldsymbol{q}_k = (X_k, Y_k, R_k)$. Note that, each difference approximation in the right term in Eq. 1 is readily calculated by using the one-to-one relationship between $\boldsymbol{q}_k$ and (x_k, y_k, z_k). We call this matrix as quasi Hessian matrix. This matrix expresses the curvature information on target boundary, where is referred as in Fig. 2. Then, the parameter for extrapolation area is calculated as follows;

$$\phi_k(\psi) = \sqrt{u_k(\psi)^2 + v_k(\psi)^2}\,\phi_{\mathrm{E}} \quad (0 \le \psi \le 2\pi), \quad (2)$$

$$\left(u_k(\psi) \quad v_k(\psi)\right)^{\mathrm{T}} = \boldsymbol{U}_k \left(\lambda_{1,k} \cos(\psi) \quad \lambda_{2,k} \sin(\psi)\right)^{\mathrm{T}}, \quad (3)$$

where ψ and $\phi_k(\psi)$ denote the elevation and azimuth angles of an extrapolated ellipsoid, respectively. $\lambda_{1,k}$ and $\lambda_{2,k}$ are eigenvalues of $\boldsymbol{S}_k$, which determine principal

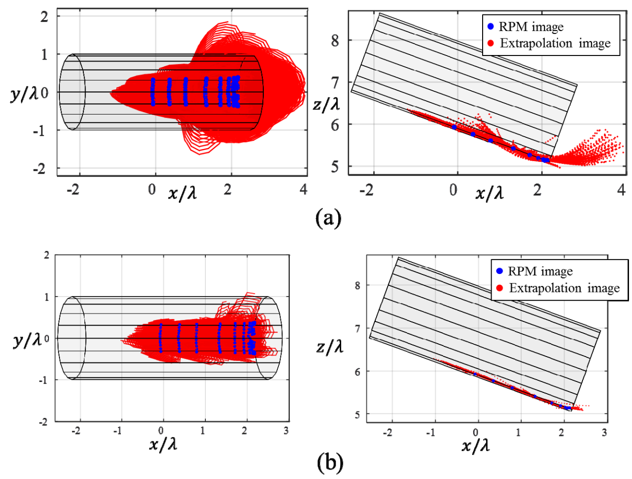

Fig. 3. Extrapolation results for cylinder target ((a): the conventional method and (b): the proposed method).

curvature on (x_k, y_k, z_k) and $\boldsymbol{U}_k$ is the matrix consisted of eigenvectors of $\boldsymbol{S}_k$. This method enables us to change an extrapolation area depending on its curvature, namely, an edge preserving is possible.

4. Evaluation By Numerical Simulation

Here, the antenna is scanned on the area $-2.5\lambda \le x, y \le 2.5\lambda$ with 0.5λ sampling interval along the x and y directions, respectively. The received signals are generated by the FDTD method, where a noiseless situation is assumed. Figure 3 shows the extrapolation results obtained by the conventional and proposed methods. This figure demonstrates the proposed method upgrades an accuracy around the edge area compared with that obtained by the conventional method, by correctly assessing a curvature value by a quasi Hessian matrix calculation. The ratio that the reconstructed points satisfies that the error is less than 0.1λ , is 73.9% for the conventional method and is 98.3% for the proposed method, respectively.

5. Conclusion

This paper proposed an edge preserved image extrapolation method by introducing quasi Hessian matrix determined by RPM feature. The investigation for more elaborate or multiple targets is our future work.

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