Optik 126 (2015) 2523–2528

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Cross-step parallel confocal image processing algorithms used in spatial domain for synthetic-aperture imaging ladars

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ARTICLE INFO

Article history:
Received 29 April 2014
Accepted 9 June 2015

Keywords:
Synthetic-aperture imaging ladar
Image processing algorithms
Fourier transform
Time-to-space domain
Spatial domain

PACS:
42.30kq
42.30Va

ABSTRACT

Two-dimensional (2D) step parallel confocal image processing algorithm for synthetic aperture imaging ladar (SAIL) is proposed. The feature of the algorithm is the collected data are confocal imaged in space domain by 2D Fourier transform. The collected data are first expressed by separation of variables and time-domain data are translated into a spatial coordinate expression suitable for space optical conversion, compensated with an azimuth quadratic phase and then imaged in space domain by 2D Fourier transform. Functions of the algorithm for SAIL with rectangular apertures is described and analyzed in terms of continuous variables and functions. Then the position of the imaging point is given. The technique is a new, one-step confocal imaging method for ladar echo signal. The confocal image processing is simplified and the imaging time is shortened. The requirement of a ladar image processing system is also reduced. It has a significant advantage in the data processing of synthetic-aperture ladar target echo confocal imaging.

1. Introduction

With the increasing demand for high resolution synthetic-aperture radar (SAR) satellite real-time observation on the ground at long range, the harsh requirement of a SAR imaging processor is proposed because of space environment and restriction systems. Compared with a digital imaging system [1], system based on the optical parallel process can effectively prevent the impacts of changes in temperature, cosmic rays, and particle aspects of flip. Such a system also reduces the constraints imposed by power consumption, volume, quality, etc. and is more suitable for application in the environment of space-borne SAR real-time imaging in orbit. Therefore, the optical parallel process of microwave SAR data has recently become a development direction with practical value.

The original concept of a synthetic-aperture imaging ladar (SAIL) is taken from microwave SAR [2,3]. However, considering its use of an optical frequency band, a significant difference exists between SAIL and microwave SAR. Its diffraction and propagation field is significantly smaller than wavelength scale components, and light signals must be converted into an electric signal by nonlinear optical detection. Therefore, they are completely different embodiments of the method [4–8]. Meanwhile, the current study on SAIL develops a full reflection of the optical properties of the new architecture based on the principle of optical wavefront transformation and is no longer able to use the microwave. We find that the target signal obtained by SAIL is more mathematically analyzed and easier to convert into two-dimensional (2D) parallel processing algorithms in the spatial domain than microwave SAR.

We propose a 2D step parallel confocal image processing algorithms, which mainly used in the optical imaging processing system of SAIL. The feature of the algorithm is that the collected data are confocal imaged in space domain by 2D Fourier transform. The collected data in time-domain is translated into a spatial coordinate expression suitable for space optical conversion and are compensated with an azimuth quadratic phase, then to be directly imaged in space domain by 2D Fourier transform. It is a key technical improvement for SAIL, especially the target echo data confocal image processing methods of SAIL. Compared with the conventional optical processing of SAR data, a two-step confocal imaging approach is first compressed in 2D data by the Fourier transform in the range direction and then match filtered with a conjugate quadratic phase to the phase history in the azimuth direction. Then 2D collected data in time domain are transformed

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http://dx.doi.org/10.1016/j.ijleo.2015.06.050

into 1D frequency domain and 1D time domain to be imaged. We proposed a new step confocal imaging approach for ladar echo signal. The confocal image processing of the collected data is simplified, and the confocal imaging time of the collected data is shortened. The requirement of a ladar image processing system is also reduced. It has a significant advantage in the data processing of synthetic-aperture ladar target echo confocal imaging.

2. Methods

An alternative of the SAIL image processing algorithms is that the collected data are imaged in frequency domain. The collected data are first compensated with a conjugated quadratic phase and then imaged by 2D Fourier transform. The feature of the algorithm is that the collected data in the time domain are transformed into the frequency domain both in the travel direction and in its orthogonal direction to be directly imaged [9]. This paper proposes a new step confocal imaging approach for ladar echo signal. The collected data in time domain are transformed into a spatial coordinate expression suitable for space optical conversion and then imaged by 2D Fourier transform in space domain. The flowchart of systematic theory is shown in Fig. 1.

We concentrate on the systematic theory, design equations and necessary conditions of the step confocal imaging of a target echo signal of a ladar. The target imaging output position, details of the principle including data collection, and the image processing are discussed.

2.1. Separation variable expression of 2D data in time-domain

An optical antenna plays a key role in the production of phase history necessary for synthetic-aperture imaging. The optical antenna system includes transmitting and receiving antennae, as well as their accessories [10–13]. Three typical telescope designs for spatial heterodyne detection are illustrated in Fig. 2. Other optical elements used in the transmitting path may differ from those in the reception path if the same primary lens of the telescope is used for coaxial transmitting and reception. Therefore, using an optical circulator to spatially separate the paths is necessary [10]. A free-space 2×4 90° optical hybrid as an important circulator is used in the heterodyne receiver (Fig. 3).

The resulting photocurrents from the 2×4 90° optical hybrid are then processed into a complex exponential [14,15] that can be expressed by a point target ladar equation as

$$\begin{aligned} i_{1D}(x_p, y_p : t_{n,f}, nT_s) &= K_d E_0 E_{lo} K_s K_{r,x}(0 : x_p) K_{r,y}(0 : y_p : nT_s) K_{t,x}(x_p) K_{t,y}(y_p : nT_s) \\ &\quad \times \Theta_x(x_p)\Theta_y(y_p - vnT_s)\mathrm{rect}\left[\frac{t_{n,f} - (\tau_p + T_f/2)}{T_f}\right] \\ &\quad \times \exp\left\{j\left[\frac{\pi}{\lambda Z/2}(y_p - vnT_s)^2 + 2\pi\dot{f}\Delta\tau_p t_{n,f}\right]\right\} \end{aligned} \tag{1}$$

and

$$K_s = \frac{D_x^t D_y^t}{j\lambda Z}\frac{\rho_p l_x l_y}{j\lambda Z}\frac{D_x^r D_y^r}{2M}\eta \exp\left(j\frac{\pi}{\lambda Z/2}x_p^2\right) \tag{2}$$

where K_s is a factor related to the total system arrangement.

Finally, we obtain a 2D data collection equation of a strip-mode side-looking SAIL for a target point (x_p,y_p) as

$$i_{2D}(x_p, y_p : t_{n,f}, nT_s) = \sum_n i_{1D}(x_p, y_p : t_{n,f}, nT_s). \tag{3}$$

The received optical power is the integration of the intensity over a receiving aperture $D_x \times D_y$ (which matches the used aperture of the detector) as the sinc function. Notably, the common regime of the illuminated and the detectable areas at the target plane is defined

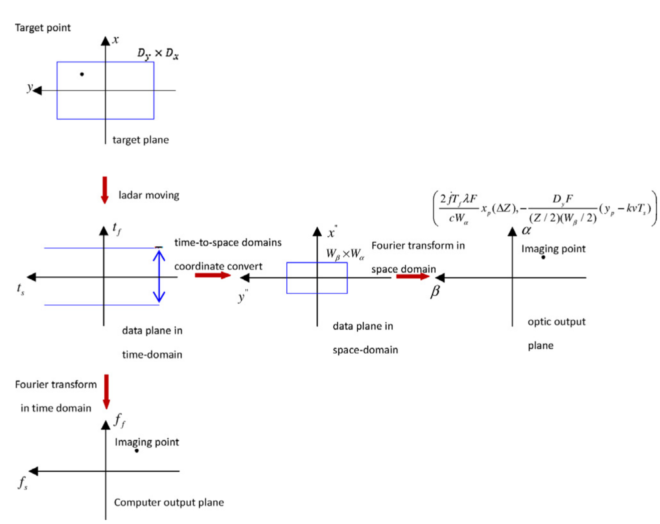

Fig. 1. the flowchart of step parallel confocal imaging processing algorithms