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Multi-channel scan mode and imaging algorithm for synthetic aperture ladar

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ABSTRACT

The tunable band of ladar which is limited by the velocity of the laser's tunable component contradict with the pulse repetition frequency (PRF), in SAL. Meanwhile, the swath of SAL is small for the micro-meter wavelength. This paper gives a novel imaging mode of SAL, which combines multichannel technique and Scan mode SAL. This system makes full use of information of the space domain with multichannel, and removes the ambiguity of the frequency domain in the azimuth direction. And then, controls the beam to scan in different swathes for a better width of the imaging scene, which could lead to a reasonable resolution loss. In view of the ambiguity in Scan mode, SPECAN analysis is utilized to resolve the ambiguity. Finally, the simulation proves the validity of the given method.

1. Introduction

Synthetic aperture laser radar (SAL) has become a hotspot in the field of laser radar, using synthetic aperture technique, i.e. coherent integration technique, which greatly improves the azimuth resolution who has nothing to do with the radar range [1,2]. In recent years, SAL experiments have been reported. In 2006, Raytheon and Northrop Grumman successfully demonstrated the airborne synthetic aperture ladar experiments [3]; In 2011, Lockheed Martin (LMCT) independently completed the flight test of the airborne synthetic aperture ladar demonstration [4], and obtained the imaging results 1.6 km away with resolution better than 3.3 cm. Liu's group, Shu's group and our group also do the SAL indoor experiments and have the SAL images [5–8]. All these experiments show that SAL has great potential in high-resolution imaging applications.

However, some problems should be solved to take SAL into practical application, such as the correlation and non-linearity of the signals [9], the atmospheric turbulence [10] and the motion error of the platform [11]. Besides that, two problems need to be solved in SAL system design. The first is the imaging scene width problem. Since the laser wavelength is generally on the order of micrometers, the spot size is very small and limits the width of the imaging scene. For example, in the airborne SAL experiment published by LMCT, the spot footprint at the 1.6 km in imaging plane is only about 1 m in size, which leads to a width of only about 1 m [4] that is too small to meet the application requirements. Secondly, the large-bandwidth linear FM signal modulation contradicts pulse repetition frequency (PRF) [12]. High range resolution requires a large bandwidth

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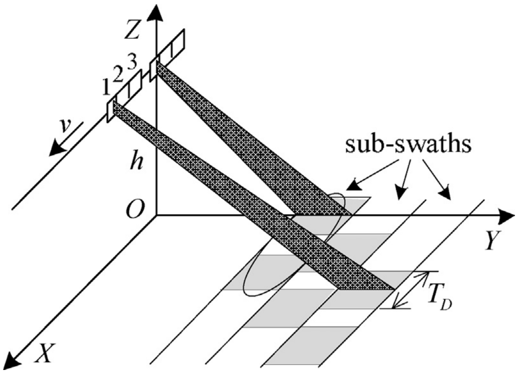

Fig. 1. Geometry of multi-channel Scan mode.

signals, but due to the limited laser modulation rate, signal bandwidth and PRF become a pair of contradictions. In addition, a lower pulse repetition frequency will cause the azimuth signal to be ambiguous.

In view of the above two problem, this paper presents a SAL multi-channel Scan mode. Using multi-channel, i.e. multi-lens, in azimuth to receive the signals to solve the problem less samples in azimuth time obtain the unambiguous images with space filtering technique [13]. Using Scan mode [14], by controlling lens beam, which periodically scans along the range direction at the cost of a certain azimuth resolution for the improvement of the imaging swath. Scan mode has a shorter beam dwell time in a sub-swath, which probably causes the ambiguity in azimuth in the case of wide-scene imaging. To solving the ambiguity, with the idea of spectral analysis (SPECAN) [15], the image in the azimuth direction is focused in the azimuth frequency domain. Finally, the simulation results of point and distribution targets are used to verify the effectiveness of given SAL working mode and imaging method.

2. Signal model

Fig. 1 shows the geometric diagram of the multi-channel Scan mode SAL and here three channels is used as a demonstration. h is the height of the platform, which moves at a constant speed v along the X axis. The transmitting-receiving system of ladar system is composed of lenses (assumed to be odd) with spacing d and only one lens as a transmitter but all of them as receivers. In order to obtain the capability of the wide-scene imaging, the laser beam is controlled periodically irradiated between several sub-swath, and the dwell time of each sub-swath is T_D.

To establish the Cartesian coordinate system with the center of the transmitted lens as the origin of the coordinates, the position of the transmitted lens at any azimuth slow time is $(v_{tm}, 0, h)$, while the i-th received lens location is $(vt_m-(i-1)d, 0, h)$, $i=1, 2, 3, ..., N$. For a point target in the scene $P(x_n, y_n, z_n)$, the transmitted and received range are respectively

$$R_T(t_m)=\sqrt{(vt_m-x_n)^2+y_n^2+(h-z_n)^2} \tag{1}$$

$$R_{Ri}(t_m)=\sqrt{(vt_m-(i-1)d-x_n)^2+y_n^2+(h-z_n)^2}$$

According to the equivalent phase center principle, the multi-channel radar transmits a signal to a channel. The other channel receives the signal. When the distance between the two channels is very short relative to the radar, it can be approximated that it is only necessary to compensate for a constant phase term by transmitting and receiving signals at the center of the center line of the transmitting and receiving channels. The constant phase term can be expressed as

$$\Delta\varphi=\exp(j\frac{2\pi}{\lambda}\frac{d^2}{4R_S}) \tag{2}$$

λ is the laser wavelength and R_S is the distance from the phase center to the center of the scene. If no otherwise specification, the phase center mentioned in this paper is the phase center mentioned above in the principle of equivalent phase center. Therefore, the equivalent phase center of the i-th receive channel is $(vt_m-(i-1)d/2, 0, h)$, and the distance to target P is expressed as

$$R_i(t_m)=\sqrt{(vt_m-\frac{i-1}{2}d-x_n)^2+y_n^2+(h-z_n)^2} \tag{3}$$

Assume that a chirp (LFM) signal is adopted in SAL as

$$s(\hat{t}, t_m)=rect(\frac{\hat{t}}{T_P})\exp(j2\pi f_c t+j\pi\gamma\hat{t}^2) \tag{4}$$