AUTOFOCUS: THE KEY TO A HIGH SAR RESOLUTION

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Abstract – **Uncompensated phase errors lead to a significant quality degradation of images obtained with a synthetic aperture radar (SAR). In the paper, an efficient approach to the SAR autofocusing is proposed. The main idea of the method is the usage of independent local phase error estimates on short time intervals for an arbitrary phase error reconstruction. The residual phase error is retrieved via a double integration of the estimated time-series of the second derivative of the phase error. A high efficiency of the approach is confirmed by experimental results.**

I. INTRODUCTION

The quality of images obtained with a synthetic aperture radar (SAR) is closely related with the precision of the trajectory measurement of the SAR platform [1] - [3]. However, even sophisticated navigation systems do not always provide the needed measurement accuracy when the required SAR resolution is better than about 1 meter. This problem is complicated in the case of using small aircrafts for the SAR deployment [4]. As the result, uncompensated phase errors are left in the SAR data. To solve the problem of the compensation of such residual phase errors, autofocus techniques are applied. The term "autofocus" emphasizes that the phase errors are estimated directly from the backscattered signals. There are a number of autofocus methods proposed so far [5]-[9].

The problem is that the proposed autofocus methods have some limitations. For example, commonly used nonparametric methods such as the prominent point processing (PPP) [5] or the phase gradient autofocus (PGA) [5] are adopted for the spotlight SAR mode only. Conventional parametric autofocus methods, for example, the map-drift autofocus (MDA) [5], [8] use some models to approximate the unknown phase error. The MDA method is used for the estimation of a quadratic phase error by measuring the linear shift between two SAR images built by dividing the processing interval in the azimuth on two parts. This method is preferred in the stripmap SAR mode, because it does not require the presence of bright point targets, but simply the contrast parts: edges, shadows, etc. However, this method becomes inefficient when the unknown phase error to be estimated is fast varying in time.

In this paper, we consider an efficient approach to the stripmap SAR autofocus called "Local-Quadratic Map-Drift Autofocus" (LQMDA). The idea of this method is to estimate the local quadratic phase errors on small time intervals. These estimates represent the values of the second derivative of an arbitrary phase error function. Therefore, the phase error can be retrieved via a double integration of the time-series of the phase error second derivative.

In Section II, the principle of the representation of an arbitrary phase error function by the local quadratic phase errors is described. Peculiarities of the SAR processing and the phase error estimation procedure on short time intervals are considered in Section III, as well as a possible implementation of the proposed LQMDA in practical systems. Experimental results obtained with the X-band airborne SAR system [10] operated from a light-weight aircraft are given Section IV.

II. NEW APPROACH TO STRIPMAP SAR AUTOFOCUS

A. Local quadratic phase error approximations on short time intervals

An accurate compensation of trajectory deviations of the SAR platform is a common requirement for a high-resolution SAR systems [1]. The problem is that the accuracy of a SAR navigation system may be insufficient. As the result, an unknown residual phase error $\varphi_E(t)$ is still presented in the SAR data. The error function is determined within the processed data frame $0 \le t \le T_{FR}$. The data frame duration T_{FR} is referred as the long processing interval.

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The long processing interval can be divided on short intervals of the duration T_S (which may overlap) with the centers at the moments of time t_n , $n = 0, 1, ..., N$. We shall assume that these intervals are short enough so that the residual phase error within each interval can be approximated by the 2-nd order polynomial:

$$\varphi_E(t_n + \tau) \approx \varphi_E(t_n) + \varphi'_E(t_n)\tau + \varphi''_E(t_n)\tau^2 / 2 , \quad (1)$$

where τ is the time within the short interval $-T_S / 2 < \tau < T_S / 2$.

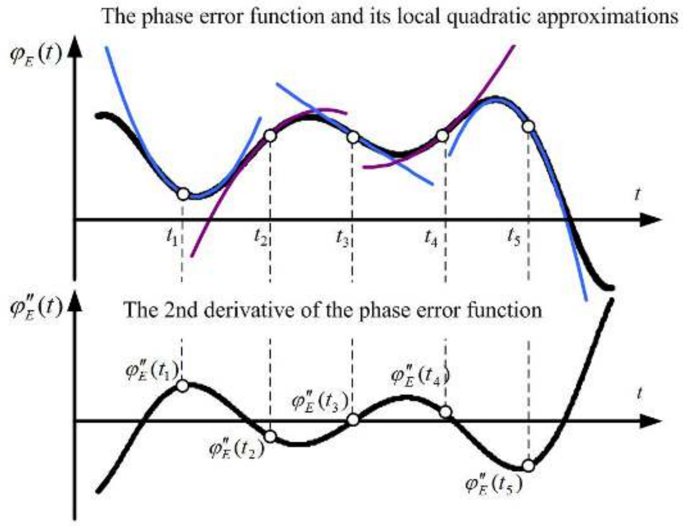

Fig. 1. The unknown residual phase error function, its quadratic approximations, and the 2-nd derivative of the phase error function to be estimated.

We propose to estimate the local quadratic errors (1) on each short interval separately by using the map-drift autofocus (MDA). As the result of such local estimations, the time-series of the phase error second derivative $\varphi''_E(t_n)$ can be obtained as illustrated in Fig. 1. After that, by a double integration we can evaluate the unknown residual error function for the whole data frame, and use it for the phase compensation.

Two SAR images for MDA are built by dividing the short time interval on two parts, and processing the short signal $s(\tau)$ with the long reference function $h(t)$ separately on each half-interval:

$$I_L(t) = \frac{2}{T_S} \int_{-T_S/2}^{0} w_S(\tau + T_S / 4) s(\tau) h^*(\tau - t) d\tau , \quad (2)$$

$$I_R(t) = \frac{2}{T_S} \int_{0}^{T_S/2} w_S(\tau - T_S / 4) s(\tau) h^*(\tau - t) d\tau . \quad (3)$$

The weighting window $w_S(\tau)$ of the length of $T_S / 2$ is applied in the time domain. The reference function is defined on the whole length of the antenna footprint $-T_A / 2 \le t \le T_A / 2$ as

$$h(t) = \exp[2\pi i(F_{DC} t + F_{DR} t^2 / 2)] ,$$

where F_{DC} and F_{DR} are the Doppler centroid and Doppler rate. The shift measured between two SAR images (2)-(3) according to MDA is related with the quadratic phase error as follows:

$$\Delta t_{\max} = \frac{1}{2\pi} \varphi_E''(t_n) \frac{T_S/2}{F_{DR}}. \quad (4)$$

B. Implementation of the LQMDA Algorithm

The above considered ideas were combined into a novel autofocus approach. The input data for the algorithm is the range-compressed SAR data after the conventional motion compensation, which is performed based on the navigation system measurements. The proposed LQMDA is applied for the estimation of the residual phase errors.

The main stages of the algorithm are illustrated in Fig. 2. At the first stage, the large input data buffer is divided on small blocks corresponding to short time intervals. Each short time interval is divided on two parts, and two SAR images are built from each part independently. After that, the relative shift between the two SAR images for each short interval is measured and used for the estimation of the local quadratic phase error coefficient. As the result, the time-series of the residual phase error second derivative is obtained. The phase error function for the whole data frame is reconstructed via double integration of the estimated sequence of the second derivative.

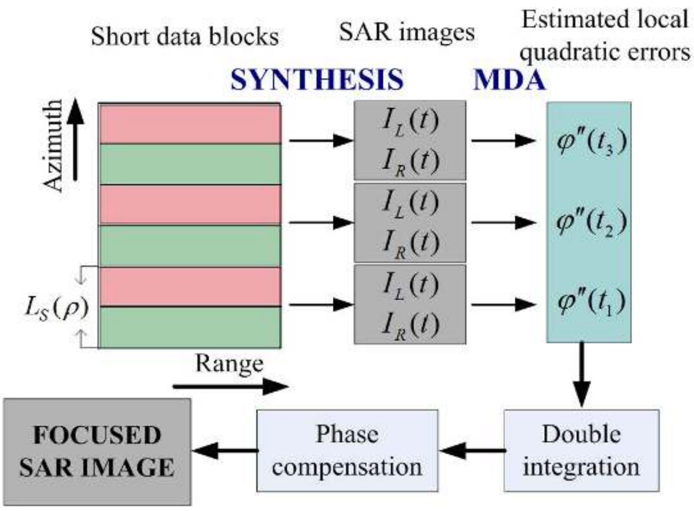

Fig. 2. The block-scheme of the LQMDA algorithm.

After the LQMDA application, the estimated residual phase errors are compensated in the SAR data, resulting in the well-focused SAR image. In the cases of significant residual phase errors, several iterations may be required.

III. Experimental Results

In this section, the performance of the proposed LQMDA algorithm is illustrated. The data were obtained with the airborne RIAN-SAR-X system [10] developed and produced at the Institute of Radio Astronomy of the National Academy of Sciences of Ukraine. The radar operates in the X-band. During the experiments, the radar was installed on a light-weight aircraft Antonov AN-2.

A 25-look SAR image with a 3-meter resolution built without autofocusing is shown in Fig 3a. One can see that this image is defocused, and shadows and small objects are not seen clearly. A well-focused SAR image built with the proposed LQMDA algorithm is shown in Fig. 3b. The comparison of these two images evidently shows a high efficiency of the proposed autofocusing approach.

(a)

(b)

Fig. 3. SAR images (25 looks, 3-meter resolution) built without autofocusing (a) and with the proposed LQMDA algorithm (b).

The key advantage of the LQMDA algorithm is its ability to estimate an arbitrary time-varying phase error. This makes it efficient for practical applications.

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