EFFICIENY EVALUATION OF AR MODEL-BASED LINEAR PREDICTION FOR IMPROVEMENT OF SPATIAL-RESOLUTION OF SPOTLIGHT MODE KOMPSAT-5 IMAGE

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ABSTRACT: In this study, the efficiency of autoregressive (AR) model-based linear prediction method (LPM) for improvement of spatial resolutions (SRs) of satellite synthetic aperture radar (SAR) image is investigated and evaluated using spotlight mode Korea multi-purpose satellite-5 (KOMPSAT-5) image, which is high resolution satellite SAR image acquired at X-band. The improvement of SRs of KOMPSAT-5 image contains three steps. First, the KOMPSAT-5 image is decompressed in range and azimuth directions using Fourier based approach, yielding scattered field dataset in two-dimensional (2D) frequency domain. Next, a new 2D scattered field dataset are generated using LPM based on AR model. Then, a new KOMPSAT-5 image having improved SRs is obtained using Fourier based approach. The efficiency was evaluated by three quality parameters of SAR image such as 3-dB bandwidth, peak side lobe ratio (PSLR), and integrated side lobe ratio (ISLR) of impulse response function (IRF) of a target in spotlight mode KOMPSAT-5 image, which was generated from a real corner reflector located at KOMPSAT calibration site in Mongolia. Experimental results show that AR model-based LPM can provide reliable improvement of SRs of spotlight mode KOMPSAT-5 image. Thus, it is expected that the LPM can assist to improve the capability of SAR remote sensing using the KOMPSAT-5 image.

1. INTRODUCTION

SR is a crucial factor of satellite SAR remote sensing, because that can affect the ability of interpretation for various targets in satellite SAR image; the better SRs of satellite SAR image, the better capability of satellite SAR remote sensing. However, range and azimuth SRs of satellite SAR image depend on the frequency bandwidth and synthetic aperture length of SAR satellite, respectively; those are determined by the hardware characteristics and imaging modes of SAR satellite, which cannot be changed by SAR remote sensing user, in general.

In radar signal processing area, the LPM based on the AR model has been proposed to improve the SRs of high-resolution radar image (Gupta *et al*, 1994; Kim *et al*, 2001; Lee *et al*, 2018; Moore *et al*, 1997). The LPM is post processing that only requires scattered field dataset associated with the high-resolution radar image, without any hardware-wise change. In this study, the LPM is applied to spotlight mode KOMPSAT-5 image to improve SRs.

2. METHODOLOGY

2.1 LPM

The LPM uses the AR model which assumes scattered field signals received from a target as a sum of undamped exponentials. Then, scattered field data should satisfy the following forward and backward predictions along range or azimuth direction in the AR model (Gupta *et al*, 1994; Lee *et al*, 2018):

$$R(k) = \begin{cases} -\sum_{i=1}^{n} a_i R(k-i), & k = n+1, n+2, ..., F \\ -\sum_{i=1}^{n} a_i^* R(k+i), & k = 1, 2, ..., F-n, \end{cases} \tag{1}$$

where $R(k)$ denote received scattered field signals in range or azimuth direction, $R(k)$ denote estimated scattered field signals by the forward and backward predictions in range or azimuth direction, a_i denotes coefficient of AR model, n denotes AR model order, and F denotes the number of radar signals in range or azimuth direction. Among many algorithms for estimation of AR coefficient, we use Burg's method due to its high accuracy and low complexity. In the

Burg's method, the forward and backward prediction errors (i.e. e_n^f and e_n^b) are defined as follows:

$$e_n^f = \left| R(k) - R(k) \right|^2 = \left| \sum_{i=0}^{n} a_i S(k-i) \right|^2, \quad k = n+1, n+2, ..., F, \tag{2}$$

$$e_n^b = \left| R(k) - R(k) \right|^2 = \left| \sum_{i=0}^{n} a_i^* S(k+i) \right|^2, \quad k = 1, 2, ..., F-n, \tag{3}$$

The sum of e_n^f and e_n^b is minimized to obtain AR coefficients a_is , which are used for estimation of radar signals.

2.2 Improvement of SRs of KOMPSAT-5 image using LPM

To improve the SRs of the KOMPSAT-5 image, the KOMPSAT-5 image is first decompressed in range and azimuth directions using fast Fourier transform (FFT), yielding scattered field dataset in 2D frequency (i.e. range-frequency and Doppler-frequency) domain.

Next, we extend range-frequency or Doppler-frequency bandwidth of the scattered field dataset using the LPM. In this step, the number of additional scattered field signals, A , is computed as follows (Lee *et al*, 2018):

$$A = Round\left[0.5 \times F \times \left(res_O / res_I - 1 \right) \right], \tag{4}$$

where $Round$ denotes the round-off operator, res_O and res_I denote the SRs of KOMPSAT-5 image before and after improvement, respectively. Then, A range-frequency or Doppler-frequency bins are added to the first and last locations of $R(k)$ [i.e. $R(1)$ and $R(F)$], as shown in Figure 1 (Lee *et al*, 2018). The scattered field signals associated with $2A$ bins are estimated using extrapolation technique based on the LPM, yielding a new scattered field dataset.

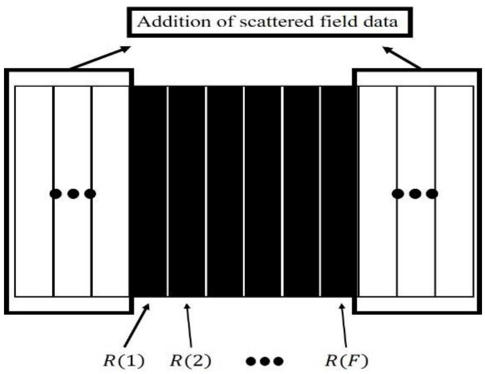


Figure 1. Addition of scattered field data.

Finally, the new scattered field dataset is compressed using inverse FFT, yielding a new KOMPSAT-5 image having improved SR in range or azimuth direction.

3. EXPERIMENTAL RESULTS

To carry out the improvement of SR of KOMPSAT-5 image, a KOMPSAT-5 image was generated from a real corner reflector located at KOMPSAT calibration site in Mongolia. The detailed information of the KOMPSAT-5 image is summarized in Table 1.

Table 1. Information of KOMPSAT-5 image.

SAR satellite	KOMPSAT-5
Observation mode	High-Resolution (HR)
Observation date	2014. 01. 03.
Polarization	Horizontal-to-Horizontal (HH)

Then, the IRF of the corner reflector is located at the center of the KOMPSAT-5 image. Figure 2 shows the KOMPSAT-5 image containing the IRF of the corner reflector.

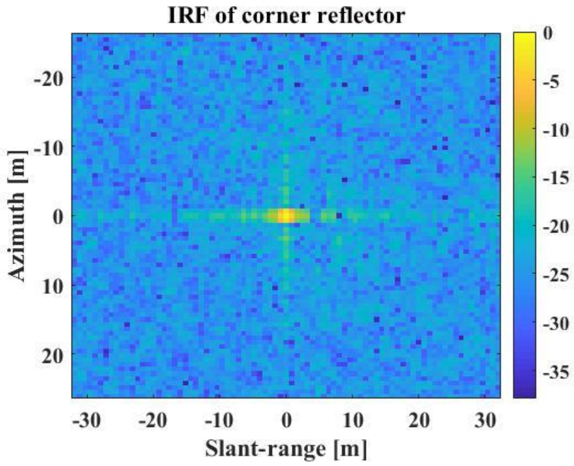
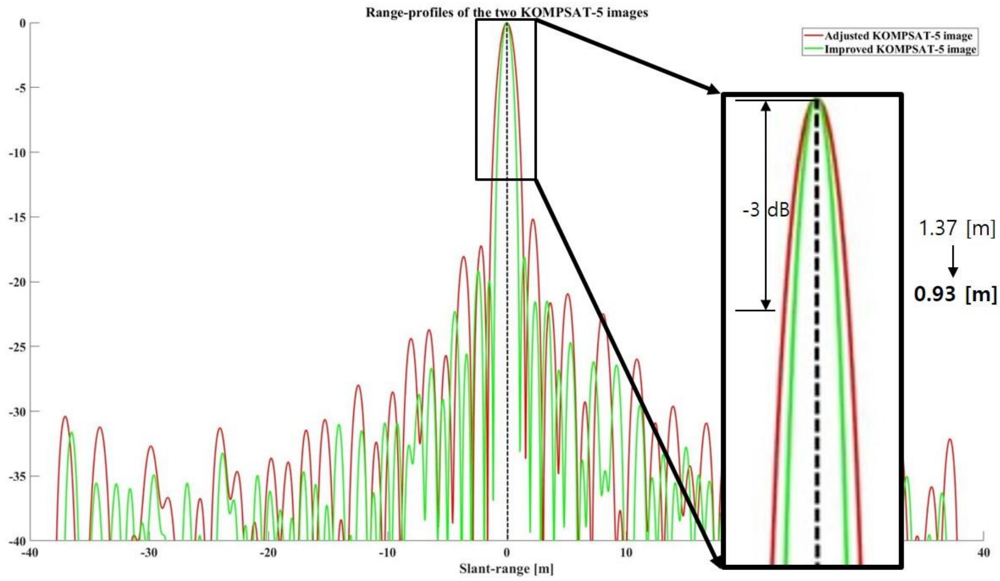


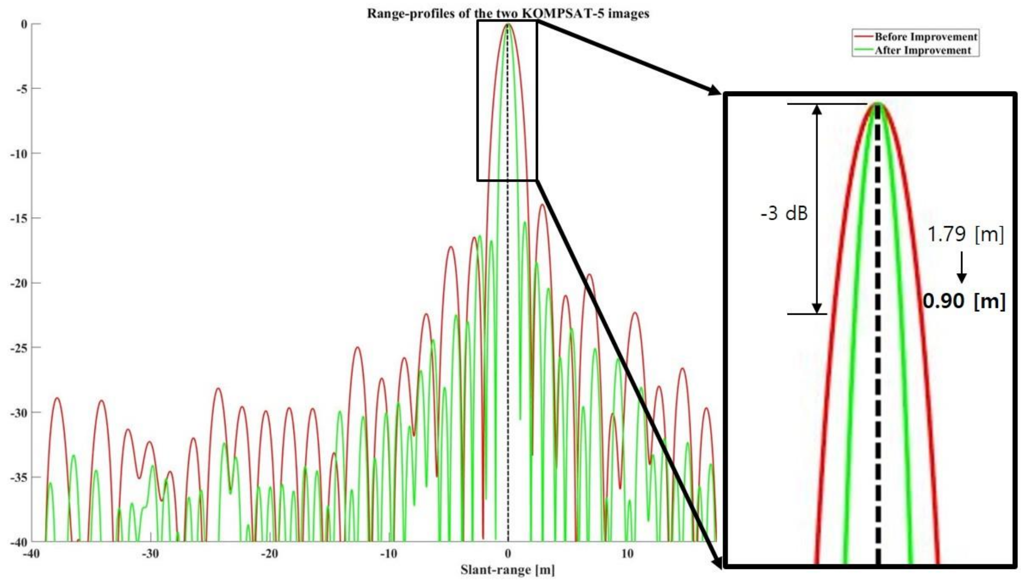
Figure 2. IRF of corner reflector.

To evaluate the efficiency of the LPM, the KOMPSAT-5 image was first adjusted so that the SR of the adjusted KOMPSAT-5 image is larger (worse) than the SR of the original KOMPSAT-5 image; the ratios of the SR of the adjusted image to that of the original image, t , were set to 1.5 and 2, respectively. Next, the SR of the adjusted KOMPSAT-5 image was improved based on the LPM such that the improved SR is the same as the SR of the original KOMPSAT-5 image.

In this study, the range-profile and azimuth-profile of KOMPSAT-5 image were obtained by cutting the KOMPSAT-5 image at center range and azimuth, respectively. Then, the 3-dB bandwidth, PSLR, and ISLR of the range and azimuth profiles were computed to measure the quality of SRs of the KOMPSAT-5 image. Figure 3 and Figure 4 show the range and azimuth profiles of the adjusted KOMPSAT-5 image and those of the new one having improved SR at two t s (i.e. 1.5 and 2). In Figure 3 and 4, the LPM narrows (improves) the 3-dB bandwidths of the range and azimuth profiles. In addition, it can be seen that the PSLRs ISLRs of the range and azimuth profiles are also improved due to the reduction of the side-lobes of the range and azimuth profiles. The comparison of the three quality parameters of the range and azimuth profiles is summarized in Table 2 and Table 3. From Table 2 and 3, it is obvious that the LPM can effectively improve the SRs of the KOMPSAT-5 image.

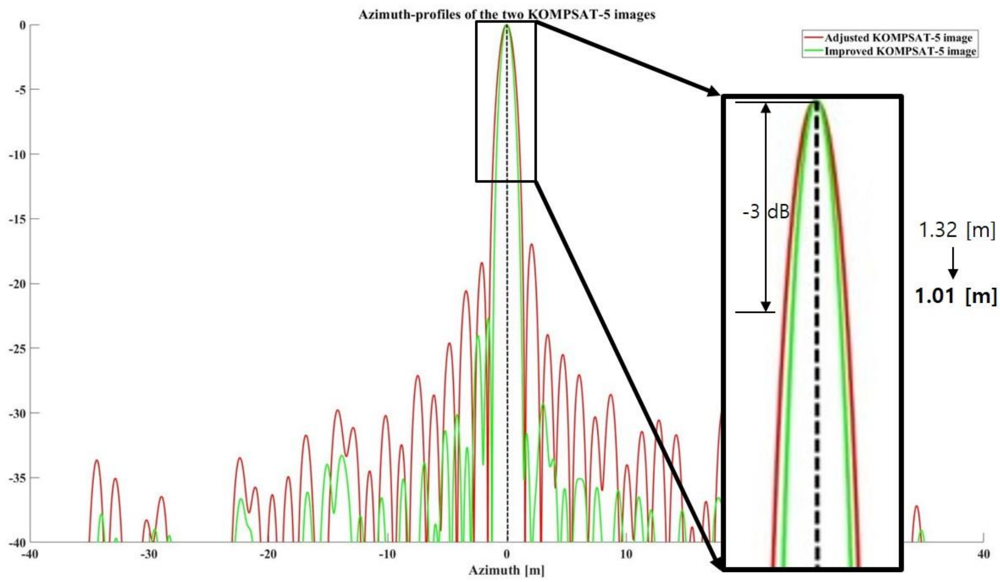


(a) Range profiles of two KOMPSAT-5 images at $t = 1.5$

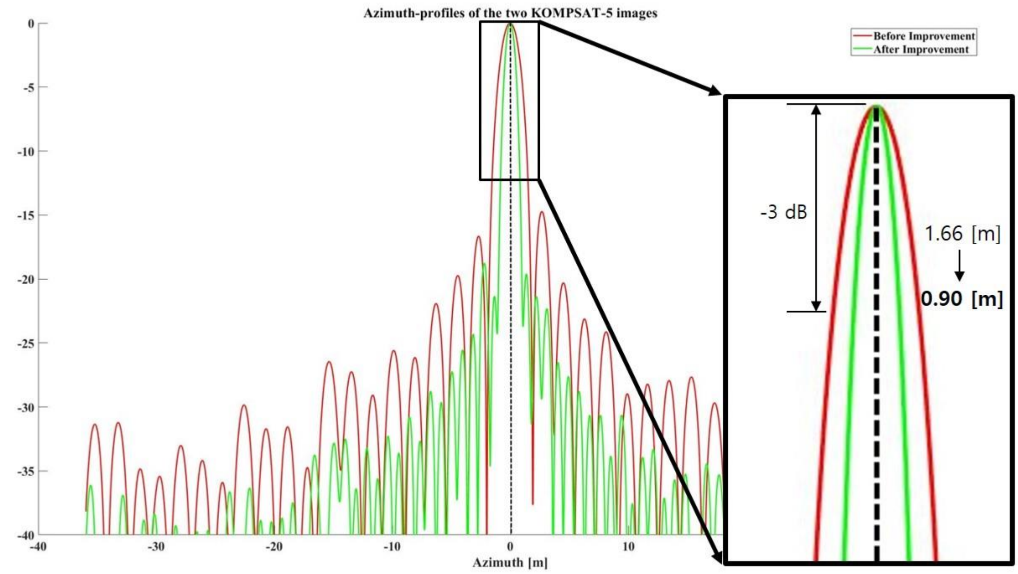


(b) Range profiles of two KOMPSAT-5 images at $t = 2$

Figure 3. Range profiles of two KOMPSAT-5 images at two different t s.



(a) Azimuth profiles of two KOMPSAT-5 images at $t = 1.5$



(b) Azimuth profiles of two KOMPSAT-5 images at $t = 2$
Figure 3. Azimuth profiles of two KOMPSAT-5 images at two different t s.

Table 2. Comparison of three quality parameters of range profiles at two different t s.

-	$t = 1.5$			$t = 2$		
	3-dB bandwidth	PSLR	ISLR	3-dB bandwidth	PSLR	ISLR
Adjusted	1.37	-15.17	-11.85	1.79	-13.95	-10.90
Improved	**0.93**	-18.09	-13.08	**0.90**	-15.29	-10.81

Table 3. Comparison of three quality parameters of azimuth profiles at two different t s.

-	$t = 1.5$			$t = 2$		
	3-dB bandwidth	PSLR	ISLR	3-dB bandwidth	PSLR	ISLR
Adjusted	1.32	-16.95	-14.15	1.66	-14.72	-12.05
Improved	**1.01**	-22.66	-19.38	**0.90**	-18.77	-14.06

4. CONCLUSION

In this study, we evaluated the efficiency of the LPM for the improvement of SRs of spotlight mode KOMPSAT-5 image. Our results showed that the LPM can effectively improve the SRs of the KOMPSAT-5 image, by improving 3-dB bandwidths, PSLRs and ISLRs of the range and azimuth profiles generated from the KOMPSAT-5 image. Thus, the LPM can assist to improve the capability of SAR remote sensing using KOMPSAT-5 image. In addition, it is expected that the LPM can also be applied to other high-resolution satellite SAR images such as COSMO-SkyMed and TerraSAR-X to improve the SRs of them**.**

5. REFERENCE

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6. ACKNOWLEDGEMENT

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