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Simulation Study for Missing Sample Estimation and Resampling in NISAR Perspective

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Abstract

NISAR (NASA-ISRO Synthetic Aperture Radar) is world's first Dual frequency (L-band 1.25 GHz & S-band 3.2 GHz) SweepSAR mission which will be operating in staggered PRI (Pulse Repetition Interval) mode in order to distribute the blind ranges uniformly across swath. Blind ranges result in missing samples in the received SAR echo data which can generate artifacts in the processed image. Thus it calls for estimation of missing samples. This paper presents the methodology for estimation of missing samples using optimum interpolator in non-uniformly sampled data. The interpolator is futher used to resample non-uniformly sampled data to uniform grid. Efficacy of the interpolation process has been demonstrated through simulation.

1 Introduction

NISAR is HRWS (High Resolution Wide Swath) SweepSAR mission. SweepSAR will provide the swath of the order of 240 Km [1]. In order to get the large swath, all the TRMs transmit the signal which illuminate a small aperture area on the reflector. This small aperture area results in a very large footprint on the ground. While receiving, the data from each of the 12/24 beams (for L-band & S-band respectively) illuminates the full aperture area of the reflector which routes the echo signal in the designated TR module corresponding to a given beam [1]. The time required for acquiring the full swath data is more than the PRI which is a hindrance for continuous data acquisition. Thus there is no reception of the data during the time a pulse is transmitted resulting in blind ranges where no echo data is available. The time required for acquiring the full swath may be greater than 3-4 times of the PRI resulting in blind range gap positions. For constant PRI SAR, these ranges occur at fix position for all azimuth records resulting in complete loss of information particular to that range. In order to distribute these blind ranges uniformly across swath, PRI is continuously varied which is called Staggered PRI SAR [2].

The data processing of Staggered SAR then requires estimation of values at these blind ranges (or missing samples in signal space terminology) and resampling to uniform grid so that further conventional SAR data processing can be performed. The missing samples hence produced in staggered Raw Data are estimated using MMSE based Interpolator [3]. The non-uniformly sampled data is then resampled to uniform grid using interpolator stated above. The two types of data studied in this paper are (a) Complex SAR Raw Data (b) LFM (Linear Frequency Modulated) Chirp. Error Analysis for Complex SAR Raw Data is done after resampling while for Chirp it is done after resampling process as well as further in point target response. In this paper, section 2 discusses about the Raw Data simulation. Selection of Interpolation Kernel is discussed in section 3. Results are demonstrated in section 4 followed by conclusion in section 5.

2 Raw Data Simulation

SAR raw data are Complex Circular Gaussian in nature. Generally it has linear frequency modulated chirp both in range and azimuth direction (formed due to motion of sensor in zero/near-zero squint scenarios).In Staggered SAR, non-uniformity of sampling will occur in azimuth direction. Thus we have simulated a non-uniformly sampled 1-D SAR signal in two forms (a) Complex SAR Raw Data (b) Linear Frequency Modulated (LFM) Chirp Signal. Parameters used for simulation purpose are tabulated in table 1 and 2.

Table 1. Parameters used for Simulation of SAR Raw Data

Parameter	Value
Data Length (N)	512
High Sampling Factor (K)	2048
PRF_{mean}	1650.0 Hz
$\triangle PRF$	100.0 Hz
PRI variation Period Length (M)	200
Missing Sample Frequency (f)	20
Signal Bandwidth (B)	1100.0 Hz

For simulating non-uniform PRI signal, a linearly varying SAW Tooth PRI pattern, repeating at every M^{th} record, has been used. PRF (1/PRI) is varied such that it covers an offset of $\pm \triangle PRF$ around PRF_{mean} in M samples. Linear type PRI variation have been chosen as they are expected to give better performance [4]. However, PRI pattern to be used in NISAR is yet to be finalized. While generating the non-uniformly sampled complex raw data, corresponding data in uniform spacing is also simulated for comparison purpose. For both type of signals, missing samples are embedded by populating every f^{th} sample with zero values in

Table 2. Parameters used for Simulation of Chirp

Parameter	Value
Aperture Time (T)	2.3sec
Data Window	2.4 sec
Data Length (N)	4096
PRF_{mean}	1650.0 Hz
$\triangle PRF$	100.0 Hz
PRI variation Period Length (M)	200
Missing Sample Frequency (f)	20
Signal Bandwidth	1100.0 Hz

the non-uniformly sampled signals generated.

3 Selection of Interpolation Kernel

Any given signal can be resampled to an arbitrary sampling interval (PRI) using the interpolator provided signal satisfies the Nyquist criteria. With the change in PRF, oversampling ratio (O_s - ratio of PRF to signal bandwidth) changes and hence the kernel length also changes. The length of interpolation kernel to be used for different O_s has been studied in [5]. The choice of kernel to be used for resampling operation is based on the O_s only.

However, in case of missing samples, sample to sample distance increases at missing sample position resulting in mean PRI getting approximately doubled. The missing sample could have been estimated accurately had the PRF been more than double of the signal bandwidth assuming only one missing sample within the kernel length.

In NISAR, S-Band alone will be operating at more than 2200Hz PRF which is double the signal bandwidth and hence will facilitate the estimation of missing sample accurately. However, in L-band, approximate oversampling factor is 1.5 only and hence may result in suboptimal performance in estimation. Thus in order to understand the impact of low oversampling ratio than required while estimating the missing samples, L-band has been chosen for simulation purpose.

In the given the scenario, Nyquist criteria will get violated while estimating the missing sample at that point. However, the impact can be minimized by choosing a kernel such that it affects the bandwidth region to the minimum extent possible. It will call for usage of margin (O_s) available between PRF and signal bandwidth. Thus, a hypothetical PRF, which have a minimum oversampling ratio with the signal bandwidth, is chosen for estimating the missing sample at that time/position.

The behaviour of absolute mean phase error, standard deviation of phase error and filter order for different hypothetical PRFs is shown in the figure 1(a) and 1(b).

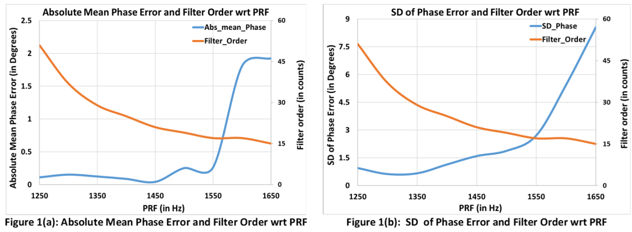

Figure 1. Statistical Phase Results for Estimation of Missing Samples and Filter Order Variation for Different PRF.

The figure 1 shows that standard deviation of phase error decreases as PRF decreases (decreasing O_s and increasing filter order). Phase error decreases due to increased kernel length for estimation. However, below 1300 Hz PRF, kernel length has increased because it encompass more than one missing sample (missing sample repeats itself at every 20^{th} sample) leading to increase in SD of phase error. Thus, a hypothetical PRF of 1300 Hz has been chosen for estimation of missing samples while azimuth re-gridding has been done using the mean PRF only.

4 Results

SAR Raw Data and Chirp Signal has been simulated using the parameters given in table 1 and 2. In simulated Non-Uniform signal, every 20^{th} sample is populated with zero value. Missing samples are estimated with a lower PRF and further the signal is resampled to uniform spacing using the kernel with the mean PRF and resampling error is estimated. Chirp Signal is further studied for point target response.

4.1 Estimation of Missing Samples

The figure 2 and 3 shows error in phase in the estimation of missing samples for complex SAR Raw data as well as chirp signal. A kernel length of 37 has been used for es-

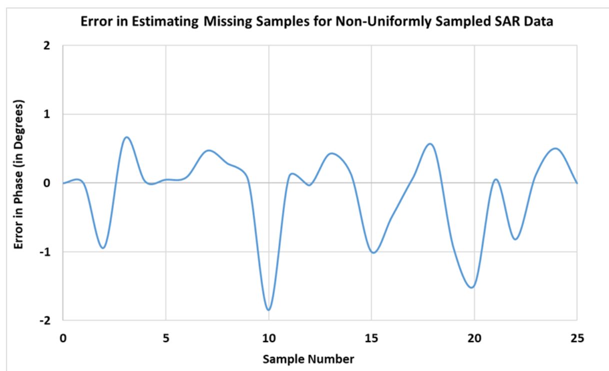

Figure 2. Phase error in Missing Sample Estimation for SAR Raw Data

timation corresonding to 1300 Hz PRF. The figure 2 and 3 shows that phase error in case of estimation of missing sample is in the nominal range of ±1°and ±0.5°for SAR Raw

Data and chirp signal respectively. Further, figures 2 and 3 show that the phase error deviates from mentioned nominal ranges at few sample points (integer multiple of 10) that in actual data corresponds to integer multiple of M. These are the points of abrupt discontinuities in PRI of simulated data.

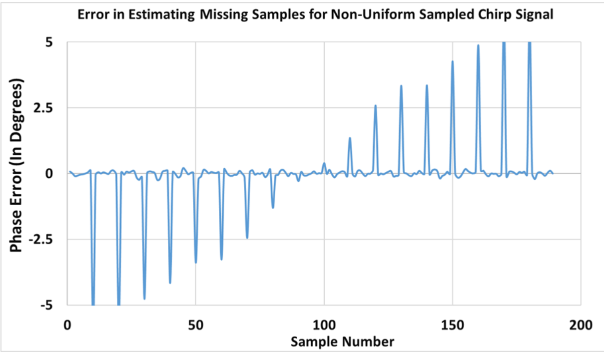

Figure 3. Phase error in Missing Sample Estimation for Chirp Signal

4.2 Azimuth Resampling to Uniform Spacing

The phase error variation in resampling of non-uniform SAR Data obtained after estimation of missing samples to uniform grid is shown in figure 4. The phase error is minimal, having mean and SD of the order of -0.083°and 0.872°respectively.

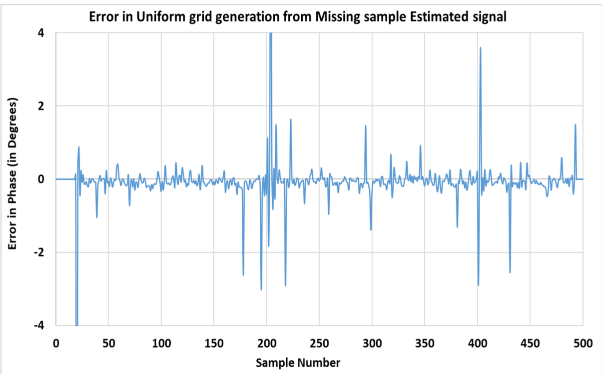

Figure 4. Resampling Error in phase after estimation of missing samples

In order to see the impact of missing samples , chirp signal is studied in two ways by generating a resampled sampled signal (1) with missing samples estimated (2) without estimatation of missing samples. The interpolation error in phase for case 1 and case 2 between resampled signal and reference signal is shown figure 5 and 6 respectively.The mean and SD of phase error for case 1 is 0.0005°and 0.329°respectively and for case 2 is -0.025°and 10.21°respectively.Figure 5 shows that phase error is in the nominal range of ±1°except at few sample points which are integer multiple of M because of abrupt discontinuity in PRI at these points.

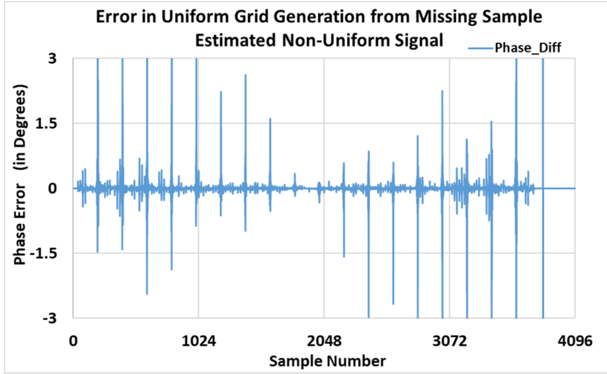

Figure 5. Resampling Error in phase after estimation of missing samples in Non-Uniformly Sampled Signal

If azimuth regridding is done without estimation of missing samples, the phase error (for chirp signal), is highly erroneous as shown in figure 6.

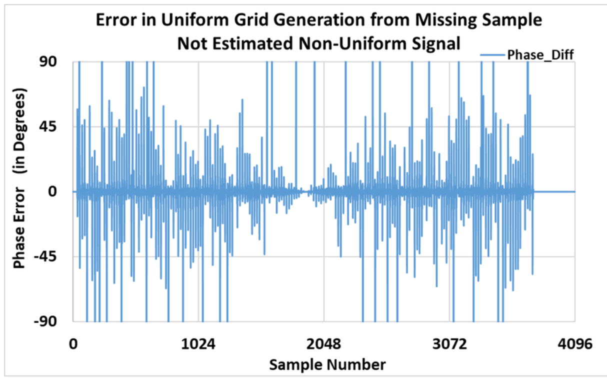

Figure 6. Resampling Error in phase after non-estimation of missing samples in Non-Uniformly Sampled Signal

4.3 Impact on Point Target Response

Resampled Chirp signal has been correlated with the reference chirp signal to analyze the impact of resampling and missing sample estimation in point target response. Azimuth regridding have been performed after the estimation of missing sample.

Figure 7 shows that point target response has multiple replicas (ambiguities) of the point target when missing samples are not estimated, which is not acceptable. However, figure 8 shows that point target response is almost similar to reference point target response when missing samples are estimated. The intended resolution (1/Signal Bandwidth) and the PSLR of -13dB could be achieved in the latter case. Thus estimation of missing sample prior to azimuth resampling is a must for avoiding the artifacts in image.

5 Conclusion

Missing sample estimation and azimuth resampling have been performed on Complex SAR raw data and chirp signal. Performance of these approaches has been analysed

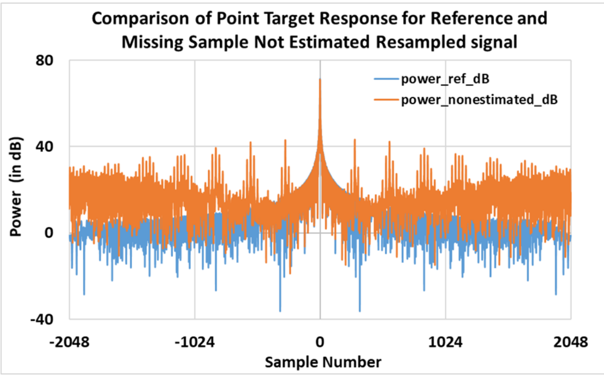

Figure 7. Point target response for reference and missing sample non-estimated signal

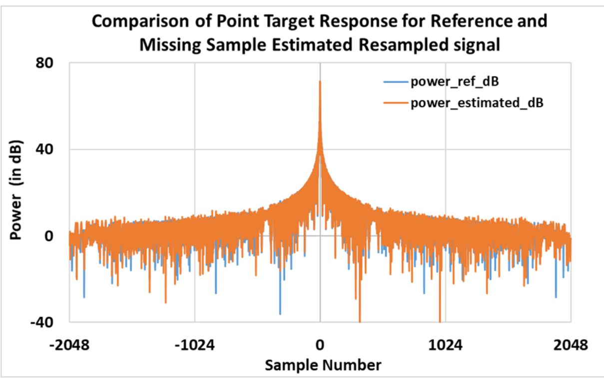

Figure 8. Point target response for reference and missing samples estimated signal

quantitatively. Nominal values of the phase error in the estimation of missing sample is $\pm 1°$and $\pm 0.5°$for complex SAR raw data and chirp signal respectively. In case of azimuth resampling an error of 0.872°and 0.329°is observed in standard deviation of phase error for raw data and chirp signal respectively. The analysis shows that any improper value of re-estimated samples will be reflected in azimuth re-gridding. Further, it is observed that when missing samples are not estimated, erroneous results are obtained as shown in figure 6 and 7. Hence, missing sample estimation is an absolute necessity for achieving the expected performance. Present technique of exploiting the margin between PRF and signal bandwidth for estimation of missing samples is also accurate up to a reasonable level. However, better methods may also be explored for re-estimating the missing samples in future.

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