Efficient RFI suppression in SAR using a LMS adaptive filter integrated with the range/Doppler algorithm

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Radio frequency interference (RFI) suppression in SAR images often requires a great amount of computation. This paper describes how significant computational savings can be achieved by integrating the RFI suppression stage, implemented with a least-mean-squared (LMS) adaptive filter, with the range compression stage of the range/Doppler SAR processing algorithm.

Introduction: Radio frequency interference (RFI) from television, mobile communications, radio and cellular phones is often a major problem for low frequency synthetic aperture radar (SAR) systems, operating in the VHF/UHF Band. A number of interference suppression algorithms have been described in the literature [1, 2, 3, 4, 7], many of which require a great amount of computation. This paper briefly describes the LMS adaptive filter, because it has been used very successfully to suppress RFI [1, 5, 6, 8], and because it can be successfully integrated with the range compression stage of the range/Doppler algorithm.

The usual processing sequence is to first suppress the interference in the raw SAR image, and only then to process the cleaned image with a SAR processor. This paper suggests to combine the interference suppression stage (implemented with a LMS adaptive filter) with the range compression stage of the range/Doppler SAR processing algorithm. This is achieved by multiplying the equivalent transfer function of the interference suppression stage with the transfer function of the range compression stage, thereby creating a new transfer function which implements interference suppression and range compression simultaneously. Assuming that this combined transfer function is valid over many range lines, then the only additional computational cost of implementing RFI suppression across those range lines is 1) the calculation of the equivalent RFI transfer function and 2) the multiplication of this transfer function with the already existing range compression transfer function. Our experience with P-Band and VHF-Band SAR data has shown that once the tap weights of the adaptive filter have converged, the same set of tap weights (and therefore the same equivalent RFI transfer function) may effectively be used for up to a few hundred range lines. This has also been confirmed by Abend and McCorkle [1]. In our experience a 10-fold increase in speed of the RFI suppression stage is viable, assuming that the time taken for the filter tap weights to converge and for the combined transfer function to be created is at most equal to the time taken to clean 10 range lines, and that this transfer function will be used for 100 range lines, a number that has yielded good results with the P-Band and VHF-Band data.

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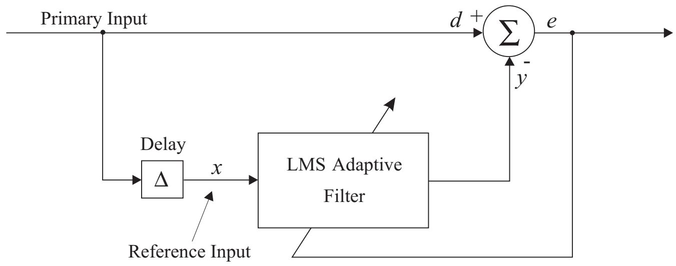

Fig. 1. RFI suppression using a LMS adaptive filter

The LMS Adaptive Filter: Fig. 1 shows a schematic of the LMS adaptive filter as it is used for RFI suppression. It requires a primary input d (containing RFI) and a reference input x, which is obtained by delaying the primary input for some time-delay Δ. The adaptive linear combiner weighs and sums a set of input signals to form an adaptive output y. This output is an estimate of the RFI. The error signal e, which is the desired cleaned radar signal, is obtained by subtracting the RFI estimate y from the primary input d.

The LMS adaptive algorithm minimises the mean-square error e by recursively altering the weight vector $\mathbf{W}$ at each sampling instant according to the Widrow-Hoff algorithm [8], yielding

$$\mathbf{W}_{j+1} = \mathbf{W}_j + 2\mu e(j)\mathbf{X}_j^* \qquad (1)$$

where $\mathbf{X}_j^*$ is the complex conjugate of the reference signal vector at some time j, $e(j)$ is the error signal at time j, and μ is a constant convergence factor controlling stability and rate of adaptation.

RFI Transfer Function: The equivalent transfer function $H(\omega)$ of the LMS adaptive filter may be obtained once the filter tap weights have converged and are kept constant, making it unnecessary to feed the error signal e back into the adaptive filter. Fig. 2 shows the transfer function block diagram of the LMS adaptive filter with the weights kept constant. In the frequency domain, the output $E(\omega)$ is given by

$$E(\omega) \quad = \quad D(\omega) - Y(\omega) \qquad (2)$$

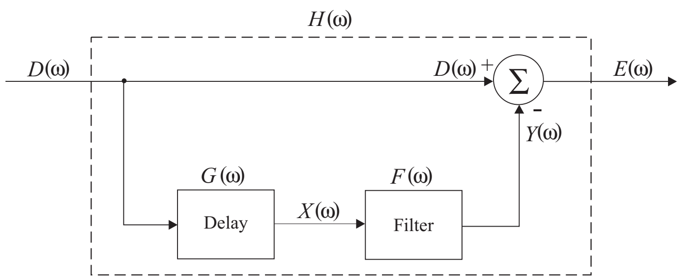

Fig. 2. Block diagram of LMS adaptive filter with tap weights kept constant

$$= D(\omega) - F(\omega)\, G(\omega)\, D(\omega) \quad (3)$$
$$= D(\omega)\, [1 - F(\omega)\, G(\omega)] \quad (4)$$

Therefore the equivalent transfer function $H(\omega)$ of the RFI suppression stage is given by

$$H(\omega) = \frac{E(\omega)}{D(\omega)} = 1 - F(\omega)\, G(\omega) \quad (5)$$

where $G(\omega)$ is the transfer function of the time-delay Δ, given by

$$G(\omega) = e^{-j\omega\Delta} \quad (6)$$

and $F(\omega)$ is the Fourier Transform of the *time-reversed* weight vector $\mathbf{W}$. Since we are dealing with digitised data, $\mathbf{W}$ must be zero-padded to the same length as the range compression transfer function described below.

Combined Transfer Function: Range compression in the frequency domain is accomplished by multiplying the received signal with a matched filter $M(\omega)$, which is typically the complex conjugate of the transmitted pulse spectrum. The combined transfer function $H'(\omega)$ is therefore given by

$$H'(\omega) = H(\omega)\, M(\omega) \quad (7)$$

This transfer function will simultaneously suppress RFI and perform range compression on the raw SAR image.

Conclusions: This paper has described how the equivalent transfer function of the LMS adaptive filter, used to suppress RFI in SAR images, can be combined with the range compression transfer function of the range/Doppler SAR processor. Since the equivalent transfer function of the RFI suppression stage is often effective for hundreds of range lines, significant computational savings can be achieved.

References

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