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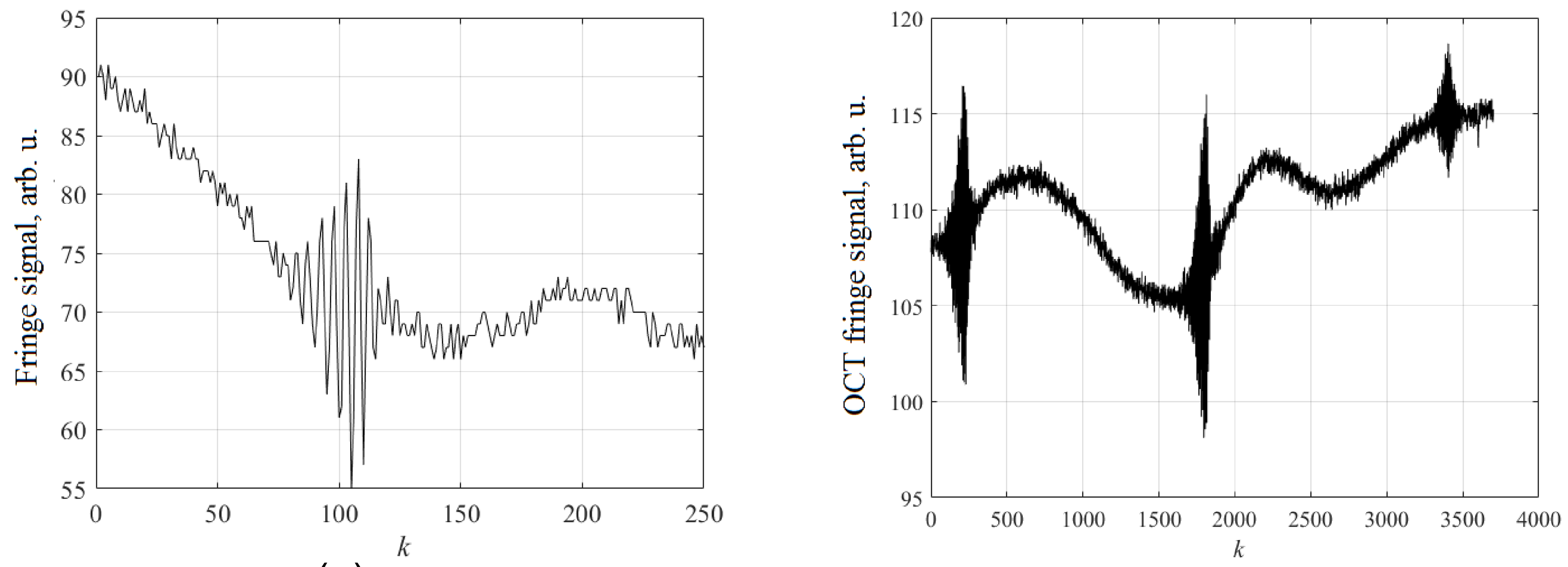
Evaluation of low-coherence interference fringe parameters by the adaptive Wiener filtering method

I.P. Gurov, V.O. Kapranova, P.S. Skakov

ITMO University, Saint-Petersburg, Russia

Introduction

Low coherence interferometry (LCI) methods are widely used in non-contact profilometry and correlation optical coherence tomography (OCT) . In the LCI methods, the low-coherence fringe signal envelope is usually evaluated. Typical examples of such signals are illustrated in Fig. 1.



(a) (b)

Figure 1. (a) LCI signal formed with single reflection and (b) LCI signal in correlation OCT (particular fringes within the envelope peaks in Fig. (b) are not visualized).

When registering an interferometric signal, a sequence of discrete signal samples is formed

$$s(k) = a(k)\cos(\gamma k + \varphi) + b(k) \quad (1)$$

where $a(k)$ is fringe envelope, $b(k)$ is essentially variable signal background component, $\gamma = 2\pi/P$ is phase step, P is a number of signal samples per fringe period, φ is initial phase that can be omitted without decrease of consideration generality, k = 0, 1, …, K.

Evaluation of fringe envelope is usually based on calculation of the signal module or by the signal squaring with subsequent low-pass filtering [1]. However, these procedures require preliminary accurate removal of the signal background component and *a priori* knowledge about the carrier fringe frequency. We developed the adaptive Wiener filter (WF) method to overcome these problems and to evaluate the LCI signal envelope.

The adaptive Wiener filter

In the adaptive WF (see Fig. 1), several signal samples $s(k)$ are added with weighting coefficients w_m with formation of the output signal $y(k)$, which is compared with the reference signal $d(k)$. The filter coefficients are being dynamically tuned to minimize difference of the signals $y(k)$ and $d(k)$.

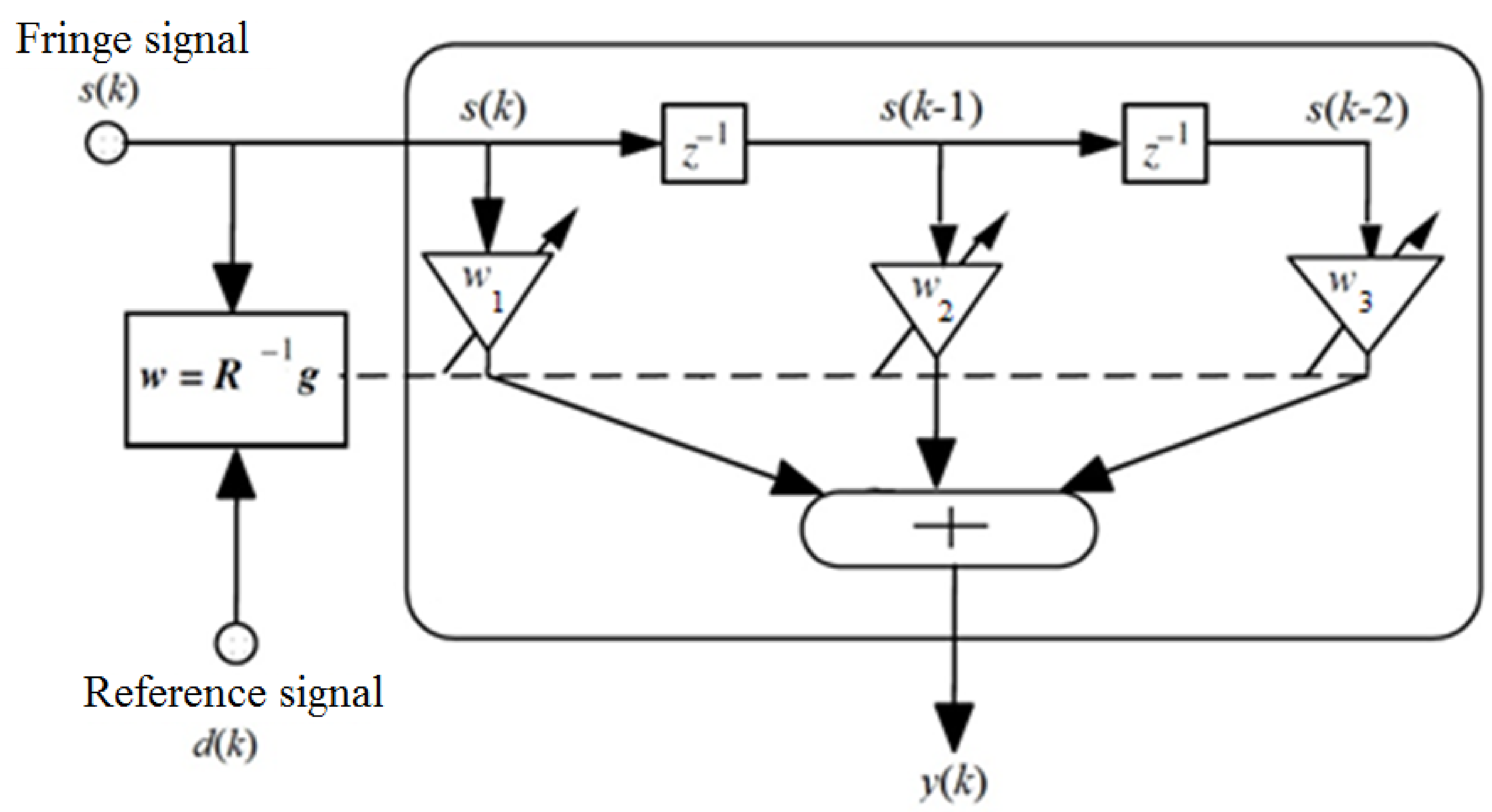


Figure 2. Block diagram of the adaptive WF with three coefficients. The notation z^{-1} corresponds to the phase shift by one step.

It has been shown (see, e.g. [2]) that the filtering mean square error minimization leads to the equation

$$\mathbf{Rw} = \mathbf{g}\,, \quad (2)$$

where **R** is the correlation (non-singular) matrix of the signal components $\mathbf{s}(k) = [s(k), s(k\text{-}1), s(k\text{-}2)]^T$, which has the inverse matrix $\mathbf{R}^{-1}$, **g** is the cross-correlation vector of the signal $\mathbf{s}(k)$ components and the reference signal $d(k)$.

Solution of Eq. (2) is expressed in the evident form

$$\mathbf{w} = \mathbf{R}^{-1}\mathbf{g}, \quad (3)$$

The reference signal is defined as

$$d(k) = A\cos(\gamma k) + B, \quad (4)$$

where A and B are set as arbitrary constants ($B > A$).

Thus, in adaptive WF, the input signal $s(k)$ with unknown parameters is transformed to the reference signal $d(k)$ with determined parameters. The transformation is conducted via the WF weighting coefficients. These coefficients are calculated in Eq. (3). It has been shown for the first time in [3] the possibility to find parameters a, b, φ of the signal Eq. (1) involving the WF coefficients and the reference signal parameters A and B in Eq. (4).

Estimation of fringe signal envelope

As shown in [3], the estimate of the amplitude of the input signal Eq. (1) is given by the expression

$$a = \frac{A}{\sqrt{w_1^2 + w_2^2 + w_3^2 + 2(w_1w_2 + w_2w_3)\cos\gamma + 2w_1w_3\cos 2\gamma}}\,. \quad (5)$$

In the paper [4], the possibility to apply Eq. (5) to evaluate variable low-coherence fringe envelope $a(k)$ in Eq. (1) with fixed constant value A in Eq. (5) has been demonstrated. However Eq. (5) includes unknown value γ in general case. To find this value, the one-step shifted input signal $s(k\text{-}1)$ is set as the reference signal instead of the signal in Eq. (4). This allows calculating the value γ as it is described in detail in [3, 4].

Experimental results

Fig. 3 shows the results of LCI signal envelope estimates in profilometry and correlation OCT obtained by the proposed adaptive WF algorithm.

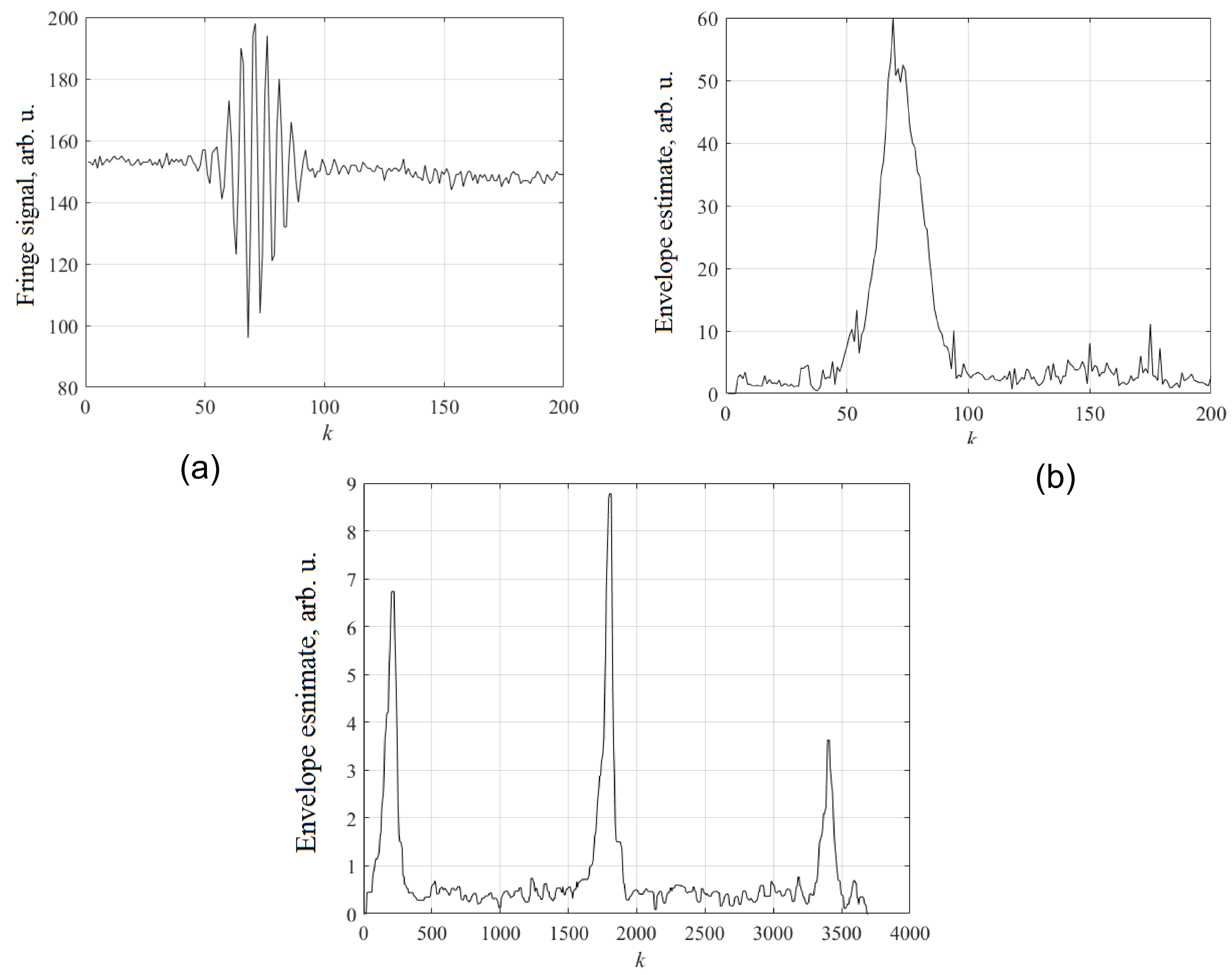


Figure 3. Low-coherence fringe envelope estimates by the proposed adaptive WF algorithm: (a) LCI signal, (b) its envelope estimate and (c) envelope estimate of the OCT signal shown in Fig. 1,b [4].

The algorithm was implemented in C. Eq. (3) solving by direct matrix inversion has shown insufficient precision of single precision floating point data type. This problem was resolved by application of the LDL decomposition. High processing speed on the CPU was achieved by multithreaded processing and code vectorization.

Conclusion

The proposed method allows evaluating low-coherence fringe envelope when the signal background component is significantly variable (see, e.g., examples in Fig. 1). The method is applicable in the case of unknown discretization step γ due to possibility to evaluate this value as described in [3, 4].

The computational speed of the algorithm is enough high to visualize B-scans in correlation OCT in real time.

Acknowledgement

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References

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