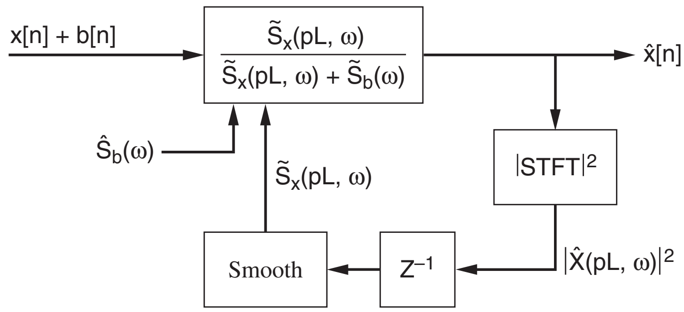

Figure 13.2 Classic Wiener filter with smoothing of the object spectrum estimate.

One approach to slow down the rapid frame-to-frame movement of the object power spectrum estimate, and thus reduce annoying fluctuations in the residual, is to apply temporal smoothing to the object spectrum of Equation (13.12). Denote the object power spectrum estimate on the pth frame by $\hat{S}_x(pL, \omega) = |\hat{X}(pL, \omega)|^2$. Then the smooth power spectrum estimate is obtained as

$$\tilde{S}_x(pL, \omega) = \tau \tilde{S}_x((p-1)L, \omega) + (1-\tau)\hat{S}_x(pL, \omega) \qquad (13.14)$$

where τ is the smoothing constant. $\tilde{S}_x(pL, \omega)$ then replaces $|\hat{X}(pL, \omega)|^2$ within the Wiener filter of Equation (13.13) (Figure 13.2). The smoothing constant of Equation (13.14) controls how fast we adapt to a nonstationary object spectrum. A fast adaptation, with a small smoothing constant, implies improved time resolution, but more noise in the spectral estimate, and thus more musicality in the synthesis. A large smoothing constant improves the spectral estimate in regions of stationarity, but it smears onsets and other rapid events. We now look at an example of the time-frequency resolution tradeoff inherent in this approach.

Example 13.2 Figure 13.3b shows an example of a synthetic train of rapidly-decaying sinewaves in white Gaussian noise; the original 1000-Hz sinewave pulses of Figure 13.3a are uniformly spaced by 2 ms. In noise reduction with a Wiener filter, a 4-ms triangular analysis window, a 1-ms frame interval, and overlap-add (OLA) synthesis are applied. The particular analysis window and frame interval ensure that the OLA constraint is satisfied.[7] A Wiener filter was derived using the spectral smoothing in Equation (13.14) with $\tau = 0.85$. The background power spectrum estimate was obtained by averaging the squared STFT magnitude over the first 0.08 seconds of $y[n]$, and the initial object power spectrum estimate $|\hat{X}(0, \omega)|^2$ was obtained by applying spectral subtraction to $|Y(0, \omega)|^2$. Panel (c) illustrates the result of applying the Wiener filter. An advantage of the spectral smoothing is that it has removed musicality in the noise residual. However, the initial attack of the signal is reduced, resulting in an aural "dulling" of the sound, i.e., it is perceived as less "crisp" than that of its original noiseless counterpart. In addition, although the Wiener filter adapts to the object spectrum, the effect of this adaptation lingers beyond the object, thus preventing noise reduction for some time thereafter and resulting in a perceived "hiss." In this example, the smoothing constant τ is selected to give substantial noise reduction while reducing musicality, but at the expense of slowness in the filter adaptation, resulting in the smeared object attack and the trailing hiss. This sluggish adaptivity

[7] The short window corresponds to a large window bandwidth and thus ensures that OLA synthesis does not inherently impose a strong temporal smoothing of the Wiener filter, as seen in Chapter 7 (Section 7.5.1).