# R & D NOTES

# Measurement Smoothing With a Nonlinear Exponential Filter

RICHARD WEBER

Exxon Chemical Company
Baytown Olefins Plant
Baytown, Texas 77520

Digital filters are used in process control computers to smooth process signals. Most process control computers include the exponential filter as their key noise reduction tool. The new nonlinear exponential filter provides noise reduction comparable to that provided by an exponential filter, without the phase lag encountered in the use of exponential filters. The nonlinear exponential filter is easily implemented on a process control computer and requires about the same magnitude of computer resources as the exponential filter. This filter is valuable for implementing advanced feedback and feedforward computer control in the noisy environment of chemical and petroleum processing units.

Simulation results for noise superimposed on step and sinusoidal signals indicate that the nonlinear exponential filter does, in fact, suppress noise without the phase lag of the exponential filter. These results have been verified in a field implementation. The nonlinear exponential filter has the property of high selectivity between noise and base signal. That is, if the base signal changes by an amount in excess of the noise level, the filter will pass the signal without much modification. On the other hand, normal noise disturbances will be substantially suppressed. As a result, filtering is achieved without much phase lag. Design of the filter requires the user to estimate the statistical standard deviation ($\sigma$) of the noise signal.



## DESCRIPTION OF NONLINEAR EXPONENTIAL FILTER

The nonlinear exponential filter is defined by

$$Y_n = Y_{n-1} + f(\Delta X_n)\,\Delta X_n \tag{1}$$

where:

$$f(\Delta X_n) = \mathrm{Min}\left(1, \left|\frac{\Delta X_n}{R\sigma}\right|\right) \tag{2}$$

If $f(\Delta X_n)$ is instead chosen to be a constant between 0 and 1, then this filter reduces to the standard exponential filter.

## DESIGN OF THE NONLINEAR EXPONENTIAL FILTER

The first step in designing the filter is calculating the statistical standard deviation of the noise. The noise magnitude at a given time is calculated as the difference between the actual measured value and the value of a smoothed curve drawn through the sample points. The data should be collected at the same frequency as will be used by the filter, and at least 100 samples should be used in the calculation.

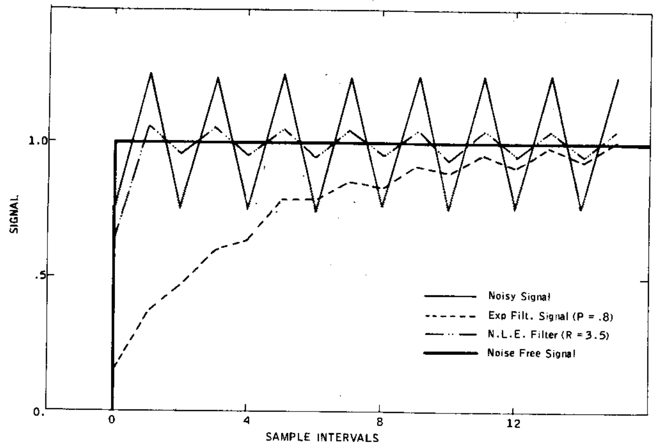


**Figure 1. Filter response to a step change in the presence of noise.**

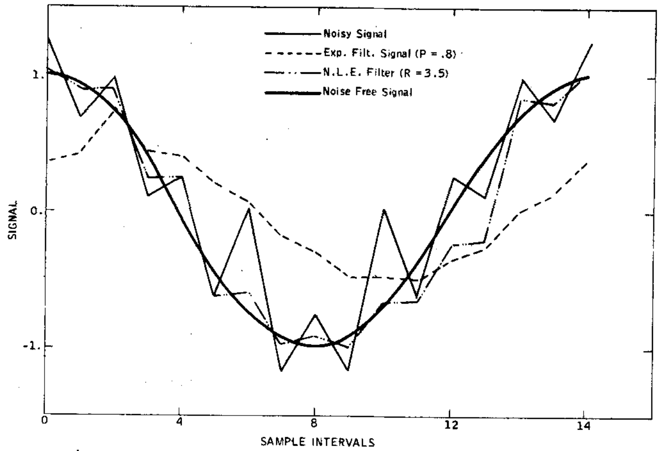


**Figure 2. Filter response to sinusoidal signal in the presence of noise.**

The second and last step is the choice of the filter tuning constant $R$. $R$ should be chosen as a value between 3 and 5. Values of $R$ less than 3 cause a large reduction in the noise suppression without improving filter response. Values of $R$ greater than 5 start adding phase lag to the filter with only a marginal improvement in noise suppression.

## RELATIONSHIP BETWEEN NONLINEAR EXPONENTIAL AND EXPONENTIAL FILTER

The exponential filter algorithm can be written as

$$Y_n = Y_{n-1} + (1 - P)\,\Delta X_n \tag{3}$$

By analogy with Equation (1), the parameter $P$ of the nonlinear exponential filter is

$$1 - P = f(\Delta X_n) = \mathrm{Min}\left(1, \left|\frac{\Delta X_n}{R\sigma}\right|\right) \tag{4}$$

or

$$P = 1 - \left|\frac{\Delta X_n}{R\sigma}\right| \quad \text{if} \quad |\Delta X_n| < R\sigma \tag{5}$$

$$= 0 \quad \text{if} \quad |\Delta X_n| > R\sigma$$

Thus, the nonlinear exponential filter acts like an exponential filter with a filter constant that varies depending on the magnitude of the difference between filtered and raw measurements. The filter constant is high for signals with magnitudes in the noise band and low for signals with magnitudes outside of the noise band. For very large magnitude signals, the filter constant is zero.

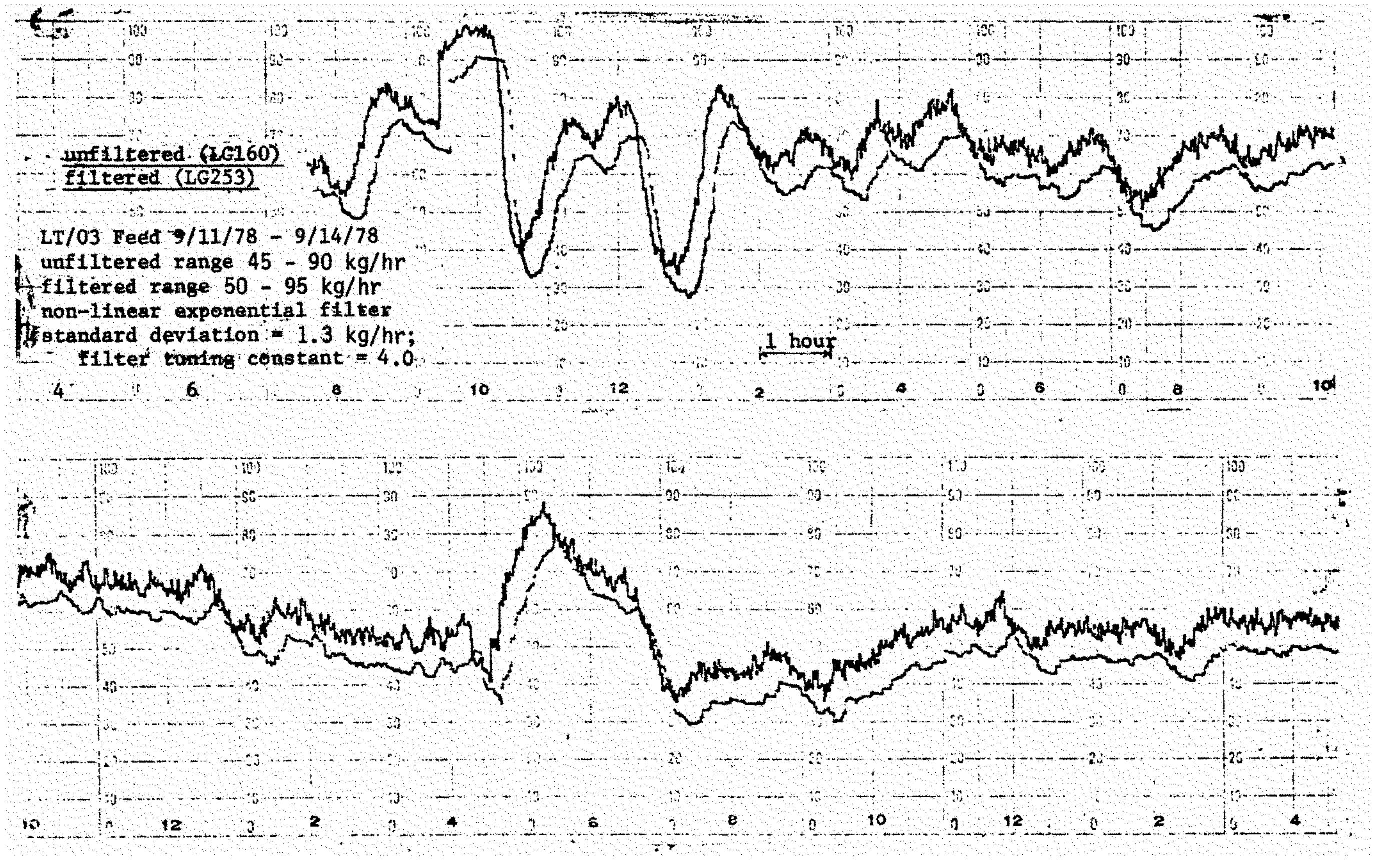


**Figure 3. Filtered and unfiltered versions of field signal (tower feed rate).**

## NONLINEAR EXPONENTIAL FILTER TESTED BY SIMULATION

In order to evaluate the worth of the new filter, it was tested vs. the exponential filter. In all cases, digital sampling was at twice the frequency of the noise. This frequency optimizes exponential filter performance (Goff, 1966*a*, *b*). Figure 1 shows the response of the two filters to a step change with noise superimposed. The filters shown use the tuning constants which give best results for a wide range of signals and noise. The ratio of the step signal magnitude to the peak-to-peak sinusoidal noise signal (signal-to-noise ratio) is 2 for this figure. Note that the nonlinear exponential filter ($R = 3.5$) reaches 100% of the signal value in just two sample intervals with no overshoot and thereafter reduces noise level by approximately 80%. This compares to the standard exponential filter which requires ten sample intervals to reach 90% of the final value with the same noise suppression as the nonlinear exponential filter.

Figure 2 shows the response of the same two filters to a sinusoidal signal of amplitude of 1, with sinusoidal noise superimposed. Note that the nonlinear exponential filtered signal follows the actual signal closely. However, the exponential filter substantially alters the magnitude of the signal and also introduces significant phase lag. These two examples are typical.

Since the nonlinear exponential filter is tuned for noise of a particular noise level, it works best for signals whose noise level is steady. It is not recommended for filtering signals with spikes of noise.

## USE IN A CONTROL LOOP

The nonlinear exponential filter is, as explained above, equivalent to an exponential filter with a variable filter constant. This means that it acts like a variable time constant lag in the control loop. However, this is not as much of a problem as would first appear. In fact, it is the main strength of the filter. That is, it allows a feedback controller to be tuned without concern for filter lag. The resulting response for large disturbances will then be optimum, since for large disturbances there is no filter lag. Naturally, if the loop is tuned assuming no filter lag, it will be less well tuned for disturbances which are smaller than the noise level. However, the presence of the noise makes tight control of these low level disturbances difficult, no matter what type of filter is used.

## COMMERCIAL EXPERIENCE

This filter has been applied in a field location within the Exxon circuit. Figure 3 shows the results of the nonlinear exponential filter applied to a typical flow signal. The tuning parameter ($R$) selected is 4. The filtered signal has been given a small bias to provide separation between pens. Note that the filtered signal closely follows the actual signal trend while significantly smoothing the signal. This filtered signal was the wild flow in a feedforward control application. The nonlinear nature of the filter did not turn out to be a problem in this application. This application confirms the simulation results presented here.

## CONCLUSION

The nonlinear exponential filter seems to be an attractive alternative method for smoothing signals which have a steady noise level.

## ACKNOWLEDGMENT

I would like to thank Dr. R. E. Zumwalt of ER&E for his help and encouragement during the development of this filter. Also, I would like to thank Mr. M. J. Veraa who applied the filter at Exxon's Baton Rouge Chemical Plant.

## NOTATION

$P$ = exponential filter tuning constant
$R$ = filter tuning constant
$X_n$ = measured value at time $n$
$Y_n$ = filtered value at time $n$
$Y_{n-1}$ = filtered value at time $n-1$
$\Delta X_n$ = the difference between the present measurement and the last filtered value
$\sigma$ = standard deviation of the process noise (after sampling)

## LITERATURE CITED

Goff, K. W., "Estimating Characteristics and Effects of Noisy Signals," *ISA Journal* (Nov., 1966*a*).

Goff, K. W., "Input Signal Conditioning," *ibid.*, 45-54 (Dec., 1966*b*).

*Manuscript received November 9, 1978; revision received March 19, and accepted April 19, 1979.*

# Olefin Hydration Catalyst Evaluation in a Backmix Reactor

**PERCY R. KAVASMANECK and P. DWIGHT SHERMAN**

**Union Carbide Corporation**
**South Charleston**
**West Virginia 25303**

A catalytic life study for an olefin hydration catalyst which normally requires 2 mos of testing in a tubular reactor can be accomplished in the short time span of only 4 days in a backmix reactor. The drastic reduction in time is made possible by capitalizing on the fact that the life of a supported, phosphoric acid catalyst is intimately associated with the retention of the acid on the support (Millidge, 1969). By suitably adjusting the impeller speed in a backmix reactor, the mass velocity can be controlled so as to permit an increased rate of phosphoric acid loss from the catalyst, thereby enabling the test to be completed in a substantially shorter time. Increasing the impeller speed could theoretically cause further reductions