# Filtering of Arterial Blood Pressure Signal Artifact using the Extended Kalman Filter.

## Signal Tracking

In an earlier post, I had discussed some mathematical techniques for mitigating alarm fatigue ("Alarm Fatigue", October 4th, 2014, revised May 18th, 2017, available at: http://www.johnrzaleski.com/2017/05/17/alarm-fatigue-nuisance/).

Expanding on the mathematical techniques employed, another reason for filtering of data includes the smoothing of artifact or spikes that are due to signal errors or other issues associated with signal acquisition.

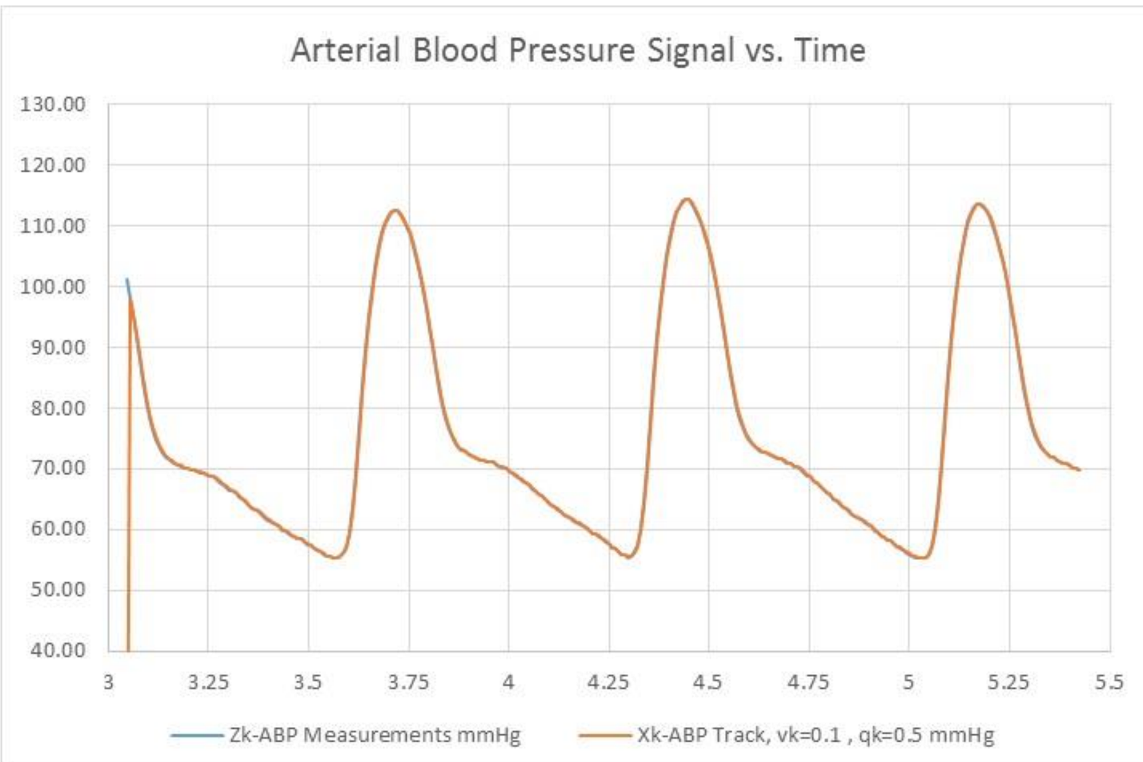


**Figure 1: Arterial blood pressure signal (from MIMIC II Database) with measurements and tracking signal overlaid.**

Figure 1 depicts several seconds of raw arterial blood pressure (ABP) data obtained from a patient within the MIMIC II physiologic waveform database.[i,ii]

This figure shows a raw signal with a tracking signal based on the extended Kalman filter (EKF) overlaid. In this case, the signal error and the process noise are very small (signal noise 0.1 mmHg, process noise 0.5 mmHg). With these settings, the filter tracks the actual signal very closely, and makes it appear as if there is not difference between signal measurement and track.

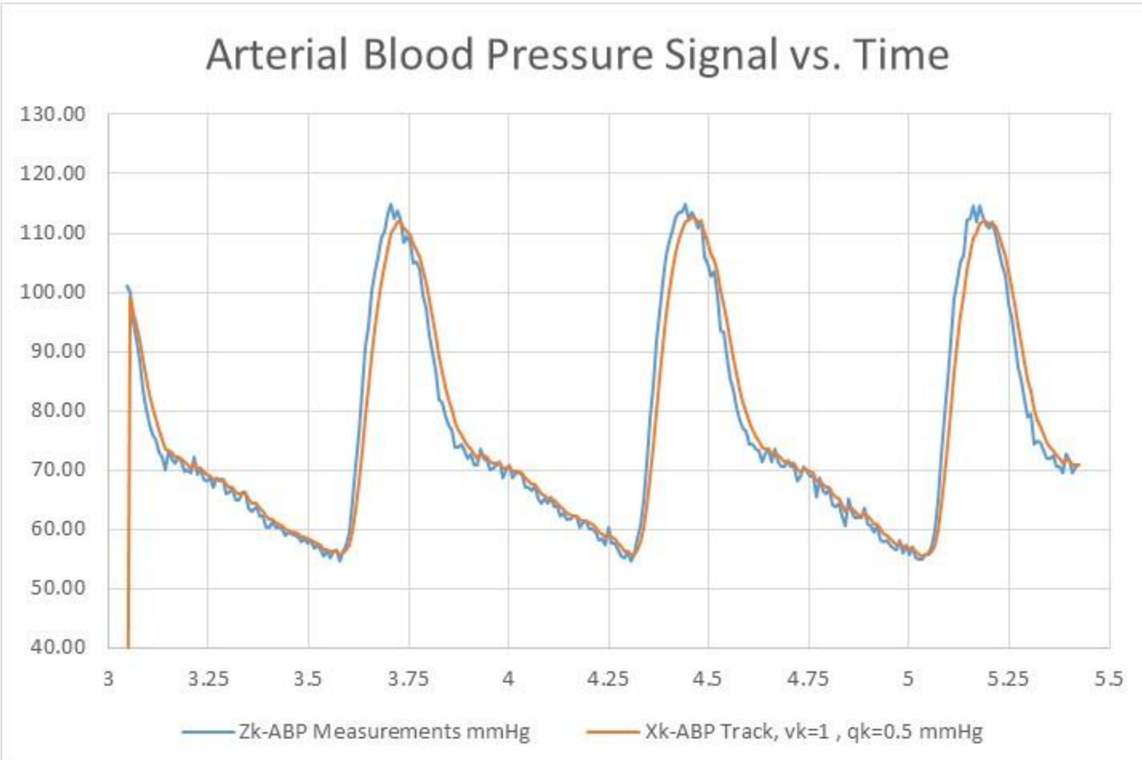


**Figure 2: ABP tracking with signal noise increased to 1 mmHg with process noise maintained at 0.5 mmHg.**

As noise is added to the raw signal (simulated artifact), with tracking parameters maintained the same (that is, process noise maintained at 0.5 mmHg), it may be seen from Figure 2 that the track begins to deviate from the signal.

## Signal Smoothing

The effect of noise is much further exaggerated in Figure 3, wherein the noise is increased to 10 mmHg. With process noise maintained at 0.5 mmHg, the track follows the rough outline of the signal but not the detailed signal artifact—in effect, smoothing the signal data.

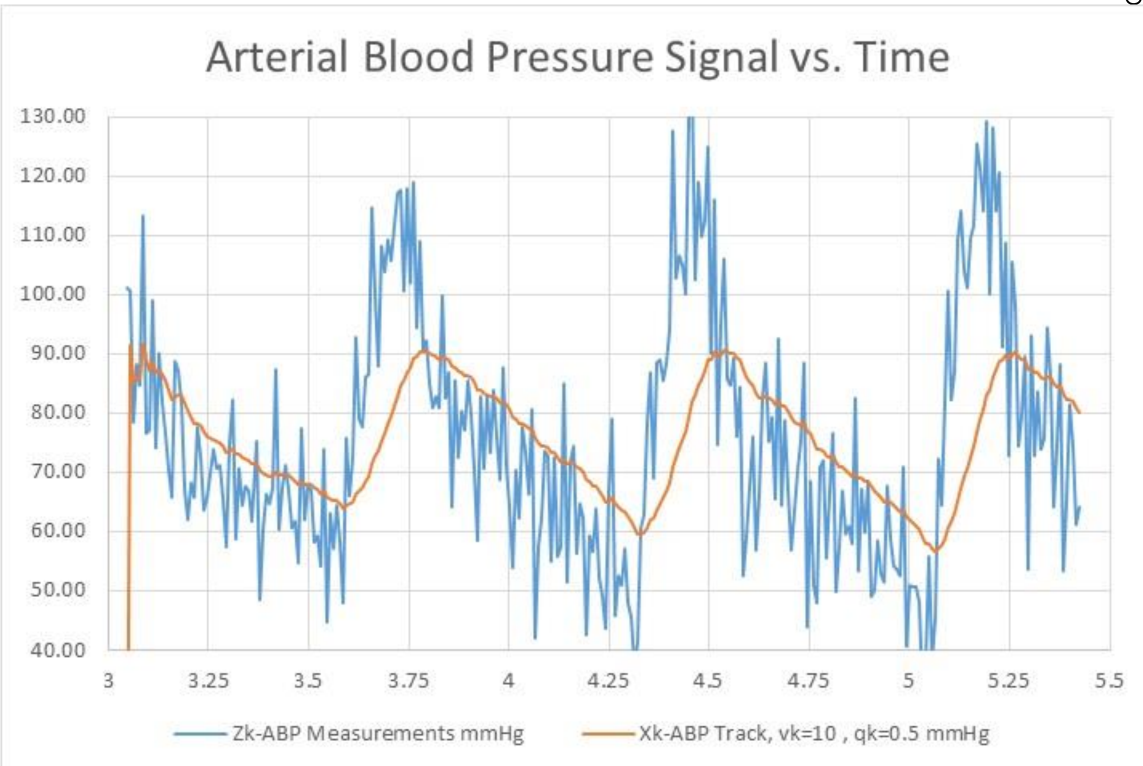


**Figure 3: ABP with tracking signal noise increased to 10 mmHg with process noise maintained at 0.5 mmHg.**

As the process noise is increased, the degree to which the estimate tracks the actual signal—including artifact—increases. Hence, a balance can be achieved whereby the track of the signal can be tuned to track the basic signal while ignoring the transient components of the signal, as illustrated in Figure 4.

As the signal noise remains constant and process noise is increased, the track approaches the actual signal. Thus, the ability to filter the transients is demonstrated. The task, then, is to determine the acceptable level of filtering of poor or noise-laden signals.

Perhaps a more "realistic" example of signal artifact would be that shown in Figure 5, in which noisy data spikes occur during the otherwise normal measurement sampling. The tracking of the signal, represented by the orange line, shows smoothing achieved by judiciously selecting process noise to minimize the impact of the artifact on the overall signal.

The challenge, of course, is knowing HOW to tune the tracking of the overall signal, so as to minimize the likelihood that true measurements are not ignored or otherwise smoothed out in the process of detecting and minimizing the impact of signal artifact.

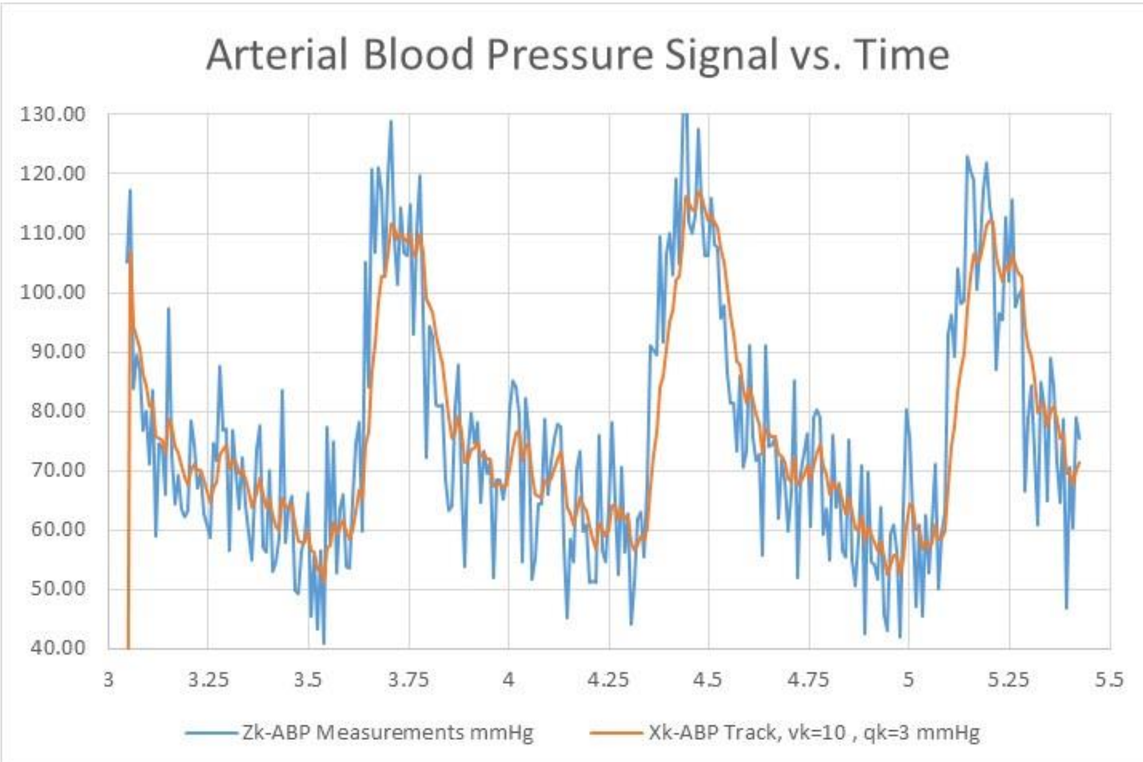


**Figure 4: ABP with tracking signal noise at 10 mmHg and process noise increased to 3 mmHg.**

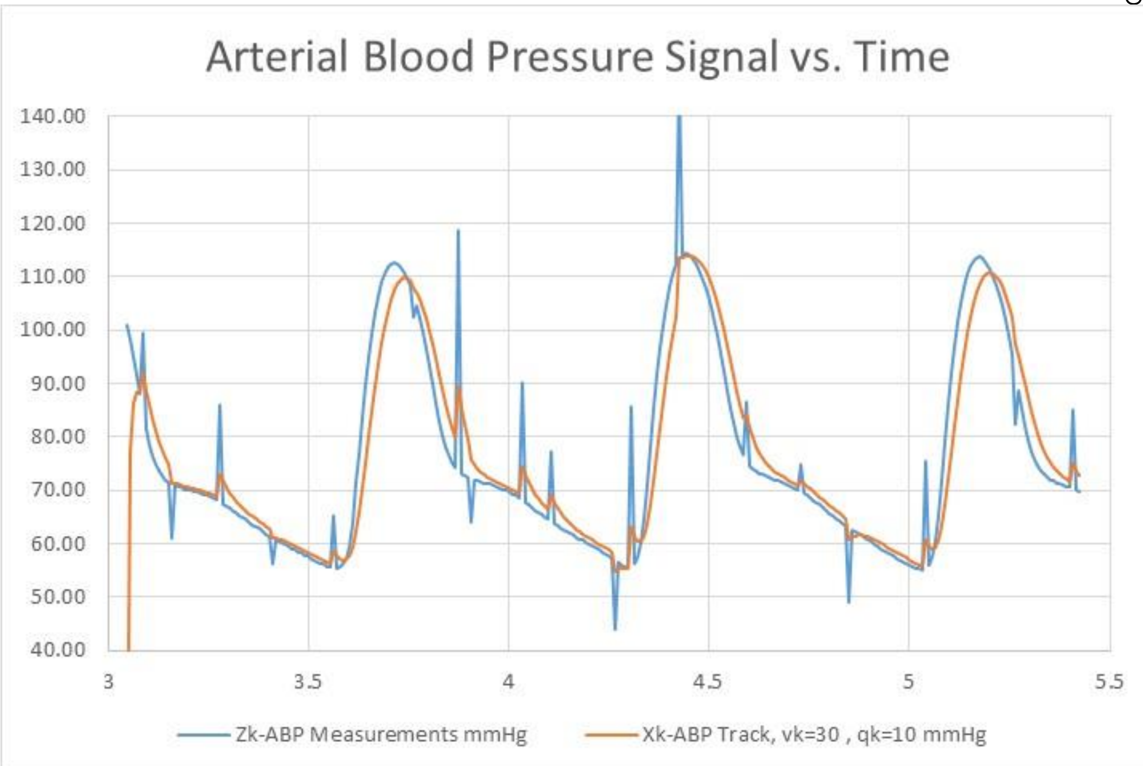


**Figure 5: ABP with occasional artifact ("spikes") and overlaid tracking of signal showing smoothing.**

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[i] M. Saeed, M. Villarroel, A.T. Reisner, G. Clifford, L. Lehman, G.B. Moody, T. Heldt, T.H. Kyaw, B.E. Moody, R.G. Mark. Multiparameter intelligent monitoring in intensive care II (MIMIC-II): A public-access ICU database. Critical Care Medicine 39(5):952-960 (2011 May); doi: 10.1097/CCM.0b013e31820a92c6.

[ii] Goldberger AL, Amaral LAN, Glass L, Hausdorff JM, Ivanov PCh, Mark RG, Mietus JE, Moody GB, Peng C-K, Stanley HE. PhysioBank, PhysioToolkit, and PhysioNet: Components of a New Research Resource for Complex Physiologic Signals. *Circulation* **101**(23):e215-e220 [Circulation Electronic Pages; http://circ.ahajournals.org/cgi/content/full/101/23/e215]; 2000 (June 13).