1982c

"Kalman Filtering for Spacecraft Attitude Estimation" (survey paper), E. J. Lefferts, F. L. Markley, and M. D. Shuster, *Journal of Guidance, Control and Dynamics*, Vol. 5, No. 5, September–October 1982, pp. 417–429.

This work, the journal publication of 1982a, presents a summary of experience in the Kalman filtering of spacecraft attitude up to 1982 and offers two possible implementations of the Kalman filter for systems with attitude sensors and gyros with noise terms describable by a first-order Markov process. The two implementations are now frequently known as the "additive" and "multiplicative" attitude EKF (extended Kalman filter), designations introduced in this article. The two implementations are, in fact, both additive, and differ only in the choice of frame for the update, as pointed out in 1993f and 2003b. Nonetheless, the names have stuck. Two different derivations are presented for the "multiplicative" EKF, one due to each of Markley and me, neither of whom was willing to see his approach excluded. Lefferts, who introduced both Markley and me to the subject, acted as host to the project (the paper was written on Saturday mornings in his basement), fed us, and prevented us from coming to blows! Landis Markley and I, in fact, have been friends since 1967, when we were both physicists.

The MEKF filter described in this work is an obvious development of the SPARS work of Toda, Heiss and Schlee of 1969 and Jim Murrell's Landsat-D work of 1978 (see 2006e for details). The AEKF filter of this work derives largely from the PADS work of Iwens and Farrenkopf (again see 4030x). The AEKF of this work should not be confused with the *unconstrained* AEKF of Bar-Itzhack and Oshman, which does not treat the quaternion norm correctly.

Although the article claimed to be only a review, there was, in fact, some original work contained in it. It surveyed the title area well enough that earlier works are seldom cited today.

This is one of the last author's three most cited publications.

The AEKF filter of this work is obscured by the so-called AEKF of Bar-Itzhack and Oshman. That work simply makes the mathematical error of neglecting the quaternion norm. It has been shown that neglecting the quaternion norm constraint in the estimation process can lead to nonsense (see 2003a and 2003b). In addition, it has been shown that the most efficient means of restoring the norm constraint correctly to the unconstrained estimate is to discard the Bar-Itzhack-Oshman result entirely and begin again with the properly constrained AEKF. The incorrect Bar-Itzhack-Oshman filter should be called the Łunconstrained AEKF, so as not to be confused with the correctly formulated AEKF of 1982c. Unfortunately, because Bar-Itzhack calls his filter simply "AEKF," one may obtain the misimpression that his AEKF is an equivalent variation of what is commonly called the

MEKF. It is not. The AEKF and MEKF of Lefferts, Markley and Shuster are correct. The AEKF of Bar-Itzhack and Oshman is not.

The unconstrained AEKF of Bar-Itzhack and his collaborators has been sharply criticized not only by me, but also by Pittelkau, Markley, Crassidis, and Cheng.

Superseded 1982a