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6 Dec 2017

in estimation algorithms. It is a more practical and rigorous addendum to their many earlier surveys, concerned with utilizing alternative EKF’s or Nonlinear Luenberger Observers (as alternatives to Extended Kalman filter-based approaches). **CONCLUSION: They admonish to “stick with using EKF”**. (10) Majji, M., Junjik, J. L., Turner, J. D., “Jth Moment Extended Kalman Filtering for Estimation of Nonlinear Dynamic Systems,” AIAA Guidance, Navigation, and Control Conference and Exhibit, Honolulu, HI, Paper No. AIAA 2008-7386, pp. 1-18, 18-21 Aug. 2008: Explores two variations on JMEKF formulations that properly handle higher order moments (that lurk in the background while trying to get good estimates and covariances from EKF’s). Approximations utilized are acknowledged and properly handled (rather than ignored, as is usually the case). Errors reduced by several orders of magnitude within 5 sec., but results in normalized units (for comparisons to ordinary EKF approach, which it beat by a wide margin). Down side is its larger CPU burden yet to be completely quantified. (11) Scorse, W. T., Crassidis, A. L., “Robust Longitudinal and transverse Rate Gyro Bias Estimation for Precise Pitch and Roll Attitude Estimation in Highly Dynamic Operating Environments Utilizing a Two Dimensional Accelerometer Array,” AIAA Atmospheric Flight Mechanics Conference, Paper No. AIAA 2011-6447, Portland, OR, pp. 1-28, 8-11 Aug. 2011: Using the latest in rigorous real-time estimation algorithms (neither a particle filter nor an uncented/Oxford/Sigma-Point filter) for enabling accurate pointing (precise pitch and roll) within an aircraft within a high dynamics operating environment is reported. While it does utilize rate integrating gyros, it also utilizes 2D accelerometer arrays and compares to an onboard gravity map to achieve its accuracy. Following reasonably large offsets, got back to within 0.1 degree pointing error within 10 seconds but results are much worse with turbulence present. (12) Jensen, Kenneth J., “Generalized Nonlinear Complementary Attitude Filter,” AIAA Journal of Guidance, Control, and Dynamics, Vol. 34, No. 5, pp. 1588-1593, Sept.-Oct. 2011: Achieves a big breakthrough by providing a proof of this particular EKF’s global stability as a consequence by stating that it possesses “almost” global asymptotic stability; however, the term “almost” is required terminology to keep probability theorists and purists happy with the wording of his claim. Author Jensen attains his results by utilizing appropriate stochastic Lyapunov functions (proper handling of such is due to Prof. Emeritus Harold J. Kushner, Brown Univ.). (13) La Scala, B. F., Bitmead, R. R., James, M. R., “Conditions for stability of the Extended Kalman Filter and their application to the frequency tracking problem,” Math. Control, Signals Syst. (MCSS), vol. 8, No. 1, pp. 1-26, Mar. 1995: **Proof of Stability for yet another EKF. Now worries about EFK divergence evaporate for this application.** (14) Reif, K., Gunther, S., Yaz, E., Unbehauen, R., “Stochastic stability of the continuous-time extended Kalman filter,” Proc. Inst. Elect. Eng., Vol. 147, p. 45, 2000: **Proof of Stability for yet another EKF. Now worries about EFK divergence evaporate for this application too.** (14) Salcudean, S., “A globally convergent angular velocity observer for rigid body motion,” IEEE Trans. on Autom. Control, Vol. 36, No. 12, pp.1493-1497, Dec. 1991: **Provides proof of Stability for Luenberger Observer use also (~ for EKF).**

9 Dec 2017

Sparse terrain profile data are stored onboard and direct measurement of relative shifts between images are used to estimate position and velocity; however, an EKF is deemed superior here to use of merely a Kalman filter that uses altitude estimates in order to estimate aircraft position and velocity. (3) Heeger, D. J., Jepson, A. D., “Subspace Methods for Recovering Rigid Motion I: Algorithm and Implementation,” International Journal of Computer Vision, Vol. 7, No. 2, pp. 95-117, Jan. 1992: Terrain matching methods are also used to estimate platform position and orientation via comparisons to an on-board digital elevation map. (4) Soatto, S., Frezza, R., Perona, P., “Motion Estimation via Dynamic Vision,” IEEE Trans. on Automatic Control, Vol. 41, No. 3, pp. 95-117, Mar. 1996: A least squares formulation is used to recover user’s 3D motion (3 translation variables and 6 rotation variables or 4 if quaternions are utilized). (5) Goyurfil, P., Rotstein, H., “Partial Aircraft State Estimation from Visual Motion Using the Substate Constraint Approach,” AIAA Journal of Guidance, Control, and Dynamics, Vol. 24, No. 5, pp. 1016-1025, Sep.-Oct. 2001: What is called an implicit EKF is used here to estimate aircraft states-aircraft velocities, angular rates, angle of attack, and angle of sideslip but not aircraft Euler angles nor inertial location. Measurements available are the image points of N featured objects, which are tracked from one frame to another. (6) Hoshizaki, T., Andrisani, D., Braun, A. W., Mulyana, A. K., and Bethel, J. S., “Performance of Integrated Electro-Optical Navigation Systems,” Navigation: Journal of the Institute of Navigation, Vol. 51, No. 2, pp. 101-122, Summer 2004: Contains good modeling and they have a “tightly coupled system consisting of INS, GPS, and EO” all working together to simultaneously benefit both navigation and photogrammetry (estimates platform states, sensor biases, and unknown ground object coordinates using a single Kalman filter). **Use of control points avoided pre-stored terrain.** (7) Kyungsuk Lee, Jason M. Kriesel, Nahum Gat, “Autonomous Airborne Video-Aided Navigation,” Navigation: Journal of the Institute of Navigation, Vol. 57, No. 3, pp. 163-173, Fall 2010: ONR-funded discussion utilizes (1) “digitally stored georeferenced landmark images” (altimeter/DTED), (2) video from an onboard camera, and (3) data from an IMU. Relative position and motion are tracked by comparing simple mathematical representations of consecutive video frames. A single image frame is periodically compared to a landmark image to determine absolute position and to correct for possible drift or bias in calculating the relative motion. (8) Craig Lawson, John F. Raquet, Michael J. Veth, “The Impact of Attitude on Image-Based Integrity,” Navigation: Journal of the Institute of Navigation, Vol. 57, No. 4, pp. 249-292, Winter 2010: Being aware of the historical importance of having good satellite geometry when seeking to utilize GPS for positioning and for timing (characterized by HDOP, VDOP, TDOP, and GDOP), they analogously extrapolate these ideas to the geometry of their airborne image collecting and refer to this as image integrity (similar to how researchers endeavor to associate sufficient Integrity to GPS measurements). Known a/c attitude significantly beats unknown attitude (altitude-indexed). **All of the above likely comparable to Classified Pointing Improvements:** Cobra Ball/Cobra Eye & airborne Laser developments!

19 Mar 2018

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counterexamples) (3) Kerr, T. H., “Fallacies in Computational Testing of Matrix Positive Definiteness/Semidefiniteness,” IEEE Transactions on Aerospace and Electronic Systems, Vol. 26, No. 2, pp. 415-421, Mar. 1990. [Lists fallacious algorithms that the author found to routinely exist within U.S. Navy submarine navigation and sonobuoy software in the late 1970’s and early 1980’s using counterexamples to point out the problems.] The third publication above has the greatest relevance in its last Section VII so readers can recognize the problems if/when they ever see them in software again (which is typically the case). The specific applications exhibiting the particular problems discussed in the open literature are only explicitly identified in the corresponding Intermetrics IV&V reports (delivered only to the pertinent NAVY customers).

My endorsement for use of Beirman's and Thornton's U-D-U^T squareroot Kalman filter formulation in Section VII was OK for its time (1990 and before). However, by the late 1990's, computers were built differently and computation of the scalar square root was no longer iterative and so no longer as time consuming. Consequently, Neal Carlson's squareroot filter has the least computations or operations counts even though it uses explicit computation of scalar square roots (now, more easily handled in hardware, using logarithm and anti-logarithm implementation).

22 Mar 2018


26 Mar 2018
Besides merely limiting one's attention to the Kalman filter algorithm itself and its mechanization in software, one must occasionally branch out and fix glitches made by others in abutting technology areas, which can occur in models to be used: fairly recently incurred by someone attempting to handle numerical gravity data using what was claimed to be a new technique for system realization (that was not their area of specialization nor area of familiarity), as corrected in: (1) Kerr, T. H., “Comment on ‘Precision Free-Inertial Navigation with Gravity Compensation by an Onboard Gradiometer’,” AIAA Journal of Guidance, Control, and Dynamics, Vol. 30, No. 4, pp. 1214-1215, Jul.-Aug. 2007. (Specifically, two counterexamples are provided where previously claimed conditions are demonstrated to not be satisfied as claimed to be the case.) Another is in simplifying a test proposed by others for two ellipsoid overlap, when the ellipsoids are not necessarily related (as they are in the CR2 failure detection approach above in Item 5 of 16), as availed in: (2) Kerr, T. H., “Comments on ‘Determining if Two Solid Ellipsoids Intersect’,” AIAA Journal of Guidance, Control, and Dynamics, Vol. 28, No. 1, pp. 189-190, Jan.-Feb. 2005. By simplifying a GPS-related optimization problem by revealing that it has a directly calculated closed-form solution as: (3) Kerr, T. H., “Comment on ‘Low-Noise Linear Combination of Triple-Frequency Carrier Phase Measurements’,” Navigation: Journal of the Institute of Navigation, Vol. 57, No. 2, pp. 161, 162, Summer 2010. Frequently having to deal with principles of operation of the actual hardware and identifying likely vulnerabilities way before others saw them and started fixing them: (4) Kerr, T. H., “Further Critical Perspectives on Certain Aspects of GPS Development and Use,” Proceedings of 57th Annual Meeting of the Institute of Navigation, pp. 592-608, Albuquerque, NM, 9-13 Jun. 2001. (An expose of several loose ends in GPS development that needed [and have now received] further attention before unabated and unabashed reliance upon GPS, as had been claimed to be the plan in the late 1990's for Battlefield 2000.)

1 Apr 2018

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1 Apr 2018


2 Apr 2018

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3 Apr 2018


8 Apr 2018


An open question (existing for numerical analysts either at The MathWorks or elsewhere) that still needs a definitive answer pertains to the possible universal validity of an alternate approach to direct calculation of the pseudo-inverse matrix that is NOT based on invoking the Singular Value decomposition (SVD). A flow diagram of this alternate approach appears in: (2) Kalman, R. E., Englar, T. S., "A User's Manual for the Automatic Synthesis Program (Program C)," NASA Contract Rep. NASA CR-475, June, 1966. A French researcher vouches for its validity in: Proceedings of the International Conference on Signal Processing Applications & Technology, Boston, MA, 7-10 Oct. 1996. The only limitation identified by this French researcher was that this alternative algorithm is not amenable to parallel implementations as a Systolic Array nor as a Cordic Algorithm; while SVD-based Pseudo-inverse calculation is amenable to such. The algorithm discussed immediately above and said to be by French researchers appeared in (3) O. Caspary and P. Nus, "Implementation of the Greville algorithm on a Motorola DSP96002 Application to Least-Squares problems," The Proceedings of the 7th International Conference on Signal Processing Applications & Technology (ICSPAT), Boston, MA, USA, pp. 142-145, 7-
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10 Oct. 1996. (It's Table 2 offers a short MatLab code implementation of the Greville algorithm that is summarized as a flow chart in their Table 1, both Tables appearing on page 145.)

15 Dec. 2018


12 Jan 2019


Introduction: Time synchronization is an important issue in multihop ad hoc wireless networks such as sensor networks. Many applications of sensor networks need local clocks of sensor nodes to be synchronized, requiring various degrees of precision. Some intrinsic properties of sensor networks, such as limited resources of energy, storage, computation, and bandwidth, combined with potentially high density of nodes can make traditional synchronization methods unsuitable for these networks; hence, there has been an increasing research focus on designing synchronization algorithms specifically for sensor networks. This article reviews the time synchronization problem and the need for synchronization in sensor networks, then presents, in detail, the basic synchronization methods explicitly designed and proposed for sensor networks.

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6 Sep 2019