Demonstrating Fast Kalman Filtering (FKF) for GNSS Navigation

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Abstract:
Safe road traffic needs new standards to secure the precise and most reliable navigation and piloting. A sufficient amount and density of information for the worldwide safe cruising of an autonomous vehichle are obtained by exploiting as many GNSS signals as possible. An uncompromised level of integrity is demanded from the car receiver. Therefore, the internal consistency of the GNSS, pseudolite, beacon, eLoran, WiFi, radar, lidar, sonar, gyro, odometer, barometric altimeter, INS unit, etc. signals must be carefully evaluated and analysed for finding outliers and their promt mitigation. The potential hazards resulting from a Selective Availability (S/A), interference or any intentional falsification of these different signals need to be taken duly care of. The Minimum Norm Quadratic Unbiased Estimation (MINQUE) is applied to the evaluation and proper control of these signal errors. The use of the conventional Kalman Filter (FK) recursions must be abandoned. The patented FKF method replaces them by applying the Helmert-Wolf blocking (HWb) method from Geodesy. The optimal speeds for safe road transports can thus be achieved by exploiting all available signals. The true navigation accuracy can now be made available also in realtime as its overly difficult computing will no longer be the bottleneck.

INTRODUCTION

Foreign GNSS signals will soon need a Federal Communications Committee (FCC) authorization for their use in the United States. All Multi-GNSS car receivers need to be certified in order to be legally used in the safety-critical transports. The Receiver Autonomous Integrity Monitoring (RAIM or ARAIM) must be effectively applied and sophisticated A Posteriori Multipath Estimator (APME) methods needs to be developed. The Fault Detection and Exclusion (FDE or FDIR) techniques must improve robustness in the presence of signal failures. The difference between an observed and the expected signal is divided by its standard deviation. This ratio is compared with a threshold value for a small probability of false alarms. However, the Best Linear Unbiased Estimation (BLUE) of the expected signal values would require superfluous computing power from the Multi-GNSS receivers. Therefore, the Real-Time Kinematic (RTK) and Virtual Reference Station (VRS) land surveys make use of the sparse-matrix method derived from the Helmert-Wolf blocking (HWb). It is fast enough and is now applied as FKF to the most stringent optimal Kalman filtering required by the truly safe car receivers.

The Satellite Navigation receivers (GPS, Glonass, Galileo, Beidou, QZSS, Doris, SBAS,... in many combinations) are autopiloting vessels, aircraft and robots today. The emerging autonomous car demands a significant improvement to their present precision and reliability. It is a matter of public safety that these new car navigation receivers conform to much more stringent regulatory and industrial standards. Unfortunately, this is not the present trend in Europe. The EU Action TU1302 (SaPPART) is responsible for the European standardization efforts. It is introducing a mere statistical concept of the receiver integrity to the car market and thus completely ignoring the scientific (i.e. the true) integrity of the receiver mathematics.

INTEGRITY OF THE FAST KALMAN FILTERING (FKF)

American mathematician prof. R. E. Kalman found in 1960 the absolutely necessary conditions under which the receiver mathematics i.e. the Kalman Filtering (FK) can be relied upon. However, these so called Kalman's stability conditions are almost completely ignored today. The Navigation Industry applies Kalman filters paying almost no attention to these absolutely necessary conditions so that the present receivers are doomed to take unacceptable risks.
The theory of optimal Kalman filtering provides the proper means of updating repeatedly the receiver positions, instrumental calibration drifts, system model and environment parameters. Only the FKF processing can exploit very large moving data windows. These must be kept sufficiently long to satisfy Kalman's observability and controlabilty conditions for all those calibration parameters that are involved in safety-critical navigation. The only straightforward way of controlling them is to monitor their true realtime accuracy by MINQUE. However, no conventional Kalman filter is able to deal with the excessive computational burden because its numerical complexity is proportional to much more than the cube of the number of the input signals and variables. Fortunately, the numerical complexity of FKF is roughly proportional only to the square and can therefore do the job.

CONCLUDING REMARKS

FKF is the only known method to solve the emerging very difficult numerical problem (from computational accuracy) with the most precise and integrity-controlled receivers. FCC is alerting the navigation communities of all the risks that also result from a selective availability (S/A), misleading satellite signals or their spoofing. Most sophisticated RAIM, FDE and APME techniques must be developed for full and safe exploitation of the many new GNSS, ground-based and INS signals. The forthcoming ultra-reliable hybrid precision receivers will improve the cruise controls and piloting of cars, robots and Unmanned Aerial Vehicles (UAV). The simulations and protos demonstrate how different signals improve the precision and robustness for Intelligent Traffic Systems (ITS).

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