December 10-14, 2018
Hyatt House Falls Church/Merrifield
8296 Glass Alley
Fairfax, Virginia, USA, 22031

Dr. Alan Pue, Instructor

Mr. Michael Vaujin, Instructor

I wanted to become more familiar with inertial navigation and the data fusion methods. The class fully met my needs and expectations. I would recommend the course to my colleagues working in tracking and navigation, particularly those doing counter-fire radar work.
— Warner Warren, The MITRE Corporation, November 2016

COURSE 557 (3.0 CEUs) (Expanded to 5 Full Days by Request)

Inertial Systems, Kalman Filtering and GPS/INS Integration

DAY 1	DAY 2	DAY 3	DAY 4	DAY 5
Dr. Alan Pue, Johns Hopkins University, Applied Physics Lab.			Mr. Michael Vaujin, Aerospace, Navigation & Defense Consultant	
Introduction to INS/GPS integration • Inertial navigation • Integration architectures • Example applications **Vectors, Matrices, and State Space** • Vectors and matrices • State-space description • Examples **Random Processes** • Random variables • Covariance matrices • Random process descriptions	**Inertial Navigation Mechanization** • Gravity model • Navigation equations • Implementation options **Inertial Sensor Technologies** • Accelerometer technologies • Optical gyros • MEMS technologies • Technology survey **Strapdown Systems** • Quaternions • Orientation vector • Coning and sculling compensation	**INS Aiding of Receiver Tracking** • Code and carrier tracking • Track loop design trades • Interference suppression • Deep integration **Tightly-Coupled INS/GPS Design** • Measurement processing • Filter parameter selection • Pseudo-range and delta pseudo-range measurement models **Multi-Sensor Integration** • Terrain aiding and relative GPS • Carrier phase differential integration • GPS interferometer/INS integration	**Aided Psi-Angle Navigator** • Description and demonstration of an aided Psi-angle wander azimuth navigator flying an aircraft type trajectory **Aided Phi-Angle Navigator** • Description and demonstration of an aided Phi-angle north-slaved navigator flying and aircraft type trajectory • Modeling position error as latitude/longitude error • Modeling position error as navigation frame tilt error • Comparison of popular state dynamics matrix elements **Partials of Measurement Equations** • Techniques and tricks for taking partials, examples • Psi-angle and Phi-angle feedback to strapdown • Pros and cons of the 3 different navigator types	**Square Root Filtering** • Square root covariance filtering and smoothing • Information filter derivation • Square root information filters • UD factorization & filtering **Suboptimal Covariance Analysis** • Effects of mis-modeling errors • Optimal and sub-optimal (two pass) covariance analysis • Error budget and reduced state analysis **Unscented Kalman Filters** • Sigma points and the Unscented Transform • Performance against the EKF • Augmentation and application to navigation • Spherical Simplex Sigma Points • Square Root UKFs
Lunch				
Kalman Filter • Filtering principles • Least squares estimation • Kalman filter derivation **Filter Implementation** • Filter processing example • Off-line analysis • Filter tuning **Navigation Coordinate Systems** • Earth model • Navigation coordinates • Earth relative kinematics	**Navigation System Errors** • Tilt angle definitions • Navigation error dynamics • Simplified error characteristics **System Initialization** • INS static alignment • Transfer alignment • Simplified error analysis **Loosely-Coupled INS/GPS Design** • Measurement processing • Filter design and tuning • Navigation system update	**Mr. Michael Vaujin, Aerospace, Navigation & Defense Consultant** **Building Extended Kalman Filter** • Linearized & Extended Kalman Filters • Radar tracking of vertical body motion with non-linear dynamics • Radar tracking of an accelerating body with non-linear measurements **Numerical Preliminaries & Considerations** • Keeping a covariance matrix well-conditioned, symmetric, & positive definite • Sequential vs batch measurement processing • Methods of measurement de-correlation **Discreet Time Strapdown Implementation** • Attitude updates and TOV of the acceleration • Propagating the position DCM • High rate vs low rate routines • Effects of errors in initialization & IMU data	**Initialization & Process Noise** • Strapdown and covariance matrix initialization • Process noise for gravity and random walk • Common sensor error models: random constant, random walk and Gauss Markov **Measurement Editing & Adaptive Filters** • Online and offline residual analysis • Advanced methods of outlier detection and rejection • Multiple Model Adaptive Estimation • Application to carrier phase integer ambiguity resolution **Methods of Smoothing** • Optimal prediction and fixed interval smoothing • Fixed point and fixed lag smoothing • Applications to navigation testing	**Ground Alignment & Integrated Velocity** • Gyro-Compassing, zero velocity and zero earth rate observations • Large azimuth static alignment, advanced methods • Small azimuth static alignment & leveling • Ground alignment observability examples • Integrated true velocity error, mapping into delta-range **Attitude Matching & Use of Inexpensive IMUs** • Attitude matching & boresight error states • Considerations for use of very inexpensive IMUs • Non-holonomic motion constraints • Magnetometer aiding • In class measurement equation exercise • Matrix partitioning for computational efficiency **Particle Filtering** • Bootstrap particle filter (PF) • Multi-modal position solutions • Particle filter example • Applications to navigation

Course Objectives

Course 557 (formerly Course 556) has been expanded to five full days based on attendee requests. This course on GNSS-aided navigation will thoroughly immerse the student in the fundamental concepts and practical implementations of the various types of Kalman filters that optimally fuse GPS receiver measurements with a strapdown inertial navigation solution. The course includes the fundamentals of inertial navigation, inertial instrument technologies, technology surveys and trends, integration architectures, practical Kalman filter design techniques, case studies, and illustrative demonstrations using MATLAB®. The full five days allow for a fuller and more detailed development of the design of an aided navigation system, combined with a more detailed discussion of the use of lower quality IMUs, and advanced filtering techniques.

Who Should Attend?

- GPS/GNSS engineers, scientists, systems analysts, program specialists and others concerned with the integration of inertial sensors and systems.
- Those needing a working knowledge of Kalman filtering, or those who work in the fields of either navigation or target tracking.

Prerequisites

- Familiarity with principles of engineering analysis, including matrix algebra and linear systems.
- A basic understanding of probability, random variables, and stochastic processes.
- An understanding of GPS operational principles in Course 346, or equivalent experience.

Equipment Recommendation

- A laptop (PC or Mac) with full version of MATLAB® 5.0 (or later) installed. This will allow you to work the problems in class and do the practice "homework" problems. All of the problems will also be worked in class by the instructor, so this equipment is *not required*, but is *recommended*.
- The course notes are searchable and you can take electronic notes with the Adobe® Acrobat®9 Reader we provide to you.

Materials You Will Keep

- A CD-ROM or USB drive with a color copy of all course notes.
- A black and white hard copy of the course notes, printed 3 slides to a page.
- *Introduction to Random Signals and Applied Kalman Filtering, 4th edition,* by R.G. Brown and P. Hwang, Wiley 2012

What Attendees Have Said

"As he [Mr. Vaujin] highlighted the first day, the combination of lecture and MATLAB® examples provide a great vehicle to teach this complex subject.
—Christian Lopez, General Atomics, Aeronautical Systems, Inc.

"My main objective was to familiarize myself with the basic concepts of inertial navigation and learn the challenges of integration of INS and GPS. The course has met them. I feel empowered by the material and the knowledge that the instructor transferred to us."
— Dmitri Baraban, The MITRE Corporation