

Short Courses (one or two days)

Power Seminar in Navigation (1 day):

This overview series of lectures introduces the art and science of navigation spanning the classical techniques of celestial astronomy to the future applications of advanced Intelligent Transportation Systems. Introductory lectures on the role of navigation in military systems, the history of navigation and the future of navigation are provided. The status and fundamentals of radio, satellite and inertial navigation are addressed.

Inertial Navigation Overview (1 day):

This overview course addresses the critical role that inertial navigation systems play in modern military warfare. The history, advantages and disadvantages of inertial navigation are addressed. A description and demonstration of systems presently being utilized or in development is provided. Introductory lectures on the theory and operation of accelerometers, gyroscopes, gimbals and strapdown systems are given. A futuristic look at new applications and the role of Microelectromechanical sensors concludes the course.

Geophysical Navigation Overview (1 day):

This overview course discusses the impact and utilization of geophysical fields including bathymetry, gravity and magnetics on navigation system. It emphasizes the interrelationships with inertial navigators. The modalities of effects including correlation navigation, compensation for vertical deflections, commonality of geophysical and inertial sensors, and collocation algorithms are discussed. The practical and theoretical basis of the interactions are discussed.

Inertial MEMS for Navigation and Guidance (1 or 2 Days):

starting with an overview of inertial component testing and DOD inertial navigation applications, this tutorial includes a survey of Commercial Off-the-Shelf (COTS) components and navigation systems as well as emerging tactical grade IMU's. The design and analysis of MEMS accelerometers are discussed including generic accelerometer concepts, open and closed loop signal processing, automotive grade sensors, and inertial grade capacitive sensors. A review of MEMS fabrication and manufacturing processes is included. The design and analysis principles of MEMS gyros are presented including Coriolis forces, coupled mode fundamentals, gyro signal processing, linear mode devices, tilt mode devices, and ring mode devices. Additional issues relating to the inertial testing of high order model terms and sensor errors are reviewed. References to critical publications in the open literature are documented throughout the course.

Navigation Software (2days):

This course describes and provides software, mostly in MATLAB, to perform many key navigation functions. The accessibility of software to execute navigation algorithms is a critical skill for navigation systems engineers. These include: a) a kinematically correct trajectory generator b) time conversion functions c) coordinate conversion functions d) GPS ephemeris, solution, path loss, troposphere, ionosphere, relativistic functions e) strapdown inertial navigation algorithms f) gravity routines and several others. The course shall include examples and applications for the software. Students will be given, where applicable, a CD ROM of the navigation software. The course is applicable to all scientists and engineers who investigate navigation problems. Some MATLAB experience may be beneficial.

Courses Presented at:

**Your Location
OR
Navigation R&D Center
Warminster, PA**



Instructors

Marvin B. May



Raymond Filler



Pratap Misra



Michel M. A. Francois



**For Fees & Scheduling Contact
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Navigation Courses



Long Courses (Three –Four Days)

Fundamentals of Navigation

Navigation Integration & Fusion

Practical Inertial Navigation

Wireless and Mobile including Satellite
Navigation

Short Courses (One–Two Days)

Power Seminar in Navigation

Inertial Navigation Overview

Geophysical Navigation Overview

Inertial MEMS for Navigation & Guidance

Navigation Software

Description of Courses

Long Courses (Three or Four days)

Fundamentals of Navigation (3 days):

This course provides the student with the formal concepts associated with all aspects of the art and science of navigation. The attributes of navigation systems are discussed as a prerequisite to the fundamental range, range rate, acceleration, angular and angular rate measurements of navigation systems. The fundamentals of lines of position, the shape of the earth, basic navigation terminology, and dead reckoning/trajectory generation algorithms are derived. Maps, charts, geographical information systems and celestial navigation concepts are introduced. Coordinates systems and their kinematics are introduced as a prerequisite for understanding inertial navigation. Inertial navigation sensors and mechanization are reviewed. The fundamentals of electromagnetic propagation as they apply to radionavigation are covered. The important characteristics of present radionavigation and satellite systems (emphasizing GPS) are covered. An examination of trends in navigation focussing on its utility for Geographical Information Systems and network centric warfare concludes the course. A navigation software package containing valuable programs and subroutines is included in the course.

Navigation Integration and Fusion (3 days):

This three day course begins with the motivational aspects of developing a navigation subsystem. It emphasizes that appropriate navigation policy mandates the use of many sensors and their subsequent integration into a best navigation solution. The concept of optimality is addressed with respect to navigation subsystem integration. Examples of integrated systems are shown with emphasis on military platforms such as submarines. Various types of fusion filters are briefly introduced including particle filters, complementary filters and Unscented filters. Most emphasis is placed on the Kalman (and extended Kalman) filter. The canonical form of the Kalman filter is developed. Practical numerical examples of the Kalman filter which are relevant to navigation are given and demonstrated in class. The student is given computer code to hone his/her own skills with the mechanization of a Kalman filter. A lecture on the synergistic relationship between inertial navigation and satellite navigation is given along with the fundamental properties of each navigation system. The development of a GPS-INS tightly coupled Kalman filter is shown.

Practical Inertial Navigation (3-4 day):

The theory and practical applications of inertial navigation systems and advanced navigation system integration concepts are addressed. The fundamental vector and matrix operations are reviewed concurrently with coordinate system definitions. Euler angle representations and direction cosine properties of coordinate transformations are studied. The role of the inertial frame in the implementation of Newton's second law is emphasized along with the examination of the terrestrial inertial navigation assumptions of a geocentric inertial frame. Time differentiations of non-inertial coordinate systems are derived along with expressions for the angular velocities between reference frames. Expressions for the acceleration of a body in different coordinate systems are derived. Fundamentals of accelerometer and gyroscope technology are examined. The principle types of accelerometer and gyroscopes used in today's inertial navigation systems including ring laser and fiber optic gyroscopes are studied. The role of geodesy in inertial navigation theory is highlighted leading to the definitions of the ellipsoid, geoid, undulation, vertical deflections and the equations which govern their interrelationships. The principle configurations of space stable, local level north slaved, local level wander or free azimuth, two accelerometer local level, and strap-down mechanizations are explored. The state space representation of the error propagation of a three dimensional local level navigator is derived. The individual effects of gyro and accelerometer biases on the local level inertial navigator are demonstrated. The strap-down attitude reference equations are presented along with a mechanization diagram. The students are given a strap-down inertial navigation software package for educational use as well as other navigation software packages. Performance characteristics and size, weight, cost of commercial and military systems are shown. Examples of current activities and ongoing research with quantification of modern inertial navigator performance are given. Where possible, the course includes a "show and tell" using equipment from the collection of the PSU/ARL inertial facility. The course concludes with a discussion of future inertial navigation developments and applications.

Wireless and Mobile Positioning including Satellite Navigation (4 days):

This course addresses wireless position estimation-how it works and what it is used for. In several wireless systems, distance measurement and position location capabilities have become a necessary adjunct to communication. Location Based Services, particularly employing Smartphone's, has been an exploding growth area. The Global Positioning System (GPS) is the most ubiquitous and successful example of wireless positioning. A thorough coverage of satellite positioning including the satellite, control and user segments will be addressed. The military and commercial signal structures are taught including an introduction to many of the new initiatives for Global Navigation Satellite System (GNSS) modernization. The globalization of satellite navigation as BEIDOU/COMPASS/GALILEO/GLONASS/GAGAN/QZSS mature is studied. Satellite navigation employment and criticality as a worldwide time reference for communications and utilities is discussed. Other technologies being utilized include RFID, WLAN, UWB,BT,BTLE IMES (Indoor Measuring System) and WPAN. The future of GNSS leads to the explanation of integrity and anti-jam/anti-spoof considerations. The theory of wireless positioning and location based servicing as they relate to the underlying signals from the aforementioned technologies is discussed. Accuracy, volumetric coverage including applicability to indoors, infrastructure, user constraints, integrity and security are aspects of navigation systems that are described. Various Smartphone navigation apps will be examined in class where possible.

Instructor Bio's

Dr. Raymond L. Filler

Dr. Raymond L. Filler is a Senior R&D Engineer at the Penn State University Applied Research Laboratory, Navigation Research and Development Center. He has over 37 years of experience in Position, Navigation and Time. Dr. Filler is a recipient of the IEEE UFFC Society W. G. Cady Award and is an IEEE Fellow. His areas of research include Navigation Assurance and Frequency Control and Time.

Dr. Michel M. A. Francois

Dr. Francois is a research scientist at PSU / ARL. His background includes over 24 years experience in research, development and fabrication of integrated circuits, smart power semiconductor and MEMS devices, flip-chip and multi-chip packaging (module), molecular- nano, optical and piezoelectric bio-sensors. He designed and fabricated the first Liquid Metal Ion Source (LMIS) and the first Lab-On-a-Chip, in this area, at Drexel University for the detection or identification of target multi-measurands such as antigens, DNA, proteins, bioagents or other bio-chemical objects or bio-chemical reactions. He is now focusing on high aspect MEMS Gyroscope design and fabrication.

Marvin B. May

Marvin B. May is the Chief Navigation Technologist at ARL Penn State's Navigation Research and Development Center in Warminster, PA. He also manages their Navigation Education Program. He has a BSEE from City College of NY and a Masters Degree from New York University and Polytechnic Institute, doctoral courses at Polytechnic Institute and is a Professional Engineer. He teaches Master's Degree and sponsor directed navigation courses for the Penn State University. He is a recognized navigation specialist with expertise in GPS, inertial and geophysical navigation. He has been the Chief Analyst of the Navy's GPS Central Engineering Activity. May has served as Chairman of the Greater Philadelphia Chapter and is the national Marine Navigation representative and the one and only Historian of the Institute of Navigation. He was the 2007 winner of the Institute of Navigation's Captain Weems Award and was selected as an ION Fellow in 2008.

Dr. Pratap Misra

Dr. Pratap Misra, a staff member at PSU/ARL, spent much of his career at Lincoln Laboratory, Massachusetts Institute of Technology. He has been active in research on satellite-based navigation for over 20 years, with focus on aviation applications. A Fellow of the Institute of Navigation (ION) and a Fellow of the IEEE, he has served as Chair of the ION Satellite Division, and is the coauthor (with Professor Per Enge of Stanford University) of a widely used graduate-level engineering textbook on GPS.

***Courses may be tailored to
your navigation requirements***