COUNT
CONSORTIUM OF OHIO UNIVERSITIES ON NAVIGATION & TIMEKEEPING

Short Courses

Year Taught	Course	Instructor
2007, 2008	Software Receiver Technology	Jade Morton
2007	Network-Based RTK GPS and Precise Point Positioning	Dorota Grejner-Brzezinska
2007, 2008	Alternative Navigation Techniques	John Raquet
2007, 2008	Laser/Inertial Navigation	Frank van Graas
2007, 2008	GNSS Adaptive Antennas	Jiti Gupta
2008	Airborne Remote Sensing	Charles Toth
2009, 2010	Antenna-Induced Biases and Errors in GNSS Receivers	Jiti Gupta
2009	Personal Navigator Supported by Machine Learning Techniques	Dorota Grejner-Brzezinska
2009	GNSS Receiver Design Fundamentals	John Raquet
2009	Aviation Software Design and Certification Aspects	Maarten Uijt de Haag
2009	Ionosphere Effects on GPS Performance	Jade Morton
2010	Aiding Techniques for Optically-aided Inertial Navigation Systems	Michael Veth
2010	Sensors, Integration Techniques and Systems Used in Personal Navigation	Dorota Grejner-Brzezinska
2010	Coherent GPS/Inertial Integration	Frank van Graas and Maarten Uijt de Haag
2010, 2011	GPS Receiver Design	John Raquet
2010, 2011	Ionosphere Scintillation	Jade Morton
2011, 2012	Calibration of GNSS Receiver Antennas	Jiti Gupta and Andrew O'Brien
2011	Collaborative Navigation and Imaging Sensor Calibration	Dorota Grejner-Brzezinska and Charles Toth
2011	GNSS Interference	Wouter Pelgrum, Maarten Uijt de Haag and Frank van Graas
2012	Calculation of GPS PNT Solution	John Raquet
2012	High Accuracy GPS	Frank van Graas
2012	High Sensitivity GPS	Jade Morton
2012	Mobile Platforms: Concept, Sensors and Calibration Techniques	Dorota Grejner-Brzezinska and Charles Toth

COUNT SHORT COURSES 2007-2012

Software Receiver Technology
Jade Morton, *Miami University of Ohio*

Key components of software-based GPS receivers, including GPS signal structure analysis, simulated GPS signal generation, radio frequency front end design and implementation issues, weak GPS signal processing blocked-based GPS signal acquisition methods, code, carrier, and frequency tracking loop algorithms, and navigation data extraction using software digital signal processing implementations.

Network-Based RTK GPS and Precise Point Positioning
Dorota Grejner-Brzezinska, *The Ohio State University*

Network-based Real-Time Kinematic (RTK) and Precise Point Positioning (PPP) techniques, including algorithms and methods, as well as descriptions and performance assessments of the available orbital, timing and atmospheric corrections and models, with a special emphasis on the ionosphere modeling. Practical examples and demonstrations based on the Ohio CORS network data will be offered.

Alternative Navigation Techniques
John Raquet, *Air Force Institute of Technology*

Fundamental principles and current state of the art for a variety of non-conventional navigation techniques, including image-aided navigation, navigation using signals of opportunity (existing signals not intended for navigation), and pseudolite/beacon-based navigation. Case studies of a number of alternative navigation systems will be given.

Laser/Inertial Navigation
Frank van Graas, *Ohio University*

Integrated laser/inertial navigation for aircraft, urban and indoor applications. Navigation principles include waypoint, line-referenced, surface-referenced and feature referenced techniques in known, unknown and sparsely known environments, laser technologies, and tight laser/inertial mechanizations. Case studies will be highlighted for several applications, including aircraft precision navigation, autoland and urban navigation.

GNSS Adaptive Antennas
Inder J. Gupta, *The Ohio State University*

Fixed reception pattern antennas, controlled reception pattern antennas (adaptive antennas), adaptive weight algorithms, space-time adaptive processing (STAP), space-frequency adaptive processing (SFAP), effects of individual elements and element distribution, carrier phase and code phase biasing due to antennas and antenna electronics

Airborne Remote Sensing

Charles Toth, *The Ohio State University*

State-of-the-art in airborne surveying, including high-performance digital camera and LiDAR (laser scanning) systems, sensor system error modeling, sensor integration and system calibration, high-precision GPS/IMU-based direct georeferencing, system and application requirements, performance validation, and typical applications.

Antenna Induced Biases and Errors in GNSS Receivers

Inder J. Gupta, *The Ohio State University*

It is well known that antennas can cause biases in code phase and carrier phase measurements in GNSS receivers, and these biases are aspect dependent in that the biases vary from one satellite to the next in view of a GNSS receiver. This results in errors in the position and time solutions. Fixed reception pattern GNSS antennas can be calibrated for these biases in GNSS measurements. The same is not true for adaptive antennas which are needed for electronics protection in GNSS receivers. In this short course, we will describe the latest methods to estimate and mitigate adaptive antenna induced biases in GNSS receivers. The methods will include optimum filtering in GNSS antenna electronics as well as modification of GNSS receivers. Methods to include the platform effects in computer simulations and wave front simulators will also be discussed. The platform of interest will include rotor crafts.

Personal Navigator Supported by Machine Learning Techniques

Dorota Grejner-Brzezinska, *The Ohio State University*

This short course will discuss the design, implementation and the performance evaluation of a personal navigator prototype, which integrates GPS, IMU, digital barometer, magnetometer, and human pedometry to facilitate navigation and tracking of military and rescue ground personnel, developed at The Ohio State University Satellite Positioning and Inertial Navigation (SPIN) Laboratory. The goal of this system is to provide precise and reliable position/velocity/heading information of the individuals in various environments. In the open sky environment, either GPS alone, or a GPS/IMU system can facilitate the basic navigation functionality with the accuracy depending on the choice of GPS and IMU sensors. In confined and GPS-denied environments, however, the main challenge for a personal navigator is to implement a backup plan to maintain the navigation information in the absence of GPS signals.

A basic human locomotion model, considered as navigation sensor, works with the step length (SL) and step direction (SD) as primary parameters, which are adaptively estimated by a machine learning system. The major focus of this workshop will be on dead reckoning (DR) navigation supported by human dynamics during GPS signal outages. It is demonstrated that in the absence of GPS signals, the sensors used in the current prototype can sense the body locomotion in terms of its dynamics and geometry that represent an implicit function of SL and SD. The implementation of the DR system based on human dynamics is based on a combination of Fuzzy Logic (FL) and Artificial

Neural Network (ANN), integrated into a Knowledge-Based System (KBS). The knowledge-based system is trained a priori using sensory data collected by various operators in various environments during good GPS signal reception, and is used to support navigation under GPS-denied conditions.

GNSS Receiver Design Fundamentals

John Raquet, *Air Force Institute of Technology*

This course will provide an overview of GNSS receiver design, with the goal of providing a solid, conceptual understanding of all of the components of a standard GNSS receiver. Topics include the front end/down-conversion, Doppler removal, correlation, signal integration, code and phase tracking loops, signal acquisition, bit/frame synchronization, and pseudorange/Doppler/carrier-phase measurement generation. The use of software receivers will also be addressed.

Aviation Software Design and Certification Aspects

Maarten Uijt de Haag, *Ohio University*

This course discusses the design of safety-critical software for avionics systems using development and assurance standards. Topics include a brief overview of systems engineering practices and the avionics certification processes; system safety assessment processes required for safety critical applications such as avionics systems and the role of software and hardware within these processes; hierarchical software design, validation and verification of software requirements and code, and other supporting processes; finally, timing analysis aspects of the software aspects are discussed.

Ionosphere Effects on GPS Performance

Jade Morton, *Miami University of Ohio*

Ionosphere causes the largest error variable in GPS code and carrier phase measurements. This course will present the basic characteristics of the ionosphere structure, the nature of its complex refractive index, the code phase delay, carrier phase advance, and Doppler shift caused by signal refraction, amplitude and phase scintillation caused by signal diffraction, signal distortion caused by the dispersive medium, and signal bending. Current techniques that correct first order ionosphere error and assessment of higher order error will also be discussed.

Aiding Techniques for Optically-aided Inertial Navigation Systems

Michael Veth, *Air Force Institute of Technology*

This tutorial provides an introduction to alternative navigation techniques for navigation in GPS denied environments such as urban indoor and outdoor scenarios. The tutorial's primary focus is on the use of passive Electro-optical (EO) sensors such as vision cameras to aid an Inertial Navigation System (INS) and provide navigation performance similar to GPS. The discussion includes the basic principles of EO sensor integration with an INS; the feature-based techniques and optical-flow-based; feature extraction and tracking algorithms; and, the basics of integrated EO/INS mechanizations. A feature-based passive aiding method is addressed in details. In this case, the integration is performed using a tightly coupled Kalman filter. EO data are applied to estimate inertial drift terms in order to mitigate the drift in inertial navigation outputs. Inertial data are applied for robust feature matching. Experimental data collected in actual indoor environments are applied to demonstrate performance of EO/INS integrated approach. Prerequisites: Familiarity with basic Kalman filter and INS principles.

Sensors, Integration Techniques and Systems Used in Personal Navigation

Dorota Grejner-Brzezinska, *The Ohio State University*

Personal Navigation Assistant (PNA) also known as Personal Navigation Device (PND) is a portable electronic tool that combines positioning and navigation capabilities, usually provided by the Global Positioning System (GPS) and possibly by other navigation sensors, to facilitate navigation indoors or in GPS-challenged environments. For location determination of pedestrians in buildings, Wireless Local Area Networks (WLAN), or transponders or beacons installed inside the buildings, are increasingly used. Other indoor positioning systems include so-called Active Badge Systems (IR-based) and RF-based tagging. These methods can provide few-meters accuracy for indoor tracking and positioning. Robustness of the ultra wideband (UWB) signal to multipath fading and its high penetration capability makes it another technique suitable for indoor positioning. An alternative method used in indoor navigation is based on optical tracking systems, also referred to as image-based systems.

This short course will provide a review of the navigation sensors and techniques suitable for personal and pedestrian navigation, including selected Artificial Intelligence (AI) methods; note that personal navigation is understood here as navigation of military and emergency personnel, while pedestrian navigation refers to location/navigation/tracking of all other mobile users.

Following the technology overview, example design, implementation and performance assessment of a personal navigation system prototype, which integrates GPS, inertial measurement unit (IMU), digital barometer, magnetometer compass, and human locomotion model to support navigation and tracking of military and rescue ground personnel will be presented. Dead reckoning (DR) navigation is supported by a human locomotion model handled by AI techniques that form an adaptive knowledge-based system (KBS). The KBS is trained during the GPS signal reception, and is used to support navigation under GPS-denied conditions. System design, as well as a summary of the performance analysis in the mixed indoor-outdoor environments, with the special emphasis on DR performance, will be discussed.

Coherent GPS/Inertial Integration

Frank van Graas and Maarten Uijt de Haag, *Ohio University*

Integration of GPS carrier phase with inertial measurements. Overview of principles and techniques to combine cm-level integrated GPS carrier phase measurements with inertial delta-angles and delta-velocities. Topics to be covered include mechanization equations, accurate GPS delta position from carrier phase, batch versus sequential processing, time synchronization, lever arm correction, and fault detection.

GPS Receiver Design

John Raquet, *Air Force Institute of Technology*

This course will cover the fundamentals of GNSS receiver processing, including front end processing, code and carrier tracking loops, acquisition, bit/frame synchronization, and measurement generation. The theory will be presented, followed by a demonstration of the theory using a Simulink GNSS receiver using both simulated and real data. Use of the Simulink receiver will enable the students to see how various design decisions affect receiver performance and provide increased understanding of the internal operations of GNSS receivers.

Ionosphere Scintillation

Jade Morton, *Miami University of Ohio*

The ionosphere is a weakly ionized plasma bathed in the geomagnetic field. It is a dynamics medium with high variability in both space and time and is greatly affected by the solar activities. One particular important characteristic of the ionosphere is the irregular ionization structures which occur most frequently in the F layer of the magnetic equatorial and the polar regions. These irregular structures cause scattering and refraction of the radio waves traversing the ionosphere, leading to fast varying diffraction patterns on the receiver's antenna plane. The results are signal amplitude fading and random phase fluctuations which we collectively refer to as the ionosphere scintillation.

Ionosphere scintillation imposes serious challenges on the GNSS receiver carrier tracking loop design. For weak and mild scintillations, the sub-optimal tracking loop performance will produce larger position and timing errors. Under strong and severe scintillation conditions, a GNSS receiver will lose lock. In order to develop robust GNSS tracking algorithms to maintain quality tracking of the GNSS signals during ionosphere scintillation, it is critical to have a good understanding of the scintillation mechanisms and scintillating GPS signal structures. This short course will discuss these fundamental issues as well as strategies to improve GPS receiver tracking performance under scintillation conditions.

Collaborative Navigation & Imaging Sensor Calibration

Dorota Brzezinska and Charles Toth, *The Ohio State University SPIN Laboratory*

With the increasing demand for sustained navigation in GPS-challenged environment, the concept of multi-sensor integration, as GPS augmentation, has been developed and implemented over the past 10-15 years, followed recently by the concept of collaborative navigation, to further improve the navigation capability of a group of users. The objective of the latter is to develop a framework which will provide an optimum navigation solution for all network users (nodes). This workshop presents the concept and the algorithmic approach of a new technique for robust navigation in a dynamic sensor network using GPS, IMU and RF ranging signals among the network nodes. The improvements due to collaborative navigation relative to the individual navigation solutions will be demonstrated under various simulated and field conditions. In the tests performed to date, master and user nodes, equipped with different classes of sensors, ranging from tactical grade IMU and P-raging GPS (master node) to consumer grade IMU (user node), were defined in the network. The performance assessment, based on simulated and field data, demonstrates the ability of a networked group of users to operate under adverse conditions, in which an individual user would be impaired. The primary KF filter design, as well as several alternative statistical network-based estimation algorithms for collaborative navigation will be discussed. In addition, major research challenges are listed and discussed, in order to properly scope the level of research and implementation efforts required to design and implement a real-time collaborative navigation system.

As the number of sensors installed in various navigation platforms has increased, and imaging sensors are gradually introduced to support/complement conventional navigation sensors, the error budget calculations for the geolocation performance of the imaging subsystem has become more complex. The individual calibration of any imaging sensor is still of high importance, but the focus of calibration has already started shifting from individual sensor calibration to system calibration, in order to consider interrelationships between multiple sensors. In addition, in situ calibration is more increasingly used, and therefore, the error contributions of the in-scene objects also play a role and must be carefully considered. The imaging sensor calibration and combined error models of geolocation, including all navigation and imaging sensor modeling errors, inter-sensor calibration errors, and object space characteristics, will be discussed.

Calibration of GNSS Receiver Antennas

Inder J. Gupta and Andrew J. O'Brien, The Ohio State University ElectroScience Laboratory

It is well known that antennas can cause biases in code phase and carrier phase measurements obtained from GNSS receivers. These biases are direction dependent in that the biases vary from one satellite to the next. This results in errors in the position and time solutions. For precise geo-location and navigation, GNSS antennas need to be calibrated. In this short course, we will describe various approaches for calibration of GNSS antennas. These approaches will include the use of differential GNSS receiver measurements with a short baseline to a reference station as well as antenna radiation pattern measurements. We will include antennas with a single element as well as antennas with multiple elements. For multiple element antennas, we will discuss fixed reception pattern antenna (for a given satellite direction, the antenna weights are fixed) as well as controlled reception pattern antennas (CRPA) where antenna weights are adjusted on-the-fly to null the interfering signals and/or mitigate signal multipath. For CRPA, one needs the response of individual antenna elements over the frequency bands of interest to calibrate the antenna. We will discuss how the differential GNSS measurements can be processed to obtain this information.

GNSS Interference

Wouter Pelgrum, Maarten Uijt de Haag & Frank van Graas, *Ohio University Avionics Engineering Center*

This course will address the vulnerability of GNSS to Radio Frequency Interference (RFI) and provides an overview of various types and sources of RFI as relevant to GNSS, their effects on GNSS receiver performance, and methods to detect and mitigate their effects. Specific topics to be covered include the description and definition of wideband RFI and narrow-band RFI; continuous-wave (CW), modulated-wave, pulsed and noise RFI; intentional and unintentional RFI; and jamming versus spoofing. The course will continue with a detailed description of the effects of interference on the code, frequency and carrier-tracking loops for the various GNSS signal structures (i.e. signals on GPS L1, L2 and L5 and Galileo L1 and E5). Next, interference detection and mitigation strategies will be addressed including adaptive antenna designs, front-end designs, signal processing and advanced signal tracking techniques, aiding from external sources and integration with other sensors such as inertial sensors. Examples will be given of these techniques using data from a software-defined radio.

Calculation of the GPS PNT Solution

John Raquet, Air Force Institute of Technology

This course will cover the fundamentals of GNSS receiver processing to obtain the position, velocity and time solutions. Processing steps include measurement generation, measurement time of validity, ephemeris decoding, orbital calculations, troposphere propagation corrections, ionosphere propagation corrections (broadcast model and dual frequency), multipath mitigation, least squares solutions, geometric dilution of precision (GDOP) and time transfer (from GPS to receiver).

High Accuracy GPS

Frank van Graas, Ohio University

Overview of high precision GPS techniques, including relative, differential, wide area differential and precise point positioning. Single, double and triple differencing concepts, and ambiguity resolution. Discussion of code and carrier phase measurements and their error sources affecting high precision GPS applications; clock and orbit errors, zero-age-of-data (ZAOD) ephemerides, propagation delays, multipath, noise, antenna phase and group delays. Implementation considerations for high precision GPS applications.

High Sensitivity GPS

Jade Morton, *Miami University of Ohio*

In the past decade, high sensitivity GNSS gained increasing attention due to the need for navigation in physically and electromagnetically challenged operation environment such as urban canyon, indoors, under forest canopy, during ionosphere scintillations, etc. This tutorial will focus on high sensitivity algorithms for stand-alone GPS receivers as there will be other sessions devoted to integrated GNSS and non-GNSS navigation sensing systems. We will provide an analysis on the fundamental constraints on GNSS receiver sensitivity limit, followed by strategies to improve the receiver sensitivity at the acquisition and tracking stage of the receiver signal processing. Extended coherent/non-coherent integration approach will be discussed to enhance a receiver's acquisition sensitivity. The issue of self-interference or multi-access noise is investigated and a partitioned subspace project method will be presented to demonstrate its effectiveness in mitigating the self-interference often encountered in urban environment acquisition. Finally, an analysis of the error sources in receiver tracking loop will be presented to illustrate high sensitivity tracking loop design limitations and means to overcome these limitations.

Mobile Platforms: Concept, Sensors and Calibration Techniques

Dorota Brzezinska and Charles Toth, SPIN Laboratory, *The Ohio State University*

Mobile sensors, and sensors installed in mobile platforms, are rapidly becoming ubiquitous in navigation and mapping. On one side, this trend is fueled by the ever-increasing sensor performance, miniaturization and affordability. The other side is a clear advantage of sensor integration, such as more robust operation due higher levels of data redundancy and complementarity enabling better QA/QC and integrity monitoring, and better object space characterization in geospatial data acquisition and information extraction. A decade ago, imaging sensors were not even considered for navigation applications, but by now, imaging is an inherent component of almost all of the navigation systems developed for challenging applications, such as indoor or GPS-denied environments. In order to fully utilize the potential of these sensors, however, the proper characterization of the sensor geometric and radiometric features, broadly referred to as calibration, is essential. In particular, this is the case for less expensive sensors that are deployed in considerably increasing numbers.

The core technologies in navigation systems are the Global Positioning System (GPS) and inertial sensors, which provide seamless, highly accurate navigation in open-sky environment, where GPS signals are available. To facilitate navigation indoors or in GPS-denied environments, additional navigation and imaging sensors are required. An overview is provided of some of these technologies, such as, wireless local area network, IR and RF transponders, and ultra-wideband, as well as 2D and 3D active and passive imaging sensors. The various error models and the calibration options available to users are discussed.

As the number of sensors installed in various navigation platforms has increased, and imaging sensors are gradually introduced to support/complement conventional navigation sensors, the error budget for the geolocation performance of the imaging subsystem has become more complex. The individual calibration of any imaging sensor is still of high importance, but the focus of calibration has already started shifting from an individual sensor calibration to a system calibration, i.e., to consider interrelationships between multiple sensors. In addition, in situ calibration is more increasingly used, and therefore, the error contributions of the in-scene objects also play a role and must be carefully considered. The imaging sensor calibration and combined error models of geolocation, including navigation and imaging sensor modeling errors, inter-sensor calibration errors, and object space characteristics, are discussed.