12.215 Modern Navigation

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Course Overview

- The development of the Global Positioning System (GPS) started in the 1960s, and the system became operational in 1992.
- The system has seen many diverse applications develop in the last few years with the accuracy of positioning ranging from 100 meters (the civilian restricted accuracy requirement) to 1 millimeter (without the need for a security clearance!)
- In this course we will apply many of basic principles of science and mathematics learnt at MIT to explore the applications and principles of GPS and contrast it to conventional navigation.
- We also use GPS and other equipment in the class (and outside on Campus) to demonstrate the uses of this system

Class Expectations

- We will have some lab sessions during the course and there will be homework once every few weeks.
- There will be an open book final exam.
- Grading will be from the homework (60%), final exam (30%) and class participation (10%).
- It will be acceptable in this course to work together on homework with the aim of better understanding the material and to refer to other books and published material provided that these additional materials are cited appropriately in the homework.
- Each student should complete the homework separately.
- It is not acceptable to simply copy the homework of another student.

Course Topics: Coordinate Systems

- General Areas:
  - Coordinate systems on a deformable, non-spherical Earth.
  - Concepts of latitude and longitude as determined by the direction of gravity (astronomical latitude and longitude) and determined by the normal to an ellipsoidal shape (geodetic latitude and longitude).
  - Relationships between coordinates; concepts of polar motion and changes in the rotation rate of the Earth; rotations and translations between coordinate systems. Effects that need to be considered for different accuracy results and the accuracies that are achievable with GPS.

Course Topics: Navigation and Maps

- Principles of Navigation.
- Dead-reckoning, true and magnetic bearings
- Use of celestial bodies for navigation
- Common map projections
- Metrics for relating curvi-linear coordinates
- Spherical trigonometry

Course topics: GPS

- Principles of GPS.
  - Pseudorange and phase measurements.
  - Spread spectrum signal structure; basic concepts of signal analysis. Contributions of pseudorange and phase (geometric positions, clock errors, propagation medium, cycles ambiguity for phase).
  - Simple atmospheric and ionospheric delay models; use of dispersive properties of plasmas (ionosphere).
  - Use of differencing techniques in the analysis of GPS data.
  - Security systems on GPS satellites (selective availability and anti-spoofing) and their effects on navigation and precise positioning.

Course Topics: Statistics and Estimation

- Estimation procedures
  - Stochastic and mathematical models
  - Correlations and their interpretation
  - Statistical descriptions of dynamic systems
  - Propagation of covariance matrices
  - Statistics in least-squares estimation.

Course Topics: Applications

- Examples of applications:
  - aircraft navigation using GPS (comparison with laser profiling)
  - examination of real data to assess the limits of accuracy obtainable with GPS
  - applications in a variety of areas including precision farming; and intelligent vehicle navigation systems.

Course Topics

- Selection of topics is based on applying principles and mathematics to actual problems
- Each of the mathematical topics covered will be used in understanding how GPS works and how the system can be used.
- Homework exercises and data collection sessions in class will be examples of how these concepts are used

Specific Schedule (see web page)

#	Date	Topic
1	09/03	Introduction; coordinate systems (this lecture)
2	09/10	Latitude and Longitude definition
3	09/15	Height Definition
4	09/17	Spherical trigonometry Motion of Sun/Earth and astronomical position determination
5	09/24	Motion of Sun/Earth and astronomical position determination
6	09/29	Almanacs paper and on-line
7	10/01	Dead reckoning and conventional navigation

Specific Schedule (see web page

#	Date	Topic
8	10/06	Use of sextant and measurements in class (determine latitude and longitude of class room)
9	10/08	Sextant results. Analysis of results previously collected
10	10/15	Linear algebra (as applied to transformations)
11	10/20	Map projections
12	10/22	Curvilinear coordinates and metrics
13	10/27	Basic statistics need for estimation
14	10/29	Propagation of variances

Specific Schedule (see web page

#	Date	Topic
15	11/03	Least squares estimation
16	11/05	Correlations
17	11/12	Electronic distance measurement
18	11/17	Basics of GPS pseudo range
19	11/19	GPS carrier phase measurements
20	11/24	Neutral atmosphere propagation
21	11/26	Dispersive propagation delays

Specific Schedule (see web page

#	Date	Topic
22	12/01	Satellite motions
23	12/03	Basics of hand held GPS
24	12/08	Practical Aspects of GPS
25	12/10	Applications of GPS in different fields

Notes on Schedule

- Specific dates of some activities will depend on the weather conditions and the schedule may change
- Last year's lecture will be left on-line (updated versions will have 2003 date).
- Reference material for the class
  - During the lectures, web-based materials and books will be referred to.
  - The topics covered in this course are sufficiently diverse that no single text book is recommended.
  - All materials for the course will be made available electronically

Electronic Materials

- The class notes are made available in three formats:
  - Microsoft Power Point documents (original format)
  - PDF in black and white for printing
  - HTML web format (The exact look of these documents will depend on your Browser and OS. Even MS internet Explorer does not render MS html documents uniformly.
- Links in documents are only active in the power point and html versions.

Coordinate Systems

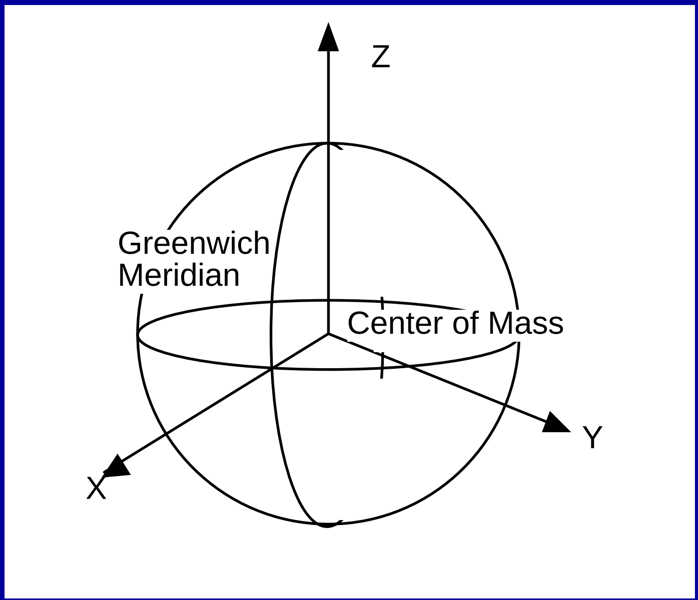
- Navigation: knowing where you are, where you want to go, and how to get there
  - Also useful: knowing how long it will take
  - To achieve these goals in a general way; a coordinate system is needed that allow quantitative calculations (Claudius Ptolemy, ~130AD)
- Reference Frames (describes coordinate system basis)
  - Definition
  - Realization (implementation of definition)

Coordinate system definition

- Definition of a 3D set of axes requires:
  - An origin (3 quantities)
  - An orientation (3 quantities)
  - A scale (1 quantity)

  (A "*Helmert*" transformation estimates these 7 quantities to relate two reference frames).
- For the Earth; terrestrial frames come in two forms:
  - **Geometric** (mathematical description)
  - **Potential field based** (gravity and magnetic)

Simplest Global Reference Frame



- Geometric: Origin at the center of mass of the Earth; Orientation defined by a Z-axis near the rotation axis; one “Meridian” (plane containing the Z-axis) defined by a convenient location such as Greenwich, England.
- Coordinate system would be Cartesian XYZ.

Simple System

- The use of this type of simple system is actually a recent development and is the most common system used in GPS.
- Until the advent of modern “space-based geodetic systems” (mid-1950s), coordinate systems were much more complicated and based on the gravity field of the Earth.
- Why?

Potential based coordinate systems

- The basic reason is “realization”: Until distance measurements to earth-orbiting satellites and galactic-based distance measurements, it was not possible to actually implement the simple type measurement system.
- Conventional (and still today) systems rely on the direction of the gravity vector
- We think in two different systems: A horizontal one (how far away is something) and a vertical one (height differences between points).

Conventional Systems

- Conventional coordinate systems are a mix of geometric systems (geodetic latitude and longitude) and potential based systems (Orthometric heights).
- The origin of conventional systems are also poorly defined because determining the position of the center of mass of the Earth was difficult before the first Earth-orbiting artificial satellite. (The moon was possible before but it is far enough away that sensitivity center of mass of the Earth was too small).

Next Lecture (next Wed not Mon)

- Definitions of Latitude and Longitude
  - Simple spherical system
  - Geometric ellipsoidal system
  - Astronomical system
- Relationships between these
- Impact of differences on precise navigation.