GPS Surveying

Natural Resources Management and Engineering 5555, Fall 2008

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Summary: This course will present the foundation information needed for a GNSS positioning professional to understand how their equipment works, with guidance to its proper usage.

Abstract: Global Navigation Satellite System (GNSS) positioning technologies are now main stream for surveyors and mappers at all levels. The appeal of GNSS positioning comes from its relative ease-of-use, thus potentially realizing time savings and increased profits. For example, GNSS positioning requires no traversing and no inter-station visibility. Furthermore, GNSS surveying equipment require no calibration and is relatively simple to use compared to a total station. Its operation typically consists of mounting the GNSS antenna either on a range pole or a tripod, powering up the receiver, and waiting a while. However, the simplicity of operation does not convey the depth of knowledge needed to use these technologies wisely. Unlike conventional positioning in which observations are intuitive and readily checked, GNSS observables are obscure and invisible, and their processing is too complex to be done, or checked, by the user. A surveyor is confronted with a "black box" whose output is complicated and often foreign. The purpose of this course is to give the participant the theoretical and practical background needed to understand and, therefore, apply GNSS positioning technologies in a manner that will yield defendable results of a desired precision and accuracy.

1. Introduction to GPS system description and technical design
    a. GPS system architecture (segments)
    b. Principles of system operation
    c. GPS ranging signals
    d. Satellite orbital configuration
    e. Current status of GPS
2. Ranging and Positioning
    a. Overview: resection requires…
        i. locations of three or more control points
        ii. accurate distances from control to point of interest
    b. Positioning
        i. To determine:
            1. Three positional unknowns (x, y, z)
            2. receiver's clock time bias
        ii. ranging equations
    c. orbits
        i. **Tycho Brahe**, and
        ii. **Johannes Kepler** discovered "Kepler's laws of planetary motion," being the laws that govern the motion of orbiting bodies, natural or otherwise.
        iii. Ellipses
            1. semimajor axis and flattening
            2. parameterization by latitude, time
            3. knowing the time gives me the coordinates on the ellipse.
        iv. "Keplerian elements"
            1. description
            2. the navigation message
        v. WGS 84 datum and coordinate system
    d. code-based range determination
        i. terminology
        ii. infer range from elapsed time
        iii. Time
            1. Atomic clocks

            2. UTC, GMT, GPS
            3. satellite time
            4. user time
            5. time biases
        iv. the range equation
        v. code ranging
            1. pseudo-random noise codes
            2. delay-lock loop
            3. application of the satellite clock correction
            4. pseudo-range
            5. C/A code vs. P code
    e. Navigation message
    f. carrier phase-based range determination
        i. waves
        ii. measuring phase
        iii. the integer ambiguity problem
        iv. fixed/float/autonomous solutions
3. Error Budget (non-blunder)
    a. System errors
        i. Satellite clocks
        ii. Orbits
    b. Geometry
        i. No SV's below the horizon
        ii. Dilutions of precision
        iii. Phase center variation
    c. Environmental
        i. Ionosphere
        ii. Troposphere
        iii. Signal-to-noise ratio
        iv. Elevation angle
        v. Multipath
        vi. Tree canopy coverage
4. Processing
    a. Precise Point Positioning
    b. Differential Correction
        i. Absolute positioning
        ii. Pseudo-range corrections
        iii. Base stations
        iv. WAAS, Beacon on a Belt, etc.
    c. Phase Differencing
        i. Relative positioning
        ii. Single, double, triple differencing
        iii. The need for control, CORS
        iv. Residuals
5. Real Time Kinematic and Real Time Networks
    a. How RTK works
    b. What is a Real Time Network?
    c. Expected performance and practical procedures
6. GNSS Hardware (purchasing considerations)
    a. Receivers
        i. Single/dual frequency
        ii. RTK
        iii. On-board Multipath rejection
        iv. Channels
        v. Constellations
        vi. Memory

        - vii. Output ports and timing controller features
    - b. Antennas
        - i. Phase center
        - ii. Antenna reference point
        - iii. Single/dual frequency
        - iv. Choke ring vs ground plane
    - c. Auxiliary equipment
        - i. tripods
        - ii. data collectors
- 7. Observation techniques
    - a. Single frequency vs dual frequency
    - b. Non-US constellations (GLONASS, Galileo, etc.)
    - c. Fieldnotes
        - i. Mark location and documentation
        - ii. Fixed height vs tripod antenna mounts
        - iii. Depth of the divot for heighting
        - iv. Wind and weather
        - v. Canopy coverage
        - vi. Site diagrams
    - d. Masks and trouble shooting, data collectors
    - e. Static vs. kinematic
    - f. Kinematic
    - g. Static
        - i. RTK, RTN
        - ii. Occupation duration vs expected precision
        - iii. Short static
        - iv. Long static
    - h. Occupation network design
        - i. NGS guidelines
        - ii. baseline length and control configurations
    - i. Occupation scheduling
        - i. redundancy
        - ii. multiple receivers running simultaneously and occupation strategies
        - iii. occupation duration and accuracy
- 8. Geodesy
    - a. WGS 84 vs NAD 83 vs ITRF
    - b. Epochs and plate tectonics, HTDP
    - c. NAD 27 and local surveys

<u>Grading</u>

3 midterm exams, 20% each	60%
assignments	10%
semester project	30%

Semester Project
All students are required to conduct fieldwork with the survey-grade GNSS receivers provided by the instructor or to use their own, if they have them. This fieldwork can include one or more of the following.

- Establishing horizontal and ellipsoid height coordinates on the CANR HARN network, or
- A project of your own, with permission of the instructor.

Fall Semester 2008

Known non-meet days:
Monday, Sept. 1: Labor Day
Friday, Sept. 5: Fieldwork

Sun Nov. 23 – Sun Dec. 1: Thanksgiving

Tentative Exam Schedule:
Monday, Sept. 29
Friday, Oct. 31
Friday, Dec. 5.

Surveying Disclaimer
"This map is for planning purposes only and contains no authoritative positional information."

Special Considerations
Any student who requires special arrangements in order to meet course requirements should contact the instructor to make necessary accommodations. Students should present appropriate verification from the University Program for Students with Learning Disabilities.

Reading Materials
There is not a required text for NRME 5555. But, read on…

[Van Sickle, Jan (1996) GPS for Land Surveyors. Ann Arbor Press, Inc., 209 pp.] is probably the best reference on the subject. This text contains most of the information covered in the lecture and is recommended.

[Hofmann-Wellenhof, B., Lichtenegger, H. and Collins, J. (1997) Global Positioning System: Theory and Practice. 4th revised ed., SpringerWien, NewYork, 389 pp.] is more technical and more in-depth than Van Sickle, covering the history of satellite-based surveying, geodetic reference systems, satellite orbits, the signal structure and observables, GPS surveying practices, mathematics for positioning, data processing, and more. This book is an excellent follow-on to Van Sickle and would be of interest to anyone who needs to know the details "behind the scenes."

[Leick, Alfred (1995) GPS Satellite Surveying. 2nd ed., John Wiley & Sons, Inc. New York, 560 pp.] This book is highly technical, presenting detail derivations of the adjustment statistics employed by the processing software for adjustment computations, details of orbits and time systems, electrical engineering details, GPS observables, the error budget, processing of phase observables, reductions and analytical cartography, and datum considerations. This book would be of interest to those who want to write software to process GPS data themselves, or to familiarize themselves with the details so as to conduct GPS research.

[Seeber, Günter (2003) Satellite Geodesy. 2nd ed., Walter de Gruyter, New York, 589 pp.] This book is not about GPS, per se. Rather, it is a general reference to satellite geodesy, of which GPS plays a major role, certainly. As such, this text covers details of the many reference coordinate systems (both space and time) used by GPS, some electromagnetic physics, orbital mechanics, and other topics not relevant to GPS. This text would be of interest to someone who is interested in satellite geodesy or wanted more coverage of the physics behind GPS.

[Strang, Gilbert and Borre, Kai (1997) Linear Algebra, Geodesy, and GPS. Wellesley-Cambridge Press, Wellesley, MA., 624 pp.] The first 274 pages of this book constitute a complete treatment of linear algebra such as needed by the most sophisticated adjustment computations. Pages 275-446 provide the statistical foundations for network adjustments, although this section of the book is entitled, "Geodesy." Pages 447-584 cover processing GPS data, including Kalman filtering. This textbook is written for people who want to know how to write software to process GPS signals.

Assorted Papers

Ananga, N. and Sakurai, S. (1996) The use of GPS data for improving local geoid determination. *Survey Review 33* (256): 334-338.

Borre, K. (2002) The GPS Easy Suite-Matlab code for the GPS newcomer. *GPS Solutions 7* (1): 47-51.

Chiusano, C. (2000) Urban Canyon GPS Surveys. *Professional Surveyor 20* (11): 22-32.

Deckert, C.J. and Bolstad, P.V. (1996a) Forest canopy, terrain, and distance effects on Global Positioning System point accuracy. *Photogrammetric Engineering and Remote Sensing 62* (3): 317-321.

Deckert, C.J. and Bolstad, P.V. (1996b) Global Positioning System (GPS) Accuracies in Eastern U.S. Deciduous and Confer Forests. *Southern Journal of Applied Forestry 20* (2): 81-84.

Even-Tzur, G. (2002) GPS vector configuration design for monitoring deformation networks. *Journal of Geodesy 76* (8): 455-461.

Featherstone, W.E. and Alexander, K. (1996) An analysis of GPS height determination in Western Australia. *The Australian Surveyor 41* (1): 29-34.

Frair, J.L., Nielsen, S.E., Merrill, E.H., Lele, S.R., Boyce, M.S., Munro, R.H.M., Stenhouse, G.B. and Beyer, H.L. (2004) Removing GPS collar bias in habitat selection studies. *Journal of Applied Ecology 41* 201-212.

Greenfeld, J.S. (2003) How long must we wait? The duration of GPS observations for short baseline measurements. *Surveying and Land Information Science 63* (2): 77-86.

Hajela, D. (1990) Obtaining centimeter-precision heights by GPS observations over small areas. *GPS World 1* (1): 55-59.

Herring, T. (2003) MATLAB Tools for viewing GPS velocities and time series. *GPS Solutions 7* (3): 194-199.

Hilla, S. and Cline, M. (2004) Evaluating pseudorange multipath effects at stations in the National CORS Network. *GPS Solutions 7* 253-267.

Hulbert, I.A.R. and French, J. (2001) The accuracy of GPS for wildlife telemetry and habitat mapping. *Journal of Applied Ecology 38* 869-878.

Meyer, T.H. (2002) Grid, Ground, and Globe: Distances in the GPS Era. *Surveying and Land Information Science 62* (3): 179-202.

Meyer, T.H., Bean, J.E., Ferguson, C.R. and Naismith, J.M. (2002) The Effect of Broadleaf Canopies on Survey-grade Horizontal GPS/GLONASS Measurements. *Surveying and Land Information Science 62* (4): 215-224.

Meyer, T.H. and Hiscox, A.L. (in press) Position Errors Caused by GPS HI Blunders. *Survey Review*

Milbert, D. G. (1991) Computing GPS-derived orthometric heights with the GEOID90 geoid height model. in Technical Papers of the 1991 ACSM-ASPRS Fall Convention, Atlanta, GA, pp. A46-55.

Milbert, D. G. and D.A. Smith (1996) Converting GPS Height into NAVD 88 Elevation with the GEOID96 Geoid Height Model. in Proceedings of GIS/LIS '96 Annual Conference and Exposition, Denver, CO, 681-692.

Næsset, E. (1999) Point accuracy of combined pseudorange and carrier phase differential GPS under forest canopy. *Canadian Journal of Forestry 29* 547-553.

Næsset, E. (2001) Effects of differential single- and dual-frequency GPS and GLONASS Observations on

Point Accuracy under forest canopies. *Photogrammetric Engineering and Remote Sensing 67* (9): 1021-1026.

Øvstedal, O. (2000) Single processed independent and trivial vectors in network analysis. *Journal of Surveying Engineering 126* (1): 18-25.

Remondi, B.W. (1985) Global Positioning System Carrier Phase: Description and Use. *Bulletin of Geodesy 59* 361-377.

Sigrist, P., Coppin, P. and Hermy, M. (1999) Impact of forest canopy on quality and accuracy of GPS measurements. *International Journal of Remote Sensing 20* (18): 3595-3610.

Smith, D. A. and Roman, D. R. NAVD 88 Helmert orthometric heights from NAD 83 GPS heights and the GEOID99 high resolution geoid height model. in 2000 Conference of the American Congress on Surveying and Mapping , Little Rock, Arkansas .

Snay, R.A., Soler, T. and Eckl, M. (2002) GPS Precision with Carrier Phase Observations: Does Distance and/or Time Matter? *Professional Surveyor 22* (10): 20-24.

Soler, T. and Snay, R.A. (2004) Transforming positions and velocities between the International Terrestrial Reference Frame of 2000 and North American Datum of 1983. *Journal of Surveying Engineering 130* (2): 49-55.

Talbot, N. C. (1993) Centimeters in the field: A user's perspective of real-time kinematic positioning in a production environment. in Proceedings of ION-GPS-93, Salt Lake City, UT, pp. 589-98.

Wilkie, R.C. (1995) Trivial Baselines as Redundant Measurements. *Surveying and Land Information Systems 55* (2): 99-108.

Yu, S.-B., Chen, H.-Y. and Kuo, L.-C. (1997) Velocity field of GPS stations in the Taiwan area. *Tectonophysics 274* 41-59.

Zilkoski, D.B. and Hothem, L.D. (1989) GPS satellite surveys and vertical control. *Journal of Surveying Engineering 115* (2): 262-281.