GPS Geodesy and Applications (GPS-GAP)—
An Internet Based Geodesy and GPS Educational Application

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ABSTRACT: Advances in GPS have outpaced the training infrastructure. To fill this void, surveyors are attending seminars or manufacturer-sponsored training courses. The courses do a satisfactory job at presenting fundamental concepts and foster basic proficiency with the particular manufacturer's receivers and software. Seminars, on the other hand, present no more than a general overview of theory. Sound theoretical principles cannot be taught in the short period of time allocated to either form of instruction. A detailed, mathematically based course of study is not possible via training courses or seminars: mainly because of time limitations, the mathematics powering the black box is either overly simplified or ignored. The University of Maine sponsors an Internet-based program—GPS Geodesy and Application Program (GPS-GAP)—which fills the need for mathematically rigorous courses of instruction for surveyors using GPS and other geodetic applications.

Introduction

The first GPS satellite was launched in 1978; initial operational capacity for civilian use was achieved in 1993. Since then GPS has revolutionized the way surveyors work. It is the first tool available to surveyors that frees them from the limitations of line of site. As GPS hardware and software has become easier to use, it has made it possible for surveyors to perform tasks that previously could only be done by experts with years of special training and education. Surveyors who started when transit and the chain were the norm are now using space-based surveying methods. However, even surveyors who graduated with four-year degrees less than a decade ago may not have received rigorous education in all the issues involved in GPS surveying. It is precisely that lack of specialized training and education that has fostered a situation where many surveyors are using tools they do not truly understand.

Advances in GPS have outpaced the training infrastructure. To fill this void, surveyors are attending seminars or manufacturer-sponsored training courses, neither of which is intended for teaching sound theoretical principles in mathematics. Another option gaining in popularity is distance learning via the Internet. One such program is University of Maine's GPS Geodesy and Application Program (GPS-GAP; http://www.gnss.umaine.edu) taught by Dr. Alfred Leick. This asynchronous, Internet-based educational program provides instruction in least squares adjustments, geodesy, and GPS. Through GPS-GAP, one can obtain undergraduate and graduate level credits toward a degree; however, there is also the non-credit (NC) option, which enables practicing surveyors to obtain continuing education credits. As a practicing surveyor, I will concentrate on the non-credit continuing education option. Those interested in obtaining college credits should consult the web page or contact Dr. Leick via the web address given above.

Being a former student of Dr. Leick's, I was asked to take the first six courses as a test student and provide feedback on the presentation and material. In the interests of full disclosure, let it be known that I was allowed to take the courses free of charge in return for my feedback.

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GPS-GAP for Surveyors

Six courses are currently available, with three more planned for release in the fall of 2005. The courses are available during the spring and fall semesters at the University of Maine. Currently taught are:

GPS 401: Adjustments with Observation Equations

GPS 402: Adjustment Algorithms
GPS 403: Quality Control with Adjustments
GPS 570: Fundamentals of Satellite Positioning
GPS 571: Precise Point Positioning
GPS 572: Precise Relative Positioning

The courses to be launched in the fall are:

GPS 441: Three-Dimensional Geodetic Model
GPS 442: Ellipsoidal Surface Model
GPS 443: Conformal Mapping Model

Each course has its own home page; Figure 1 shows the home page for GPS 572. From the course page, the student can proceed to the lecture and lab pages. Additional links for extra reading material or to the review questions for quizzes and the final exam are also provided.

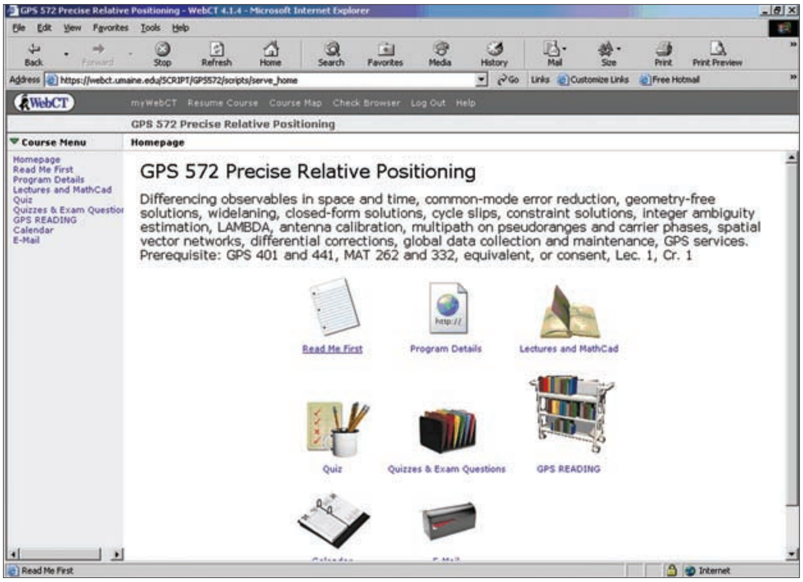

Figure 1. GPS 572 home page. Links on the course home page provide access to all course resources.

Class presentation is through the web browser. For specific browser and software requirements, see the GPS-GAP web site at http://www.gnss.umaine.edu. The class format is:

- Nine lectures of about an hour given via streaming audio with synchronized view graphs;
- Demonstrations of the principles expounded in the lectures using Mathcad based labs; and
- Testing through four quizzes and a comprehensive final exam.

The required text for all the courses is Leick's *GPS Satellite Surveying* (3rd ed.). As in a traditional classroom setting, the lectures expound on the text and aid in the understanding of the subject matter—the mathematics and physics needed to understand GPS. No gross simplifications are permitted; students are exposed to as much math as is needed to understand the processes, and, unlike at a one- or two-day seminar, they have time to delve into details. Mathcad takes much of the sting out of the calculations, while maintaining the necessary mathematical rigor.

While the lectures and Mathcad demonstrations are comprehensive and well presented, some concepts may be more difficult than others, requiring specific answers to specific questions. At such times, students can contact the professor via e-mail. However, since the purpose of the GPS-GAP program is to automate the instruction process as much as possible, the number of direct e-mails a student is allowed to send is limited to ten, but with nine lectures per course, this should be more than adequate. I found that I often answered my own questions while researching and writing out questions.

The asynchronous nature of the classes means that all the lectures are available any time during the duration of the course. Figure 2 illustrates the format of the lectures. Using the Rewind, Back, Pause and Forward buttons, the student controls the progress of the lecture. The student can replay the audio explanation for a view graph as many times as needed to grasp a difficult concept or repeat the entire lecture, if desired. The audio can be paused and resumed as necessary to take notes. Using the numbered links under the buttons, the student can jump directly to the desired viewgraph.

Mathcad demonstrations of concepts follow most lectures. Figure 3 shows a typical Mathcad demonstration. Mathcad (http://www.mathcad.com) is a symbolic math program enabling the student to concentrate on the theory being studied instead of the minutia of individual calculations. Mathcad has its own programming language. This language has been used to program everything from simple matrix manipulations in GPS 401 to double difference integer ambiguity resolution in

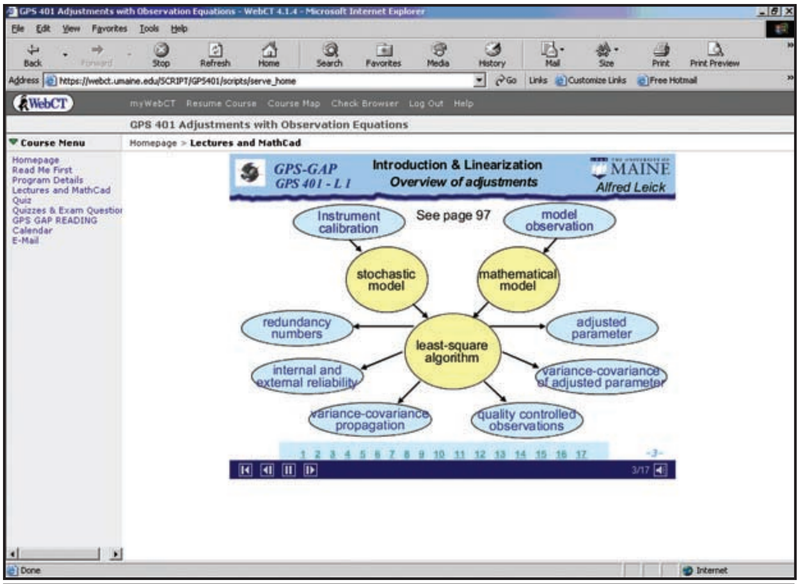

Figure 2. Lecture view graph. Controls at the bottom of the view graph allow the student to control the progress of the lecture.

GPS572. The Mathcad demonstrations run on the Mathcad application server at the University of Maine, so there is no need for the student to have his own copy of Mathcad. However having one's own copy of Mathcad makes it much easier for the student to follow the demonstrations and experiments. The source code for the algorithms is presented in the labs for the student to copy and for experimentation. Audio explanations accompany each Mathcad demonstration. As with the lectures, the audio can be paused or rewound to help with difficult concepts. Presently, the Mathcad demonstrations are not interactive; plans are in place to allow students to manipulate the inputs to the various algorithms. Once these enhancements are implemented, students will be able to experiment with the inputs online and instantly see the effects of changing the datasets.

Four quizzes and a comprehensive final exam have been designed to test the students' progress. Review questions are available for each quiz by way of links on each course's home page. It is while studying for these quizzes and the final exam that the real learning takes place. Quiz questions are drawn from the lectures, Mathcad demonstrations, and the text. Quizzes and final exams are taken online. Students have 50 minutes to complete a 50-question multiple-choice quiz or final exam, the questions being randomly selected from a larger pool of review questions. Upon completing a quiz or the final exam, the results are tallied and presented to the students with all the questions marked for review. This provides instant feedback. Students are expected to demonstrate a basic level of comprehension before being given credit for the course. Progress evaluation via quizzes and final examination is another feature distinguishing GPS-GAP from a typical continuing education seminar.

When the full set of courses is released, one third of the courses will deal directly with least squares adjustments. In *GPS Satellite Surveying*, two chapters are devoted to adjustment theory and practice. Chapter 4, Least Squares Adjustments, is the longest chapter in the text. This chapter is the basis for GPS 401, GPS 402, and GPS 403. Chapter 8, Network Adjustments, is referred to in lecture eight of GPS 572, which explores the adjustment and quality control of GPS baselines in geodetic networks.

The adjustment courses cover more theory than many dedicated least squares adjustment texts and could stand on their own, if one were not interested in GPS processing. Topics discussed range from the formation of the observation equation model in GPS 401 to more esoteric concepts such as redundancy numbers, absorption, and minimally detectable blunders in the advanced adjustment course GPS 403. All these courses are a worthwhile investment for surveyors attempting to interpret the results of their least squares adjustment program. The importance of least squares in the development of a sound understanding of GPS processing cannot be overstated. The principles of least squares adjustment, and its derivative the Kalman Filter, are threads that run through all the courses; time after time, GPS-specific courses will refer to a least squares adjustment principle to derive a result.

The GPS-specific courses are comprehensive. Starting with coordinate systems, orbits and signal structures in GPS 570 and culminating with ambiguity fixing in GPS 572, these courses cover every major topic in satellite positioning with GPS. Error sources that cancel in relative positioning, do not cancel in Precise Point Positioning (PPP); GPS 571 takes a hard look at such error sources as the troposphere and iono-

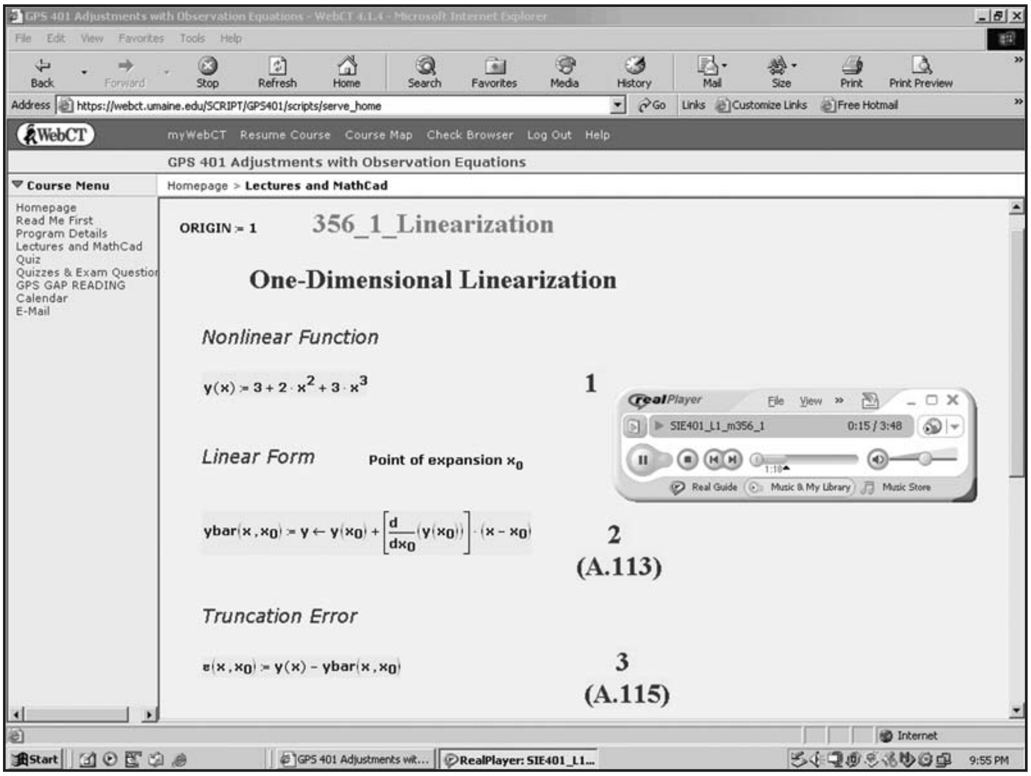

Figure 3. Mathcad demonstration. Detailed Mathcad calculations accompanied by audio explanations, provided by realPlayer streaming audio, illustrate the concepts covered in the lectures.

sphere. Other topics include, but are not limited to, solid earth tides, ocean loading, and antenna phase-center variations. Actual PPP calculations are demonstrated in Mathcad using the Kalman Filter. The single-difference, double-difference, and triple-difference observables are tackled in GPS 572, where wide-lane and extra wide-lane observables are presented as a means of expediting ambiguity fixing. The highlight of GPS 572 is a Mathcad implementation of the Least Squares Ambiguity Decorrelation Adjustment (LAMBDA) algorithm, which is employed to fix double-difference integer ambiguities using actual GPS observations. Progressively smaller data sets are processed until only one epoch of data is used to fix double-difference integer ambiguities. The Russian GLObal NAvigation Satellite System (GLONASS) is introduced and contrasted with GPS. GLONASS processing is presented in detail, including combined GPS and GLONASS processing. The final lecture in GPS 572 summarizes the three GPS courses. After listening to this lecture, the student may be surprised to realize how much material has been presented. Once students complete these three GPS-specific courses, GPS processing ceases to be a black box technology, rather, a coherent application of least squares adjustment and physics.

The GPS-GAP distance learning courses are an excellent investment of time for surveyors who are serious about understanding their GPS tools. Making the material available on the Internet makes it much easier to fit the courses into almost any schedule. ■