Photogrammetry Instruction in a Civil Engineering Technology Curriculum.

Dr William H. Sprinsky
Pennsylvania College of Technology

Abstract

At the Pennsylvania College of Technology, we feel that tools of project design and management such as Geographic Information Systems (GIS) should be taught along with the more usual subjects in a Civil Engineering Technology curriculum. Such a tool is Photogrammetry, where the actual image of the ground, ortho-rectified to remove distortion, due to lens irregularities, film distortion and primarily to displacement of image because of elevation differences, is used as a layer in a GIS. Students learn the use of aerial imagery to construct coordinated Digital Terrain Models (DTM), from which mapping can be derived for project planning and construction management.

Our portfolio includes associate's degrees in both Civil Engineering Technology (CT) and Surveying Technology (SUT), both ABET accredited, and a new bachelor's program in Civil Engineering Technology with emphasis in Surveying (BCT). Photogrammetry is a required course in both the SUT and BCT degrees and can be taken as an elective in the CT program. The use of GIS is taught to students in all degrees. A more advanced course in Land Use/Information is part of the BCT program.

The Photogrammetry course is in the lecture/lab format, where theoretical discussions are reinforced by assignments on both our analog Kelsh and analytical Zeiss P-3 plotters. The assignments require teams of two students to perform relative and absolute orientation/scaling on the Kelsh plotter to produce a manuscript with contours from which a fair drawn map is made. The same teams perform interior, relative and absolute orientation/scaling on the Zeiss P-3 analytical plotter. Their product, a DTM, is then handled through ASCII and .DXF file protocols in much the same way as ground surveying data to produce a fair drawn map with contours and scale in the appropriate State Plane Coordinate System (NAD83).

This paper discusses instruction and performance of laboratories in this course.

Introduction

At the Pennsylvania College of Technology, we feel that tools of project design and management such as Geographic Information Systems (GIS) should be taught along with the more usual subjects in a Civil Engineering Technology curriculum. Because so much of the work on any Civil Engineering project depends on a knowledge of the land both before and after a project, all of our programs emphasize point positioning through Surveying or Photogrammetry, so that our students understand the strengths and weaknesses of the tool at hand. These strengths and weaknesses include accuracy, time to perform the work and cost of point positioning. A tool such as photogrammetry, where a byproduct of the positioning is an actual image of the ground, ortho-rectified, can be used as a layer in a GIS or a means of assuring client understanding of the sometimes arcane processes involved in the project itself. After gaining a working understanding of traditional ground surveying for point positioning, our students learn the use of aerial imagery to construct coordinated Digital Terrain Models (DTM), from which mapping and site plans can be derived for project planning and construction management.

Our portfolio of curricula includes associate's degrees in both Civil Engineering Technology (CT) and Surveying Technology (SUT), both ABET accredited, and a new bachelor's program in Civil Engineering Technology with emphasis in Surveying (BCT). Photogrammetry is a required course in both the SUT and BCT degrees and can be taken as an elective in the CT program. The use of GIS is taught to students in all degrees. A more advanced course in Land Use/Information is part of the BCT program. The structure of our curricula can be seen on the College's website, http://www.pct.edu.

Our Photogrammetry course (CET 344) is either a second or third year subject, depending on the degree being pursued. It is a three credit offering in the lecture/lab format, where theoretical discussions are reinforced by assignments on both our analog Kelsh and analytical Zeiss P-3 plotters. Plotter lab assignments require teams of two students to perform relative and absolute orientation/scaling on the Kelsh plotter to produce a manuscript with contours from which a fair drawn map is made or interior, relative and absolute orientation/scaling on the Zeiss P-3 analytical plotter. For the analytical plotter, their product, a DTM, is then handled through ASCII and .DXF file protocols in much the same way as ground surveying data to produce a fair drawn map with contours and scale in the appropriate State Plane Coordinate System (NAD83).

Why Surveying and Photogrammetry?

Originally, Civil Engineering programs of all types included instruction in many of the "trades" areas such as plumbing and electricity. These have been dropped from the curriculum, in part in recognition of the role the licensed subcontractor plays in construction projects and inspections. Until fairly recently, surveying was a staple of many Civil Engineering programs. This has changed as well, with surveying and mapping curricula being a rare offering. Licensed subcontractors do not "sign off " on surveying and point positioning, in general. The licensed surveyor usually verifies the property boundaries and offsets required by law. The majority of the rest of the point positioning work, to include layout of all types and topographic surveys, is done by what the US Department of Labor would classify as a "skilled laborer," a worker knowledgeable in the use of surveying equipment but not licensed. With the advent of GIS as a management tool and value-added benefit to the client, understanding these skills has become important to the Civil practitioner. It is the practitioner who orders the work, specifies the accuracy of the work, and ultimately applies the work to design and construction. We believe that a knowledge of point positioning techniques at a deeper than "introductory" level best equips our students for professional practice. Our Civil programs emphasize point positioning and mapping for that reason. Feedback from former students and employers reinforces this belief. Also this coursework gives our students an additional option. In Pennsylvania, the surveying and mapping coursework in our program allows our students to qualify for the licensure exam as a Surveyor.

Teaching Approach

Photogrammetry is the process of measuring on imagery, generally to obtain geographically referenced object locations. When the term stereo-photogrammetry is used, it refers to measurements made in the overlapping area of two adjacent images. This technique, along with classical surveying and satellite (GPS) positioning, is becoming a more important part of the modern Civil Engineer's tool of Geographic Information Systems. We integrate this type of mapping with GPS satellite surveying and ground survey applications we currently teach so students have an appreciation of the continuum of mapping from all sources**.** Photogrammetric positioning has the distinct advantage of providing not only positional information but also an image of the area, helping both the engineer and the client understand relationships between a proposed project and the land it effects.

At Penn College, we teach Photogrammetry in both our Surveying associate's (SUT) and Civil Engineering Technology bachelor's (BCT) programs. We have divided the photogrammetric techniques into analog and analytical photogrammetry. In analog photogrammetry, as the name implies, the position and attitude of the camera at the moment of exposure are recreated. At the instant of exposure, light rays reflected from all objects enter the lens of the taking camera and create the image. In analog stereo-photogrammetry, projectors supply the light rays that go through the image. Once the attitudes of the taking cameras have been recreated, light rays from two overlapping images intersect at a point in the model space, recreating the geometry of the ground. In analytical stereophotogrammetry, this recreation of light ray intersections is done mathematically, generally modeled in equations of the transformation of image (x,y) coordinates to ground (X,Y,Z) coordinates modeled to reflect the geometry of the instant of exposure. Unlike analog stereo-photogrammetry, no light ray intersections are created. Instead the intersections are solved for mathematically to determine the (X,Y,Z) coordinates of the object being mapped. Our students currently study both analytical and analog photogrammetry, although analog has been replaced in industry with an all-analytical and often automated approach. We plan to continue with analog curriculum and devices. Retaining the analog devices helps students understand the physical meaning of the orientation angles "tip", "tilt" and "swing". Students need this to appreciate the analytical approach of modeling those motions mathematically with more than an intellectual understanding. Our curriculum offers the understanding of analytical approach by requiring students to perform all necessary steps to produce a digital terrain model and engineering scale map. The curriculum emphasizes adjustments of observations and their interpretation. Our students will be able to recognize what tool best provides a product used in the Civil Engineering design.

To do this, we build on the lessons learned by students in their previous surveying courses. See Sprinsky, 1997 [1] for the initial approach to construction of large scale mapping. We also emphasize the continuum of the large scale mapping task by using photogrammetry to obtain the (X,Y,Z) coordinates of points in the DTM, as students did in their previous ground surveying classes. From the construction of the DTM onward the process is identical. An additional product of the Photogrammetry instruction and practice is an understanding of the role played by

ASCII and .DXF files in the integration of products from a number of very different software packages. As well, the students learn to judge each step of the process for quality and fidelity to the ground they are portraying. Many of the steps the students perform would be automated in a commercial operation. We prefer to interrupt this automation at key points so students can make human judgments on the success of the operations.

Our classroom instruction contains the traditional instruction in single and multiple image geometry, the nature of the photogrammetric observation, and the association of image (x,y) coordinates with ground (X,Y,Z) coordinates. Concepts such as use of the CAD, scale and State Plane Coordinates are already familiar to students from previous coursework (CET113, CET122 and CET123) and need only be reviewed. The transformations that occur in interior orientation using a six parameter affine procedure are covered in detail. Students have already mastered the "rigid body" three parameter affine and "conformal" four parameter affine in CET123. An understanding of how to judge the success of the interior orientation process comes from their own work on the Zeiss P-3 Analytical Plotter and class examples and homework. The Colinearity Equations are studied in detail, again through theoretical discussions, homework with "canned" numbers and their plotter experience. It becomes less theoretical when the students do their assigned task on the Kelsh Analog Plotter, and see what a wing up, swing or nose up motion really does to the projected images. Additional instruction in preliminary flight planning and computing the approximate cost of the project are also included.

Laboratory Organization and Student Tasks

To illustrate and reinforce classroom instruction, groups of two students perform relative orientation absolute orientation/scaling and production of a map manuscript on our Kelsh analog Plotter. They also perform interior orientation, relative orientation, absolute orientation/scaling and DTM creation with our Analytical Plotter. For completeness, these operations will be described. Interior Orientation is the process of transforming image coordinates for the two dimensional image into the fiducial coordinate system of the calibrated metric photogrammetric camera. This step is performed in the analytical task but not in the analog process, due to the age and delicate nature of the equipment. Relative orientation is the step which either physically (analog procedure) or mathematically (analytical procedure) models the position of the taking camera in both of its exposure positions with respect to one another. After both of these orientations are performed, the model is then related to the ground in absolute orientation/scaling.

In our lab periods, it would be ideal to assign each student group to one of a room full of plotters. Unfortunately, the College owns only two analog devices and one analytical device. In the standard semester, the students would spend 45 hours at these processes. With our limited equipment, student groups are assigned a two week period in the semester to each of the plotters. Aside from an initial lab that determines student's ability to see stereoscopically, the labs are "as arranged" by the instructor and students.

For the analog task on the Kelsh plotter, diagramatically portrayed in figure 1, students start at the relative orientation step for a stereo image pair already installed in the machine. When they think that they have accomplished this task, commonly known as removal of y parallax, they call the instructor, who verifies that any residual parallax is small. If it is not small, students continue to do the iterative relative orientation procedure until it is. Once this task is mastered, they students perform approximate scaling and, using a control diagram showing the (X,Y) location and elevation of ground control points, level the model so that elevations read from the position of a light dot on the platen of a light table are reasonably close to their ground values. The instructor does a check at this point and if the student group is successful, they adjust the final scale of the model to match the control diagram. Again the instructor checks this step and assigns an area in the model to be mapped. This project usually takes approximately twenty hours, with an additional one or two hours spent on a light table drafting the "fair drawn" final graphic.

The analytical task is somewhat different. Students perform interior orientation and have their work checked. After the results of this step have been approved by the instructor, they continue to the relative orientation step. Rather than an iterative step, this procedure involves a solution from placing a measuring mark on the same location in the overlap area in two overlapping images. Additional points are added to strengthen the solution of the relative orientation procedure. The results of this procedure are checked and, if successful, the student group continues on to a much simplified absolute orientation/scaling procedure. Here, the measuring mark is placed in a number of control points, whose (X,Y,Z) position is assumed "known." Residuals at ground scale between the known coordinates and their photogrammetrically determined positions are examined. If these residuals are sufficiently small, a mapping area is assigned. At this time the usual procedure is to associate the analytical plotter output with a CAD and do linework directly. Due to time constraints and the previously mentioned objective of unifying this procedure with that of the ground surveying mapping, students use a "pass point" procedure to read a number of new points, identified by label, in ground (X,Y,Z). These are recorded as a series of files and with pencil and paper to describe the nature of the point. Once this data is acquired, it is transferred to one of our Intergraph workstations and the mapping process is done as described in Sprinsky, 1997, [1], to produce a planimetric graphic with contours. See figure 2, a plot of points by (X,Y) position with label. From this plot and the students' descriptions, noted when the points were positioned, a rough planimetric map is made, used for checking and a guide to the CAD placed linework. Contours are added using an Intergraph enhancement called Modeller, a ground scale grid is added using an Intergraph Gridding enhancement, a legend box is constructed in the underlying CAD, Microstation '95 and the final product plotted at "D" size, see figure 2. We estimate that this project will take approximately 15 hours on the plotter and another 5 on our workstations.

Future Changes in CET344, Photogrammetry

Today, analytical plotting capability may be as near as the engineering work station and very inexpensive. New procedures with digitized imagery, called softcopy photogrammetry, are currently on the market. Recent imagery for preliminary project estimates may be available from State and Federal sources inexpensively. To keep the curriculum in CET 344 current with these modern applications that illustrate classroom instruction, we plan to add some additional hardware and software that accomplishes softcopy photogrammetry. While classroom instruction can include softcopy procedures, only hands-on experience with the technique will drive home the advantages of this procedure, compared to standard analytical photogrammetry. Specifically, we plan to request the following software and hardware:

The Intergraph SSK suite, which includes:

ImageStation Photogrammetric Manager – provides photogrammetric project setup, translators, and data entry functions.
ImageStation Model Setup – Manual Interior, Relative, and Absolute Orientation functions.
ImageStation Digital Mensuration – has the same functions as Model Setup, plus advanced automatic functions for Interior and Relative Orientations, multi-image measurement, and on-line bundle adjustment.
ImageStation Stereo Display – Stereo display engine, including Intergraph's ImagePipe™ technology which provides in-line image preprocessing, real-time epipolar resampling, stereo roaming, and software JPEG image compression and decompression.
ImageStation Feature Collection – provides the interface for table driven feature definition and collection.
ImageStation DTM Collection – Intergraph's semiautomatic interface for DTM collection, automatic contour and TIN surface generation and editing.
ImageStation Base Rectifier – provides the stand-alone functions for image orthorectification.
I/RAS C – advanced image display and manipulation, plus mosaicing of orthophotos.

The hardware supplied with the program is the ImageStation SSK hardware. It includes:

Intergraph's Intense 3D™ 2200S Stereo Frame Buffer
CrystalEyes® Stereo Kit – including glasses and emitter
3D Mouse – provides integrated Z-axis control
Software runtime protection lock (dongle)
The workstation upon which these hardware/software additions will run is a suitably configured Intergraph TDZ2000GL2.

This equipment and software will enable us to perform photogrammetric reductions on a digitized stereo model to construct a digital terrain model from which a map can be extracted, using procedures discussed in Sprinsky [1], 1997. This modern equipment and software further reinforces the connection between classic surveying and photogrammetric techniques in projection of mapping. Again, it illustrates the theme of point positioning and mapping to compliment what we already do with ground and GPS surveying.

Summary

Photogrammetry is the process of measuring on imagery, generally to obtain geographically referenced object locations. This technique, along with classical surveying and satellite (GPS) positioning, is increasingly a part of the modern Civil Engineer's tool of Geographic Information Systems. Photogrammetry provides the distinct advantage of positional information and an image of the area, helping both the engineer and the customer understand relationships between a proposed project and the land it effects. Penn College teaches Photogrammetry in both our Surveying associate's (SUT) and Civil Engineering Technology bachelor's (BCT) programs. Students currently study analog Photogrammetry, which has been replaced in industry with an all-analytical approach. We plan to continue with analog curriculum and devices for pedagogic reasons, along with giving students capability and hands-on experience in analytical stereo-photogrammetry. Retaining the analog devices helps students understand the physical meaning of the orientation angles "tip", "tilt" and "swing", describing the attitude of the taking camera at the instant of exposure. Students need this to appreciate the analytical approach of modeling those motions mathematically. The curriculum offers the understanding of analytical approaches, eventually including softcopy photogrammetry, by requiring students to perform all necessary steps to produce an engineering scale map, either directly from the analog procedure or through manipulation of a digital terrain model, in the analytical procedure. The curriculum emphasizes adjustments of observations and their interpretation. Our students will be able to recognize what tool best provides a product used in the Civil Engineering design, based on required accuracies and approximate costs. Students will also be capable of providing future customers with the start of a facilities management system for life cycle planning, particularly when used in association with a Geographic Information System (GIS), Sprinsky,1997 [2].

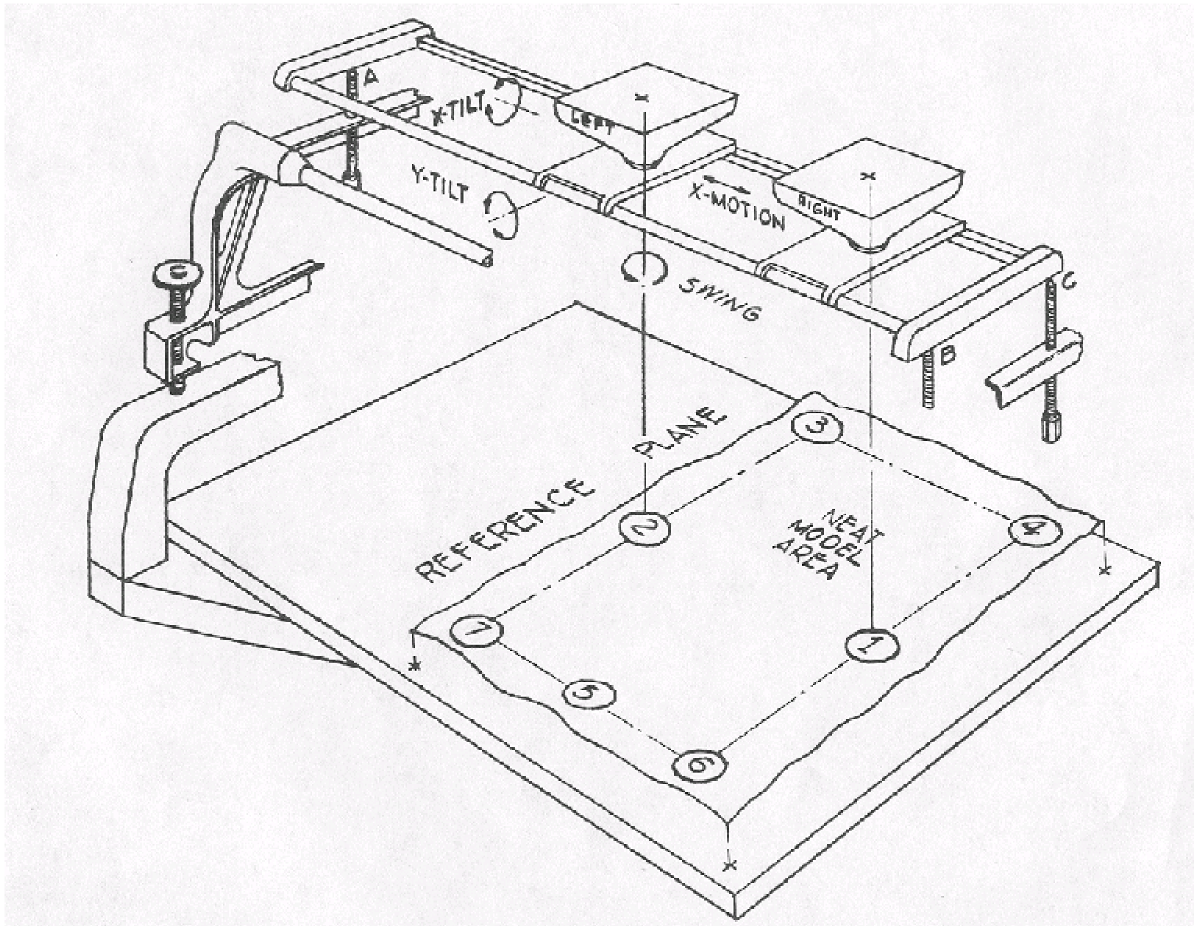

Figure 1a The physical layout of a kelsh Plotter, as seen from above. The devices marked "left" and "right are the projectors in which the images are mounted. The motions "x-tilt" and "y-tilt" are misleading. The actual attitude controls for the projectors are better appreciated in Figure 1b.

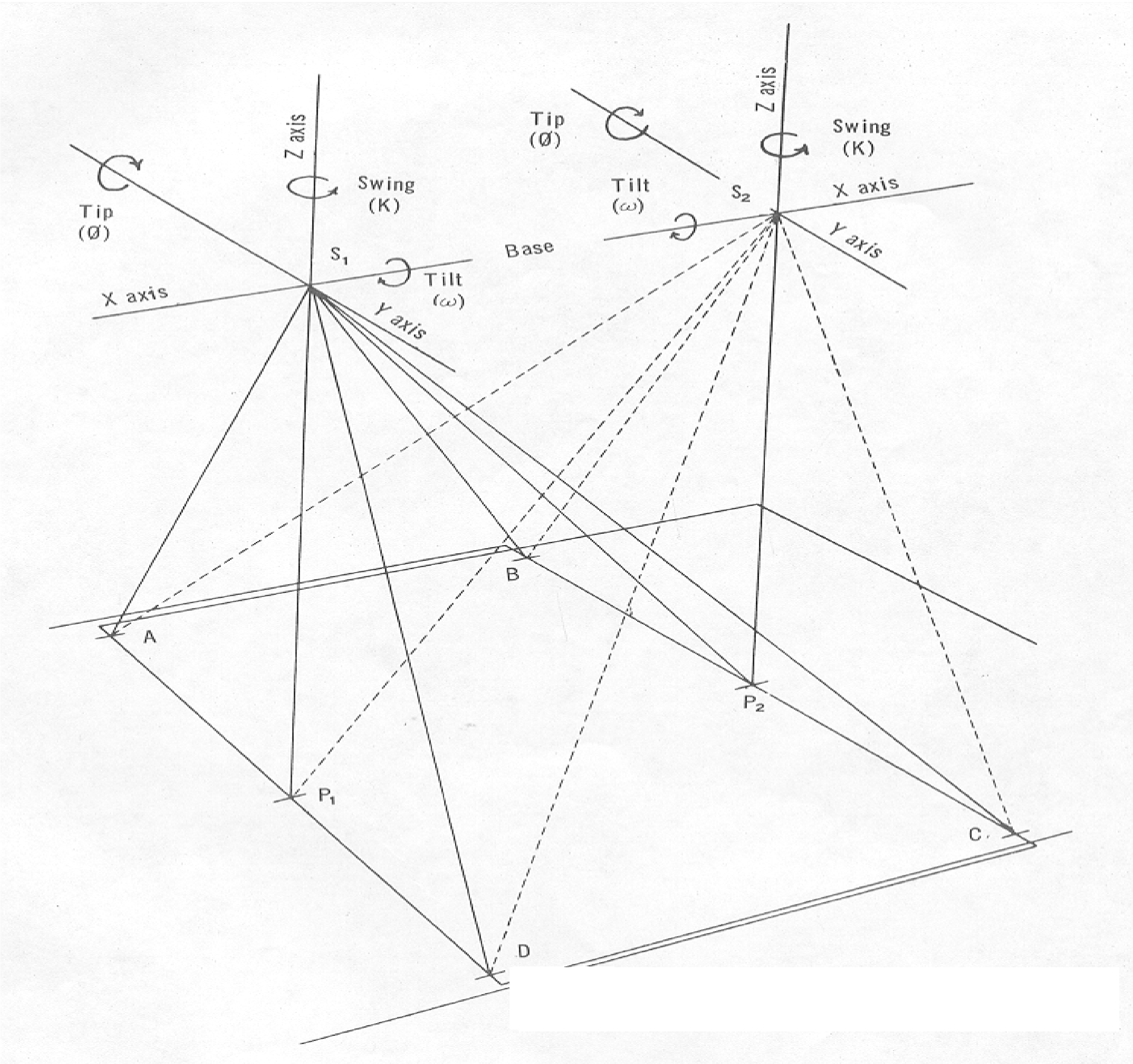

Figure 1b The attitude controls that the operator uses in accomplishing relative and absolute orientation are illustrated here. The "tip", "tilt" and swing controls model the attitude of the camera at the moment of exposure.

Gp6.d03 - Notepad

File Edit Search Help

00013	84121.162	98073.080	5751.840	U
00023	84135.504	98073.364	5751.904	U
00033	84136.911	98014.174	5750.079	U
00043	84120.185	97996.717	5750.079	U
00053	84121.220	97934.709	5747.901	U
00063	84135.973	97929.965	5747.805	U
00073	84142.716	98056.654	5764.488	U
00083	84143.220	98032.868	5757.027	U
00093	84168.535	98031.895	5757.059	U
00103	84168.224	98053.283	5757.027	U
00113	84093.895	98007.424	5755.458	U
00123	84093.764	97992.975	5755.522	U
00133	84084.745	97992.301	5755.522	U
00143	84084.692	97982.564	5755.554	U
00153	84113.047	97983.650	5755.618	U
00163	84112.282	98007.496	5755.618	U
00173	84113.437	97982.258	5753.569	U
00183	84113.166	97940.908	5753.601	U
00193	84093.285	97940.538	5753.601	U
00203	84093.965	97906.635	5753.601	U
00213	84156.457	97966.785	5756.066	U
00223	84178.303	97966.502	5756.130	U
00233	84178.533	97961.542	5756.130	U
00243	84191.754	97961.319	5756.130	U
00253	84191.926	97931.474	5756.130	U
00263	84156.421	97932.604	5756.098	U
00273	84119.783	97906.136	5745.628	U
00283	84137.012	97906.186	5745.660	U
00293	84120.808	97868.909	5744.987	U
00303	84137.167	97866.048	5745.051	U
00313	84140.306	97906.412	5746.332	U
00323	84166.596	97906.619	5746.428	U
00333	84178.283	97906.188	5745.308	U
00343	84181.137	97905.990	5745.340	U
00353	84209.169	97865.700	5743.034	U
00363	84147.568	97818.360	5750.335	U
00373	84147.065	97852.196	5750.335	U
00383	84180.382	97853.394	5750.399	U

Figure 2a A Notepad image from the analyticl plotter pass point program for the third measuring session. Columns are (from the left) point identification number, x (Easting), y (Northing) and z (elevation). These are associated with the students notes describing the nature of the point.

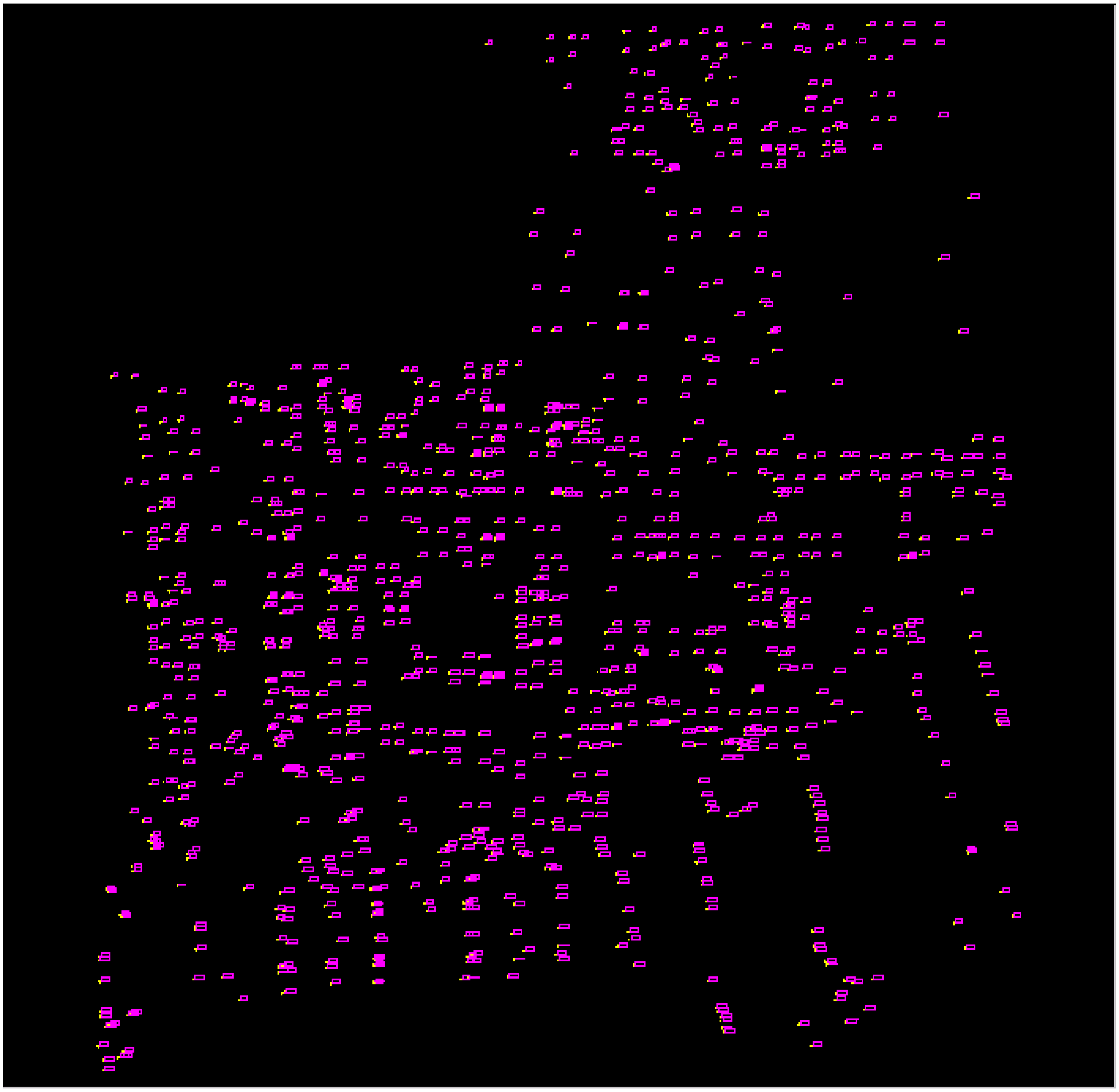

Figure 2b The pass poiunt data is read into a Digital Terrain Map program and converted to .DXF format for import into the CAD after a "D" sized plot is reviewed for completeness and checked for blunders. Figure 2c is the upper right hand corner of this image enlarged.

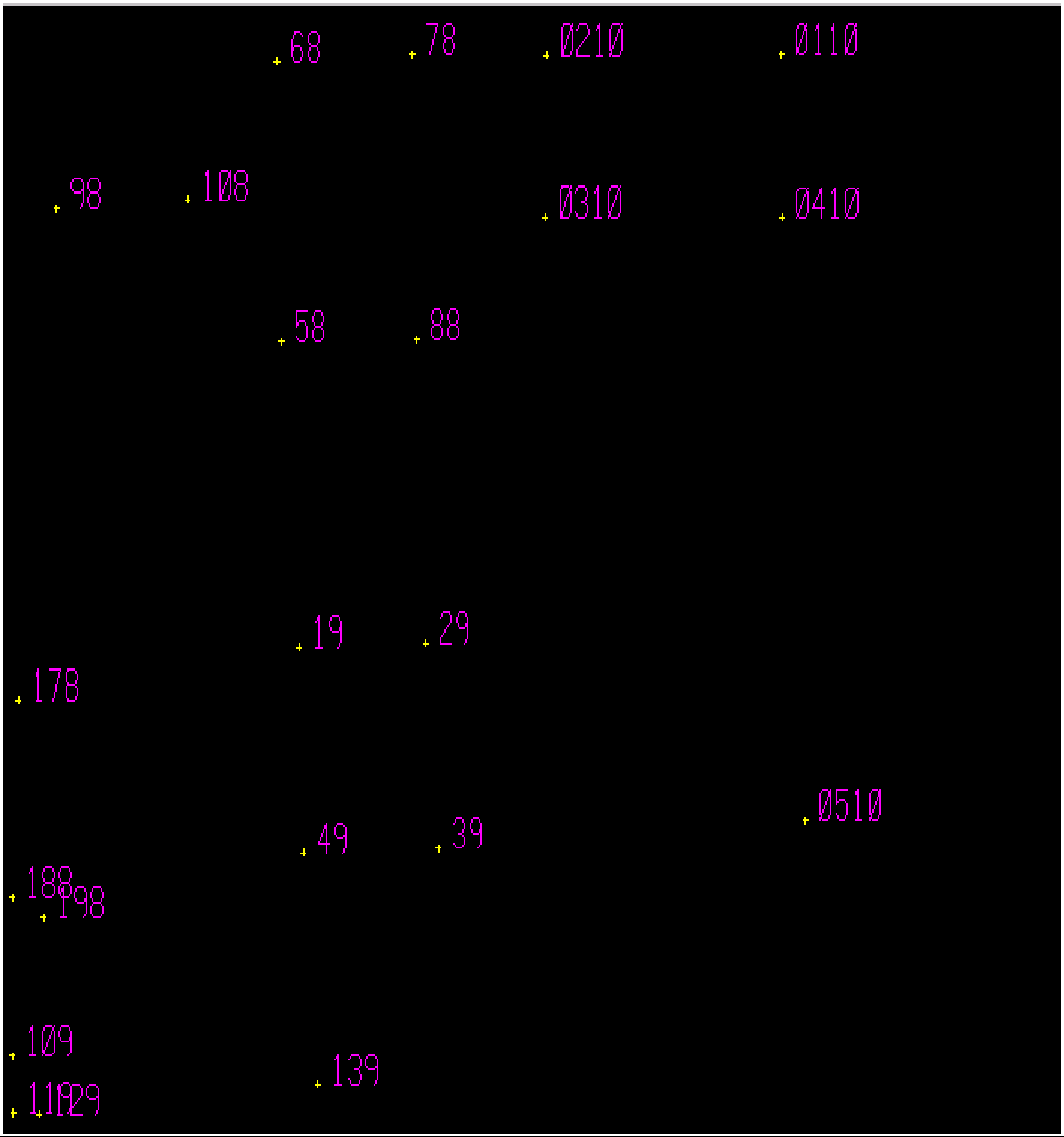

Figure 2c The upper right hand corner of the "D" sized plot students use for checking and blunder detection. The yellow "+" symbols denote the position of the object and the magenta numbers the object's point identification number.

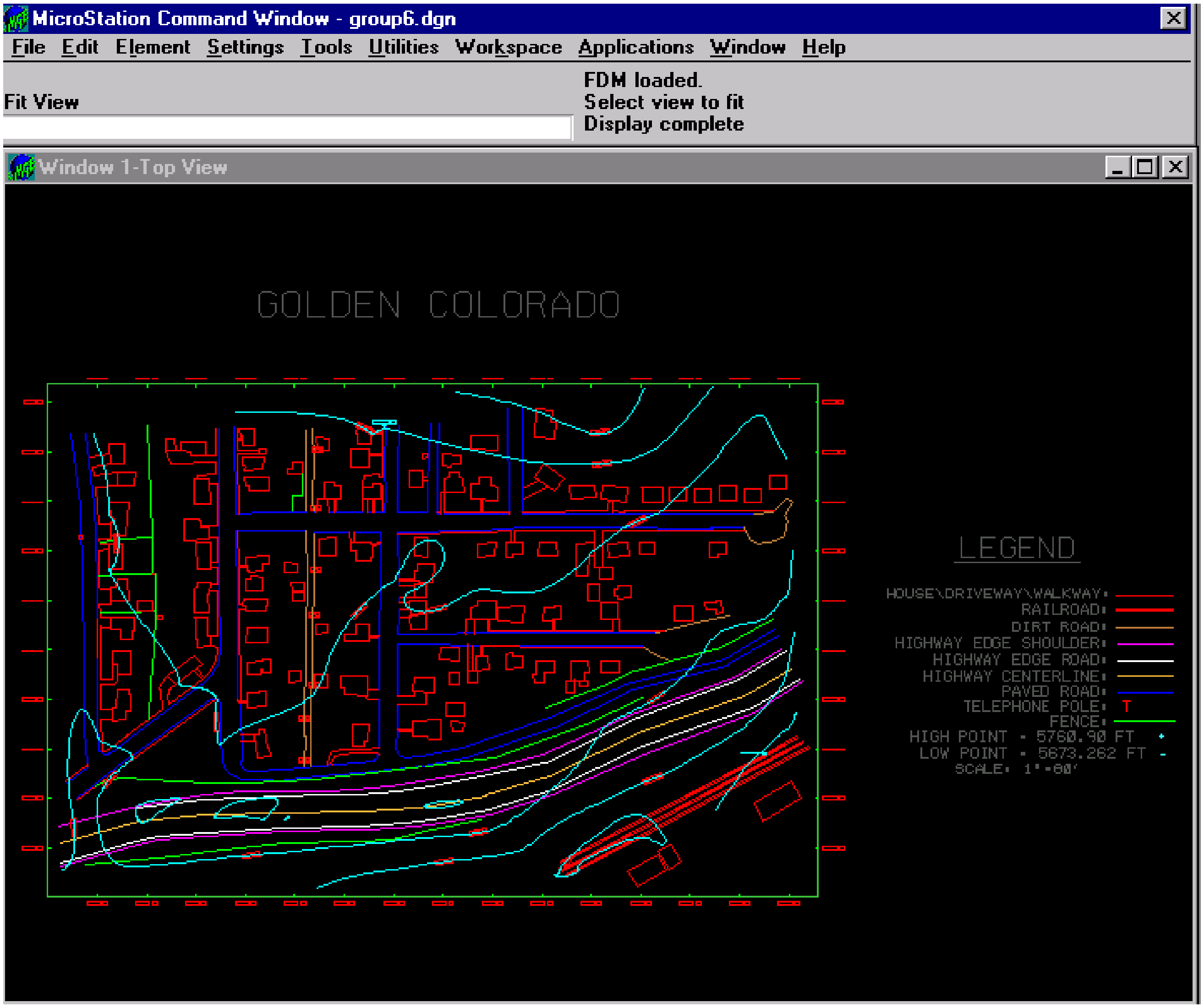

Figure 2d The final student map, at scale 1 inch = 80 feet with man made and elevation detail shown. The light blue lines are contours, the green frame and red numbers are a grid in State Plane Coordinate units. This Microstation image is scaled and setup for a "D" sized plot, so numbers and some of the symbols may not be readable.

Bibliography

Sprinsky, W. H.,1997 [1],"Surveying Education in the '90s - something Old and Something New." 1997 ASEE Annual Conference Proceedings. Alternatively, see "http://www.pct.edu/courses/wsprinsk/delos".

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William H. Sprinsky
Dr Sprinsky is an Associate Professor at Penn College. His M.S. and Ph.D. degrees are from The Ohio State University in Geodetic Science. He has a B.S. in Physics from the Polytechnic Institute of Brooklyn (Polytechnic Institute of New York). He has over twenty years of experience in civil engineering and mapping with the Army Corps of Engineers. His major research interests are in surveying and geodesy.