Including Geomatics as an Essential Element of the Civil Engineering Curriculum

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Abstract

Many civil engineering programs at major Universities are struggling with how to accommodate surveying in an already crowded undergraduate curriculum. Some schools continue to require an introductory surveying class. Others have decided to abandon a surveying requirement altogether instead opting for surveying to be an elective or not offered at all. There are many reasons that neither of these options are desirable for entry level civil engineers in the job market. First, technologies related to surveying are among the fastest developing in the industry, and consequently there is significant demand for skills in latest technology. Second, spatial data collection and analysis is essential to all civil engineering disciplines, thus a fundamental understanding of spatial data collection and analysis techniques is desirable. Furthermore, surveying is covered on the Fundamentals of Engineering exam as well as the Civil Engineering Professional Engineers exam. Because of the specialized nature of today's Civil Engineer, their surveying knowledge may be limited to what was learned in their Civil Engineering undergraduate curriculum. This paper describes a widely transferable and technically up-to-date course in Geomatics that expands on traditional surveying by incorporating modern methods of spatial data collection, management, and analysis. The course can serve as a Civil Engineering undergraduate requirement typically taken during the student's sophomore year. The paper presents lessons learned in developing Geomatics courses taught at Clemson University, Georgia Tech, and The Citadel. Findings and recommendations are summarized with respect to broader application issues impacting the civil engineering curriculum. Course topics primarily focus on spatial data collection techniques and methods to process, analyze, and present data within the larger context of addressing engineering and project design issues. Topics include traditional surveying, global positioning systems (GPS), digital photogrammetry, remote sensing, geographic information systems (GIS,) and digital terrain modeling (DTM). The paper includes a discussion of lecture material, organization of laboratories, software programs and equipment.

Introduction

At the dawn of the 21st century, a technologically advanced job market is sustaining an on-going demand for civil engineering programs to address instructional needs in the discipline of spatial data collection and analysis [1,2.] Increased expectations are constantly being placed on civil engineering graduates to deal with vast amounts of data related to traditional surveying, database geocoding, digital mapping, 3-D modeling and real-time spatial location. As a result, numerous civil engineering programs are struggling to accommodate surveying type courses in an already crowded undergraduate curriculum. The number of schools continuing to offer surveying as part of the required curriculum have decreased considerably in recent years. Another trend is for schools to abandon surveying offerings, even as an elective. In the summer of 1994, the Georgia Tech School of Civil Engineering followed a different approach and replaced

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their required introductory surveying course with a new course that was titled "Surveying and Spatial Data Analysis." This course expanded on traditional surveying topics via extensive incorporation of modern techniques in spatial data collection, management, and analysis within the larger context of civil engineering and project design issues. The additional material included coverage of global positioning systems (GPS), remote sensing, geographic information systems (GIS), and digital terrain modeling (DTM). To make room for new topics, some conventional surveying topics had to be reduced or omitted. For example, the lectures and laboratories on taping techniques were reduced considerably from what was covered in the past. Further, in an effort to respond to recommendations from local surveyors, more emphasis was placed on the use of total stations in the surveying portion of the class.

The Georgia Tech course quickly improved by responding to feedback from students and alumni. The course was further improved when enhancements in software and hardware used for the course were added. To better reflect the broader spatial emphasis of the course, its name was changed to "Geomatics." This paper presents lessons learned in developing the Georgia Tech Geomatics courses as well as similar courses taught at Clemson University and The Citadel. Findings and recommendations are summarized with respect to broader application issues impacting the civil engineering curriculum.

Defining Geomatics

The term *Geomatics* is new to the English language and is not yet found in the Oxford or Webster's dictionaries. GEO is a prefix for earth, and MATICS suggests the practical application of inforMATICS (information science) and matheMATICs. The term was introduced in Canada in 1988, when the then Canadian Association of Aerial Surveyors expanded its mandate and scope of membership to encompass the disciplines of surveying, mapping, remote sensing, and geographic information systems (GIS) [3.] The new name was adopted as Geomatics Industry Association of Canada, selected to represent a broader constituency of firms who shared the common characteristic of dealing with geographically referenced information. The term has gained widespread use throughout North America, Europe, and Australia.

While there are many definitions for geomatics (which is understandable considering the term's relative infancy), there is one common underlying theme—working with Earth-based data, often termed spatial data. Surveying which involves the collection of spatial data, is just one component or discipline of Geomatics. Many university surveying departments have changed their titles to "Department of Geomatics" or "Department of Geomatic Engineering" which better describes their departments' broader emphases. The definition used in this paper is that Geomatics is the modern scientific term referring to the integrated approach of measurement, analysis, management, storage and presentation of the descriptions and locations of spatial data. These data are collected using a variety of methods, including earth orbiting satellites, air and sea-borne sensors, and ground-based instruments. They are processed and manipulated with state-of-the-art information technology using computer software and hardware.

Figure 1 illustrates various activities included in the realm of Geomatics. Depending on the application, each activity may be performed once, more than once, or not at all. Activities identified in Figure 1 are very general and several intermediate steps may be necessary to complete a particular activity. For example, presentation may be as simple as printing a table or as involved as designing and printing a detailed map using symbols and colors to show road characteristics and indicators of scale and orientation.

Need for a Broad Emphasis

It is important that students understand why there is a need to embrace traditional survey techniques with new technologies under the domain of Geomatics [4.] The term surveying doesn't sufficiently capture activities associated with collecting spatial data. Before using spatial data, several activities must be performed.

If we take the example of global positioning systems (GPSs), the objective is to obtain the position of a point. Figure 2 illustrates a typical process for conducting a GPS survey. First, mission planning is done to determine the best time to conduct the field survey. After setting up a GPS base station at a known point, the rover GPS receiver is set up using a tripod on a point of interest. The unit is initialized and allowed to collect data for a period of time during which data are stored in its internal memory or to an interfaced data logger. Upon returning to the office, collected data from the base station and the rover are transferred to a personal computer (PC) containing software used to process the data and discard erroneous data. Remaining data are combined with other data such as manually surveyed control points and are manipulated (adjusted) with computer software to improve accuracy. Results are analyzed to see if data conforms with accuracy requirements. If results are acceptable, the values are published or presented in some other form, e.g. the intersection of two roads, which can be plotted on a map using a drawing program. Thus, before GPS data becomes useable, several activities falling within the realm of Geomatics must be utilized. The above example illustrates the importance of computing in Geomatics. Spatial data is usually too cumbersome to manipulate and analyze manually. The PC, along with sophisticated software, provides a powerful environment for working with spatial data.

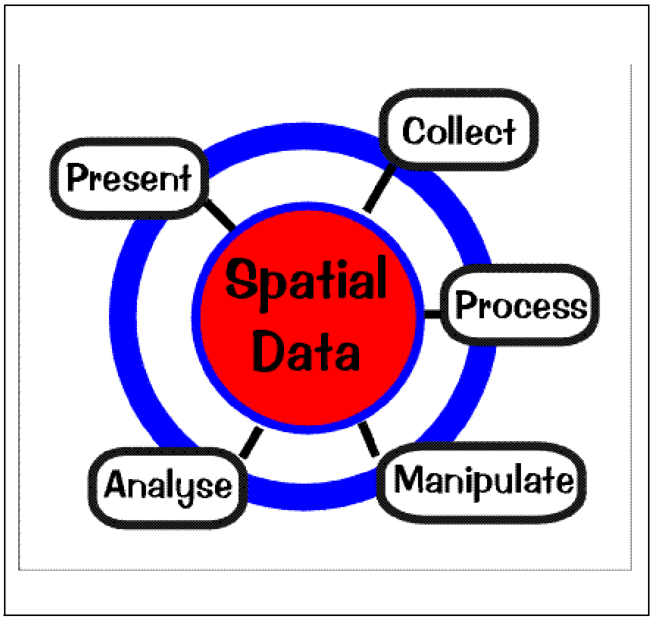

Figure 1 – Realm of Geomatics

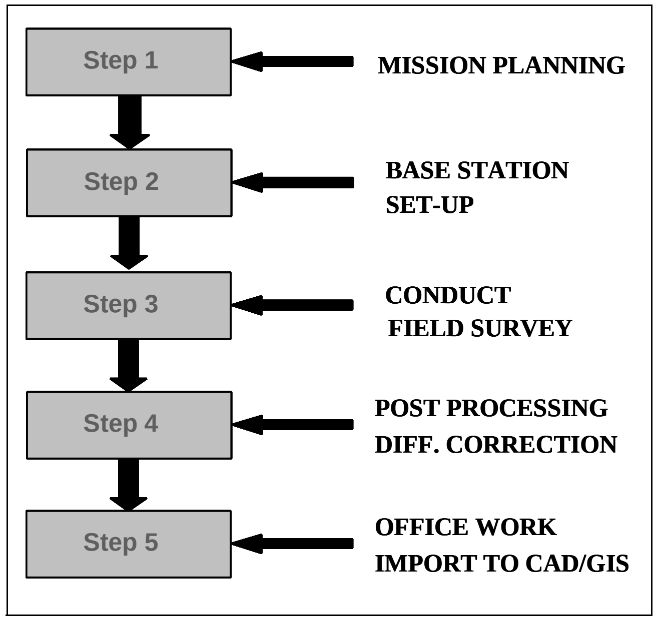

Figure 2 – Typical GPS Exercise

Developing A Framework for a Geomatics Course in Civil Engineering

By its very nature, civil engineering relies heavily on the field of Geomatics. Spatial data includes both natural and man-made features and phenomena. Essentially all man-made features fall within a civil engineer's perspective, with specific interest placed on the interaction between constructed features and natural phenomena. Even completion of small-localized civil engineering projects necessitates the use of methods that fall within the realm of Geomatics. Whereas traditional surveying is typically sufficient for small projects, larger projects may require a combination of approaches. For example site location and design of an airport can require use of a variety of data collection methods. Once these data are collected, extensive data processing and analysis are necessary to determine the most suitable location with consideration of environmental impacts, volume of earth to be moved, land acquisition, and proximity to major roads. Furthermore, presentation of this data to decision makers prior to development of final design plans can be greatly enhanced through use of Geomatic methods. As the project progresses into construction, Geomatics can be used to precisely locate important elements and features identified in the project drawings. These practical issues can be addressed by using traditional survey techniques or potentially can be accomplished in a more efficient manner through use of highly accurate GPS equipment.

The Geomatics courses developed at Clemson, Georgia Tech, and The Citadel were designed to focus on many of the sub-areas of Geomatics with the major emphasis on specific areas most critical to Civil Engineering. These courses evolved over the last few years with the addition of improvements based on lessons learned during previous offerings. The following can be considered essential elements of a required course on Geomatics. These elements are probably best used within the context of a single required undergraduate course on Geomatics including both traditional surveying and spatial data topics. This course provides a foundation for further elective study in any or all of the geomatics disciplines. Individual elements of the undergraduate geomatics course include:

- To reinforce lecture topics, it is essential that the course be offered in conjunction with a laboratory;
- While traditional surveying is a primary topic, the major emphasis is on modern methods. Thus, a digital theodolite and a total station are necessary for laboratory exercises. A total station can be used to mimic a digital theodolite by ignoring the total station's electronic distance measuring capabilities. Secondary topics such as reading verniers on older theodolites may be included if time permits;
- The course is designed so that the order of topics is flexible to accommodate weather considerations. Thus, exercises requiring outdoor labs can be either taught first in the fall and last in the spring;
- Software and equipment, as well as space limitations, have a significant influence on lab activities, thus, exercises should be configured based on these considerations, even if less than ideal.

Geomatics Course Topics

Topics covered in the Geomatics course and associated laboratory are summarized in Table 2. Additional discussion of the topics is presented in the following sections. The course can be taught as a 3-unit 15-week semester course (includes 14 2-hour laboratories) or a 4-unit 10-week quarter course (includes 9 3-hour laboratories). Optimal class size would be in the range of 50 students or less for lecture, with laboratories comprised of 15 students or less allowing approximately five three-student lab crews, depending on equipment constraints. Larger classes are viable with additional teaching assistant resources. Currently, Clemson teaches a single section of a maximum of 72 students with 3 laboratories of 24 students each. Each lab has 6 groups of 3/4 students. Two teaching assistants are required to effectively lead most labs.

Surveying and mapping

Surveying and mapping, which comprises roughly half of the course material (approximately 15 lectures), focuses on traditional surveying, map projections, and coordinate systems. In the associated lab, students are exposed to hands-on instruction in the use of the equipment in groups of 3 or 4. The laboratory format presented in Table 2 is for a 15-week semester course. For a 10-week quarter course, labs 1, 2, and 3 can be combined into 2 3-hour labs; and labs 4 and 5 can be consolidated into a single 3-hour lab.

Digital photogrammetry and remote sensing

The lecture material on digital photogrammetry and remote sensing covers basic underlying theory on aerial and satellite remote sensing applications most relevant to civil engineers. The purpose of the associated laboratory is to demonstrate digital image retrieval and processing of remotely sensed data. The laboratory that is currently done in Clemson's Geomatics course has four parts, each taking about 30 minutes. The first part explores different types of remotely sensed data including basic retrieval and interpretation; the second involves working with digital elevation model data; the third looks into creating orthophoto mosaics; and the fourth entails orthophoto rectification of a raw aerial photograph.

Table 2 – Summary of Lecture Topics and Laboratory Exercises

Lecture Topics	Laboratory Exercises
Distances, elevations and leveling	1. Distance Measuring (pacing, taping, chaining)
Traversing and Angle Measurements	2. Leveling with an autolevel and level rod
Latitudes, Departures and Coordinates	3. Level Loop closure and adjustment
Calculation of Areas and Volumes	4. Angle Measurement/Traversing I
Property, Topo, Hydro, and Construction Surveys	5. Angle Measurement/Traversing II
Coordinate Systems, Datums and Map Projections	6. Use of Total Station I –set-up/data collection
Digital Photogrammetry	7. Total Station II - Topographic Survey
Remote Sensing and Image Interpretation	8. Remote Sensing and Aerial Photo lab
GPS – Introduction and basic concepts	9. GPS lab – Planning/data collection
GPS – Accuracy and post processing	10. GPS lab – processing/differential correction
GIS - Overview and basic concepts	11. GIS lab 1
GIS -Spatial and attribute management	12. GIS lab 2
GIS - Spatial analysis, and modeling	13. DTM lab 1
DTM - Grids, TINS, faults, profiles, aspect and relief	14. DTM lab 2

GPS

The use of GPS in surveying is typically more involved than other applications because of accuracy requirements [5,6.] In addition to coverage of basic GPS fundamentals, the lecture, homework and laboratory material are designed to provide students with a basic understanding of how GPS surveying applications can achieve millimeter accuracy. Mission planning data used to determine the most appropriate time to conduct a GPS survey by minimizing position dilution of precision (PDOP) is discussed (Figure 3). GPS laboratories follow the same procedure as previously illustrated in Figure 2. In a 10-week quarter format, a single 3-hour lab can provide sufficient exposure if mission planning is assigned prior to the lab. A sample final product produced by students is a map, shown in Figure 4, that displays raw GPS survey data along with differentially corrected data. The data are overlaid on a map that identifies the actual location of a surveyed point relative to nearby planimetric features. When necessary, non-survey grade GPS units can be used for teaching purposes to minimize lab equipment costs [7.]

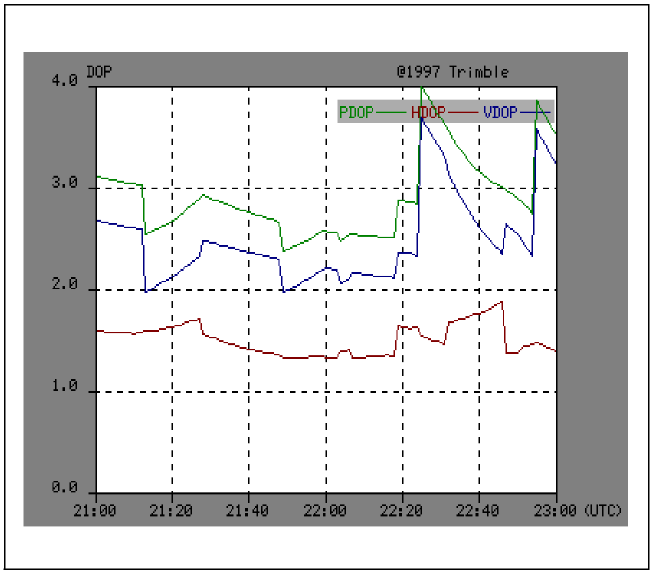

Figure 3 – Satellite Signal Quality

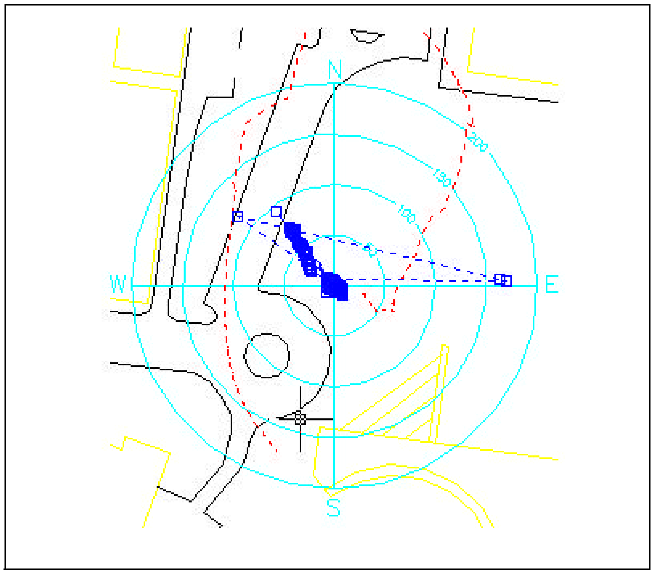

Figure 4 – Raw and Corrected GPS Data

GIS

The GIS lectures cover basic theory reinforced with a presentation of a series of applications from different civil engineering disciplines. Both the lectures and the labs can be divided into 3 distinct areas: 1) spatial database management, 2) spatial analysis, and 3) modeling. The GIS laboratories follow a tutorial format to train students in a particular GIS. An example lab problem would be to use the GIS to route oversized trucks through a state in a safe and efficient manner without exceeding any bridge load limits.

DTM preparation

Digital terrain modeling has become an integral component of numerous civil engineering design projects [8.] The DTM lecture material focuses on methods for collecting necessary data to build a DTM; methods for digital representation of a DTM (e.g. triangular irregular network); using fault lines to help ensure the DTM's spatial accuracy; DTM visualization techniques; and using a DTM to estimate earthwork requirements on civil engineering projects [9, 10.] The laboratory exposes the student to off-the-shelf DTM software that can aid a civil engineer in road or site design. In the first DTM lab, students learn how to manually digitize contour data from large scale contour maps. Using this digitized data, the students construct and visualize a DTM. They are also required to build a DTM from surveyed point data they collected during the topographic survey lab. This DTM is used to represent existing ground on a site design project that is conducted during the second DTM lab. Figure 5 illustrates resulting finished ground DTMs that are created in the second lab.

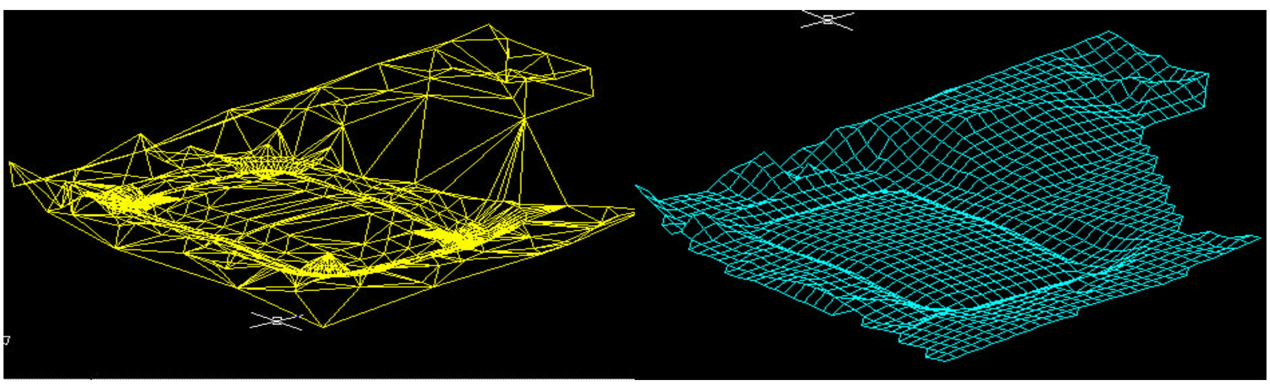

Figure 5 – Triangulated Irregular Network and Grid Representation of a Ground DTM

Equipment Required

The equipment required for a Geomatics class similar in format to the one presented in this paper can be divided into two groups: 1) field data collection devices used during outdoor laboratories (conventional surveying equipment and the GPS receivers); and 2) computers and associated devices and software used for indoor laboratories. .

Field Data Collection Devices

The surveying labs require at least one setup for each lab group. Each setup includes a steel tape, a set of taping pins, 2 range poles, an autolevel and level rod, a digital transit or theodolite, and a total station and prism. Total stations can be very expensive. Their costs are usually dependent on their specified accuracy. While quality is important, greatest consideration should be given to quantity if funds are limited.

At least 2 GPS receivers are needed for the GPS labs. One of these units will serve as a GPS base station that is set up on a known point. The other receiver can be demonstrated in the field to the lab as a group. Ideally, students should use a GPS receiver in groups of 3 or 4 but this would add considerably to the equipment costs. In lieu of surveying grade receivers, mid-grade receivers capable of post-process differential correction can be substituted with little impact to the lab's learning objectives. If GPS receivers used are incapable of storing data in internal memory, notebook computers or data loggers are needed.

Computers and associated devices and software

For indoor laboratories, computers can be used in groups of two. The choice of computers should be updated pentiums PCs running the Windows operating system with sufficient memory to run the various software that will be used in the lab. The minimum desirable computer would be a Pentium II class machine with a 10 gigabyte hard disk and 64 megabytes of internal memory. Other hardware that is needed is a digitizing device for each computer (11" x 11" or larger), and a high capacity network printer and color inkjet plotter.

The software requirements for the GPS lab are mission planning software and post-processing software required for differential correction. Much of this software will be specific to the brand and model of GPS that is used. The remote sensing laboratory requires digital image processing software. Examples include ERMapper, ERDAS, or ENVI. There are several GIS software packages that run on windows. Most of these have similar capabilities and are suitable for use in a Geomatics lab. Examples include Arcview, Geomedia, Map Info, and Maptitude. The procedures for DTM are pretty generic regardless of the software used. Some DTM software require the use of a CAD software as well. Others can operate independently because of their built-in CAD capabilities. Examples of DTM software that are suitable for a Geomatics lab include Autodesk Civil (requires AutoCAD), Caice, CEAL, Eaglepoint (requires AutoCAD), Geopak (requires Microstation), and Terramodel.

Conclusions

This paper has presented a Geomatics course that expands on traditional surveying by incorporating modern methods of spatial data collection, management, and analysis. The course can serve as a Civil Engineering undergraduate requirement typically taken during the student's sophomore year. The course is a culmination of lessons learned from offering similar courses at Clemson University, Georgia Tech, and The Citadel. The feedback from students and alumni has been very positive. While some have indicated that there is too much material or that some topics are covered too quickly, most have indicated that the topics presented have been very important to their development. Some students have used what they have learned in this class to assist them on projects in future classes. For example, one group of structural engineering students from Clemson University decided to perform, as a master's project, the design of a pedestrian footbridge across Lake Hartwell on the 16th hole of the University's golf course. They used GPS technology to establish nearby control points and used a total station to conduct a topographic survey around the bridge's location. They transferred the data to a computer and constructed a digital terrain model and superimposed their alternative bridge designs. In their presentation to a committee of faculty, they made it clear how Geomatics helped them to develop a design that minimized the visual and environmental impact of the bridge on Lake Hartwell and the surrounding land.

There are numerous other examples of how students have benefited from this course by applying what they learned to future courses or even in their jobs after graduation. Further, exposure to the Geomatics topics has given students educational opportunities that they would have otherwise not received or known about. Students who develop an interest in a particular topic after taking the required Geomatics class are encouraged to take additional course work in that topic for added breadth.

“Selling” the course to other Civil Engineering faculty at Clemson, the Citadel, and Georgia Tech when the course was first proposed was not difficult using the very same arguments elaborated on in this paper. The Authors agree that the greatest obstacle in implementing a Geomatics course are the extensive resources required due to the cost of the equipment, computers, and software used in the laboratory, as well as graduate teaching support. In many cases, institutions can use existing surveying equipment and computer facilities. Some topics may be omitted from a Geomatics course initially such as digital remote sensing and added once funds for software become available. Using mid-level GPS units, as described earlier in the paper, to mimic surveying quality units is another way to cut costs. Many of the software vendors give generous discounts for using their software. Further, many institutions have site licenses for some of the software needed for a Geomatics course. For example, Georgia Tech has a site license for ArcView as well as multiple licenses for AutoCAD and digital terrain modeling software. In this case, it was possible to use the existing licenses to provide much of the software resources necessary for the course.

Regardless of the needed resources, the benefits of exposing students to modern spatial data collection, management, and analysis tools are far reaching. This is because of the reliance of today's Civil Engineer on Geomatics technologies. These benefits are the primary justification for including a Geomatics course as an essential element of a civil engineering curriculum.

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