EDUCATING AND PREPARING STUDENTS FOR THE EXTENSIVE RANGE OF SURVEYING ACTIVITIES

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SUMMARY

Today's surveyors are regularly involved in a wide range of activities and interface with people from multiple disciplines. For example, the International Federation of Surveyors (FIG) defines eleven detailed activities that surveyors may perform in practice, ranging from gathering and managing data in space to interpreting and displaying spatial information. Due to the breadth and interdisciplinary nature of the eleven activities, development of a program that educates students on all of the necessary fundamentals of each activity can prove challenging. This paper discusses important concepts of each of the eleven surveying activities, as defined by FIG, and presents a matrix-based approach for identifying potential educational courses that teach those concepts. The matrix format enables visualization of which concepts are taught the most to which are taught the least, which is helpful for designing a well-balanced curriculum. As an example of this approach, graduate geomatics courses (laser scanning, digital terrain modeling, photogrammetry, control surveying, least squares adjustments, boundary law, property surveying, and geographic information systems (GIS)) from the School of Civil and Construction Engineering at Oregon State University are evaluated in the matrix format.

BACKGROUND

Although the fundamentals of surveying have not changed, rapid advancements in technology and digital data processing continue to create new tasks and opportunities for today's practicing surveyors. Many believe the term "surveying" does not adequately describe the full range of potential tasks taken upon by today's professionals; instead, many prefer the term "geomatics". Regardless of what we call it, surveyors or geomatics professionals can be involved in a wide range of ever-evolving spatial information tasks. In an effort to define this range of tasks, the International Federation of Surveyors (FIG) described eleven detailed activities that today's surveyors may perform in practice (FIG 2004). These activities range from measuring and monitoring objects in space to interpreting and displaying spatial information. Due to the breadth and interdisciplinary nature of the eleven activities, development of a program that educates the fundamentals of each activity can prove challenging.

Olsen (2011a) announced that the School of Civil and Construction Engineering (CCE) at Oregon State University (OSU) is expanding its graduate civil engineering program with an emphasis in geomatics. The expansion involves adding new faculty, graduate students, and course offerings. With this expansion, it is desirable to develop a graduate program that offers educational courses covering the wide range of activities taken upon by practicing surveyors or geomatics professionals. To ensure development of such an educational program, this paper: (1) identifies important concepts of each of the eleven surveying activities, as defined by FIG; and (2) presents a matrix-based approach for identifying potential educational courses that teach those concepts. The matrix format enables visualization of which concepts are taught the most to which are taught the least, which is helpful for designing and maintaining a balanced curriculum.

In addition to providing opportunities for students specializing in geomatics, CCE at OSU believes it is important to educate other civil engineers about basic principles in geomatics and the current roles geomatics plays in various sub-disciplines of civil engineering. The professions of surveying and civil engineering are closely and historically intertwined and complementary, and civil engineers should be kept abreast of newly developed surveying techniques (Soler 2010a). Soler (2010b) emphasized that for many civil engineering projects, application of emerging surveying methodologies is vital, and civil engineering departments should consider augmenting their curricula with courses covering state-of-the-art surveying technologies. Unfortunately, due to a variety of reasons, most civil engineering programs in the United States offer limited educational opportunities in geomatics innovations.

FIG SURVEYING ACTIVITIES

On May 23, 2004, the general assembly of FIG summarized that surveyors have the academic qualifications and technical expertise to conduct or collaborate with other professionals in at least one of the following four functions: (I) determine, measure, and represent land, three-dimensional objects, point-fields and trajectories; (II) assemble and interpret land and geographically related information; (III) use spatial information for the planning and efficient administration of the land, sea, and any structures thereon; and (IV) conduct research into and develop the aforementioned practices. FIG (2004) expanded these four primary functions into eleven detailed surveying activities which are somewhat overlapped and discussed below:

Activity 1: Measure/Monitor the Earth

A surveyor may be involved in measuring or monitoring the size, position, shape, and contour of any part of the Earth. This activity may range from small scale projects where the Earth is modeled as a flat surface (i.e., plane surveying) to large scale projects where models account for the true shape of the Earth (i.e., geodetic surveying). Although plane surveying remains popular, more surveyors today are using Global Navigation Satellite System (GNSS) technologies which require more thorough understanding of the principles of geodesy. Because GNSS receivers return geodetic positions on the Earth, and because these positions are often exported into georeferenced Geographic Information System (GIS) databases, it is ever important for surveyors to understand geodetic coordinate systems, reference ellipsoids, geoid undulations, datum transformations, and new realizations of datums. Surveyors often use geodetic theory to establish high accuracy control networks which enable precise measuring of locations on the Earth, as well as enhanced monitoring of the Earth's crustal motion, tides, and polar motion. It is also becoming ever-increasingly important for one's work to be integrated into a network, rather than on an arbitrary, local coordinate system for a variety of applications.

Activity 2: Measure/Monitor Physical Objects

A surveyor may monitor or determine the spatial position of physical features, structures and engineering works on, above, or below the surface of the Earth. This particular definition of a surveying activity by FIG (2004) encompasses the other ten activities in the most general terms. Surveyors locate and monitor physical objects in space. Some professionals survey underground works, such as mining tunnels or buried utilities. Many professionals locate or monitor objects on the surface of the Earth using terrestrial control or by observing celestial objects, such as Polaris, the sun, or (more commonly today) Earth orbiting satellite systems. To this end, surveyors use a wide variety of instruments to collect, archive, and monitor spatial information, including steel tapes, theodolites, electronic distance meters, digital automatic levels, GNSS receivers, and remote sensors such as LIDAR. Technologies (as well as accuracy and resolution capabilities) used for these measurements evolve rapidly; hence skills for data acquisition, processing, and analysis require surveyors to stay up-to-date with emerging technologies.

Activity 3: Develop/Test/Calibrate Surveying Equipment

A surveyor may develop, test, or calibrate sensors, instruments, and systems for surveying purposes. Fundamental tasks of surveyors are to make and use measurements for a variety of analyses. However, no matter how carefully made, a surveyor's measurements are never exact and will always contain errors (Ghilani and Wolf 2012). Surveyors develop and calibrate instruments to reduce measurement errors to within tolerable specifications, while maintaining or increasing production. During this activity, surveyors should have expertise in the different types, sources, and propagation of errors. Surveyors commonly design measurement systems to test and calibrate measuring equipment. Such systems allow surveyors to assess the significance of the measurement errors, determine the precision of the measurements, and/or distribute errors after measurements are taken.

<u>Activity 4: Acquire/Use Spatial Imagery</u>

A surveyor may acquire and use spatial information from close range, aerial, and satellite imagery using remote sensing techniques. During remote sensing, spatial information about an object is collected without making physical contact with the object using passive or active sensors. On one hand, passive sensors, such as photography (film or CCD digital) or infrared devices, detect natural radiation that is reflected or emitted by an object. On the other hand, active sensors, such as Radio Detection and Ranging (RADAR) and Light Detection and Ranging (LIDAR), emit energy and then detect and measure the radiation that is reflected back from the target. Rapid advancements in sensor technology and automated collection techniques (i.e., terrestrial, mobile, aerial) provide numerous opportunities for surveyors to acquire, develop, and use highly detailed three-dimensional data in ever-complex and large areas. Yu et al. (2010) emphasizes that both academia and industry do not adequately utilize these new and rapidly emerging technologies.

<u>Activity 5: Locate Property Boundaries</u>

A surveyor may locate the position of the boundaries of public or private land, including national and international boundaries. The general public considers surveyors as experts in locating property boundaries. Michigan Chief Justice Thomas M. Cooley stated, "Surveyors are not and cannot be judicial officers, but in a great many cases they act in a quasi-judicial capacity with the acquiescence of parties concerned" (Robillard et al. 2011). As such, it is imperative that surveyors have expertise in boundary control and legal principles in order to protect the rights of property owners. During this activity, surveyors first search for and identify original boundary monuments and allow them to control the location of boundaries. If original monuments are missing, surveyors must collect necessary boundary evidence, interpret legal land descriptions, and offer their expert opinion of the location of the boundary according to the rules of the courts. During this activity, surveyors often determine the areas of real property parcels, prepare legal land descriptions, document and record boundary evidence, provide expert testimony, and recommend methods for resolving boundary disputes.

<u>Activity 6: Create/Manage GIS databases</u>

A surveyor may design, establish, and administer geographic information systems (GIS) to collect, store, analyze, manage, display, and disseminate spatial data. Originally, GIS was focused primarily on data management, spatial analysis, and visualization. However, with advancements in double precision datasets and digital data processing, GIS is now capable of also managing and storing highly precise surveying measurements and coordinates. Furthermore, with more surveyors collecting georeferenced positions using GNSS technologies, surveyors are finding increased opportunities to collaborate with GIS professionals to create or update GIS databases to be based upon survey-grade data. Surveyors are developing new work flows to export georeferenced survey data to GIS, and are encouraging GIS professionals to use their survey data in GIS work environments, whenever available.

Activity 7: Analyze/Display GIS data

A surveyor may analyze, interpret, and integrate spatial objects and phenomena in GIS to enable visualization and communication of such data in maps, models, and mobile digital devices. In addition to storing spatial data in GIS, more surveyors are using GIS technologies to perform new services, such as providing digital maps and geovisualization, web-based geospatial databases, (near) real-time navigation, and other location-based services. Surveyors commonly use GIS technologies to view and analyze aerial photography, and support property management and taxation services (e.g., Activity 10).

Activity 8: Resource Management

A surveyor may study the natural and social environment, and measure land and marine resources in order to plan development in urban, rural, and regional areas. Surveyors assist in developing Land Information Systems (LIS), enabling improved management and governance of land, forests, fisheries, and other environments. Such tenure systems are meant to promote secure property rights and provide spatial information to resource managers, such as types of land use, access options, duration of use, water and mineral supply, etc. LIS's are commonly created, maintained, and analyzed in GIS.

Activity 9: Plan Property Development

A surveyor may plan the development and redevelopment of property (i.e., land and buildings) in both urban and rural settings. During this activity, surveyors often work with civil engineers with similar interests to plan the layout and design of infrastructure, land subdivisions, and other property improvements. Surveyors will locate the boundaries and find the encumbrances (i.e., rights-of-way, easements, reservations, zoning ordinances etc.) of a property prior to development/redevelopment. They often provide necessary topographic and feature location information to the development designer.

Activity 10: Assess Property Value

A surveyor may assist in assessing the value of real property in both urban and rural settings. For example, surveyors may work with tax assessors and appraisers to create, maintain, and update tax maps. Many of these tax maps are currently created and maintained in a GIS, enabling automated management of property data. Such digital maps are used to keep orderly inventory of the ownership, shape, size, and location of parcels of land and structures. Tax assessors and appraisers use the maps to assess property value based on numerous factors including the size of the property, types of land improvements, types of structures, land ordinances and zoning types, location, composition and quality of the land, etc. Surveyors often compute the areas of land parcels, volumes of buildings, and location and size of developable or developed space, which are key inputs to these analyses.

Activity 11: Measure/Manage Construction Projects

A surveyor may plan, measure, and manage construction works, including the estimation of costs. In addition to being involved in the planning stage of a construction or property development project (e.g., Activity 9), surveyors are also involved in ensuring that the specifications of the designer are met during and after construction. It is often said that the surveyor is the first and the last on a project. For example, a surveyor may begin a construction project by planning an available location for a road. Afterwards, a surveyor establishes vertical and horizontal control networks for the construction project. During construction, a surveyor ensures the road is built according to the designed horizontal and vertical alignment. Finally, a surveyor often documents and records the as-built documentation of the road when the construction project is completed. Given recent trends in asset management, surveying is also needed to record updates to the road during its lifecycle of maintenance and operation. Such work requires close coordination with property owners (i.e., clients), project managers, contractors, civil engineers, designers, construction regulators, etc.

CURRICULUM

Oregon State University-Civil Engineering has been developing a graduate educational program that covers the wide range of activities for today's surveyors. The following section of this paper evaluates the graduate geomatics curriculum offered and being continually developed at OSU using the previously discussed surveying activities identified by FIG (2004). The School of Civil and Construction Engineering (CCE) at OSU offers a Master of Science (M.S.) degree, Master of Engineering (M.Eng.) degree, and a Doctorate of Philosophy (Ph.D.) degree in civil engineering with an emphasis in geomatics. The M.Eng. degree is a coursework-only degree; the M.S. and Ph.D. degrees require students to complete coursework and conduct research into and develop geomatics practices (i.e., FIG primary activity IV). Students seeking an M.S. degree must complete a thesis, suitable for publication in a national academic journal, involving a unique or contemporary civil engineering-geomatics research topic; or, students may complete a research project culminating in a technical report. Students seeking a Ph.D. degree must complete a dissertation involving original, independent research that contributes significantly to the body of civil engineering-geomatics knowledge.

Currently, the geomatics faculty within CCE teach eight graduate courses: 3D laser scanning and imaging, photogrammetry, control surveying, least squares adjustments, GIS in water resources, digital terrain modeling, Oregon land survey law, and property surveying. Students desiring an M.S., M.Eng., or Ph.D. in civil engineering with an emphasis in geomatics are required to take the first four courses in this list. (The students are also highly encouraged to take the remaining four courses. If students are seeking a state-issued professional land surveying license, they must take the Oregon land survey law and property surveying courses.) In addition, the graduate students are required to take a course in geodesy from the geophysics group in the College of Earth, Ocean, and Atmospheric Sciences. Each of these nine courses is briefly discussed below. Although not further discussed in this paper, students are also encouraged to take geospatial courses from other programs at OSU, such as from the Geoscience, Forestry, and Computer Science departments. OSU coordinates with several departments and colleges in order to offer an undergraduate and graduate geographic information science (GIScience) certificate to both on-campus and online students.

<u>3D Laser Scanning and Imaging</u>

The 3D laser scanning and Imaging course introduces the key principles of collecting, processing, visualizing, and applying LIDAR data. Students set up and use a georeferenced GNSS control network to collect laser scanning data. Students learn how to georeference, filter, model, transform, and analyze LIDAR datasets. Afterwards, students assess errors in the laser scan point clouds, and perform calculations using the 3D data. A portion of the course focuses on new techniques such as structure from motion for creating 3D models from a series of 2D photographs. Students perform work in Leica Cyclone software, but are also encouraged to write computer code to automate processing, modeling, and analysis tasks.

In summary, this course teaches students how to acquire, process, and use remote sensing data (Activity 4) to measure, monitor, and model the Earth (Activity 1) and objects in space (Activity 2).

<u>Photogrammetry</u>

This course presents the fundamental principles of photogrammetry and remote sensing. Students learn how to collect, measure, and interpret spatial information from both aerial and terrestrial photographs. Students use stereoscopic parallax, account for differential rectification, and derive 3D coordinates from photographs using analytical comparators and digital computers. The students convert the rectified aerial photos into orthophoto maps using digital image processing techniques. Finally, flight planning and photo interpretation concepts are introduced.

This course teaches students how to acquire and use spatial imagery from remote sensors (Activity 4) to measure and monitor physical objects in space (Activity 2).

Control Surveying

During this course, students study GNSS theory and develop control networks using GNSS technology and geodetic leveling methods. Such networks are developed to highly precise control specifications. Students minimize systematic errors by performing field instrument adjustments, and distribute random errors by adjusting networks using principles of least squares. In addition, students account for errors in large area measurements.

This course teaches students how to develop and lay out in the field precise control networks for measuring/monitoring the Earth (Activity 1) and physical objects in space (Activity 2), and for testing/calibrating surveying instruments (Activity 3).

Least Squares Adjustments

This course reviews statistical hypothesis testing and error theory. The course discusses the propagation of systematic and random error in both indirect and direct observations; and, studies how to develop proper stochastic models for distributing random errors from redundant observations. Students are taught how to adjust by principles of least squares level nets, horizontal networks (e.g., trilateration, triangulation, traverse networks), and GNSS survey networks; and, estimate the error ellipses of the adjusted observations. In addition, students execute conformal, affine, and projective coordinate transformations. Students write computer code in MATLAB® to perform numerous types of least squares adjustments.

This course assists students in developing high accuracy control networks for measuring/monitoring the Earth (Activity 1) and physical objects in space (Activity 2), and for testing/calibrating surveying instruments (Activity 3).

Geodesy

The geophysics group in the College of Earth, Ocean, and Atmospheric Sciences offers a course in geodesy. During this course, students study physical and observational geodesy, including how to determine the gravity field and geoid of the Earth. The course discusses how to interpret geoid anomalies and geoid undulations. Students study numerous geodetic measurement techniques, including GNSS, Interferometric Synthetic Aperture Radar (InSAR), and Very-long baseline interferometry (VLBI). The course covers geodetic reference frames and reference ellipsoids.

This course teaches how to use principles of geodesy to measure/monitor the Earth (Activity 1).

GIS in Water Resources

This course presents the basic concepts and operation of GIS for solving water resource problems. Students create geometric hydro networks of rivers and streams; and, define digital hydrologic data models from catchments, digital elevation models, and time series measurements at gauging stations. With these digital models and networks, students perform hydrologic calculations using map algebra on raster grids. A term project is assigned for students to research a water resource problem, create a GIS database from existing data sources, perform calculations, and present results orally and by web posting. In the future (AY 2013-2014), this class will alternate bi-annually with a GIS in transportation course.

The course teaches students how to create and manage a GIS database (Activity 6), and how to analyze and display data in GIS (Activity 7). In addition, students study management of water resources (Activity 8) during this course.

Digital Terrain Modeling

This course teaches how to create, analyze, and apply digital terrain models (DTMs) from various survey and remote sensing sources (e.g., total station, LIDAR, photogrammetry) and data repositories (USGS, NOAA). This course, designed to link surveying, engineering, GIS, and computer science into geomatics, is discussed in detail in Olsen (2011b). Students develop DTMs by collecting, processing, geo-referencing, and filtering LIDAR datasets. Afterwards, students analyze data quality and assess uncertainties in the DTMs. To improve efficiency in developing and analyzing DTMs from varying sources, students write computer code in C++. Students then use the DTMs and computer algorithms to compute surface areas, volume changes, and slope.

This course teaches students how to acquire, process, and use remote sensing data (Activity 4) to measure, monitor, and model the Earth (Activity 1) and objects in space (Activity 2).

Oregon Land Survey Law

This course covers Oregon state statutes, common law decisions, and administrative rules dealing with boundary law. The course discusses written and unwritten methods (i.e., agreements, adverse possession, and acts of nature) for transferring land title, differing guarantees of title, and how to interpret/write legal descriptions. Students study case law in order to answer complex boundary survey questions, and learn the statute requirements for record of survey plats, partitions, and subdivisions to meet local government requirements.

This course teaches the legal principles that must be applied when surveying or resurveying boundaries (Activity 5).

Property Surveying

During this course, students learn how to research chain of title and chain of survey records from government offices, and how to identify monuments marking original property boundary corners. They are introduced to the United States Public Land Survey System (USPLS) and learn how to reestablish lost or obliterated corners by evaluating boundary evidence. Further, students study how to subdivide sections according to the USPLS, and how to design property partitions and subdivisions for development. The course teaches how to research government LIS/GIS to determine numerous factors affecting property, including the ownership, encumbrances, size, location, zoning types, types of improvements, etc. The course assigns a term project to survey and design a subdivision or partition, write legal description(s) of the subdivided property, and present the project in a subdivision or partition plat.

This course teaches how to apply legal principles when surveying or resurveying property boundaries (Activity 5), how to find property management information using LIS (Activities 8, 10), and how to plan the layout and design of land subdivisions (Activity 9).

EVALUATION OF CURRICULUM

Table 1 summarizes which of the above courses cover important concepts from the eleven surveying activities defined by FIG (2004). The matrix-based format of this table is useful for identifying which concepts are taught the most to which are taught the least. As can be observed in the table, fundamental principles for activities 1 and 2 are covered in five graduate courses. This is likely due to the general and overarching definition of these two surveying activities and their relevance to the remaining a categories. Although activities 6 and 7 appear poorly represented, numerous additional graduate courses in GIS are available from other departments and colleges at OSU (i.e., Geoscience Department, College of Forestry). In addition, the geomatics group in CCE is currently developing another graduate course in GIS for transportation engineering applications. As the program expands, additional courses will be developed to fit within this framework.

We do not report which courses cover principles for Activity 11. We believe material from all of the discussed courses can be applied to measuring and managing construction projects. Furthermore, CCE at OSU offers numerous undergraduate and graduate courses in construction engineering management and civil engineering to students seeking degrees in civil engineering or construction engineering management with an emphasis in geomatics. Such courses help broaden a student’s education, thereby enhancing the student’s ability to succeed while performing the eleven surveying activities of FIG (2004). By learning both engineering and geomatics principles, the students can more readily complement engineers on projects.

Table 1. Curriculum evaluation matrix of the geomatics program in the School of Civil and Construction Engineering at Oregon State University

Class Name	FIG (2004) Surveying Activity										
	1	2	3	4	5	6	7	8	9	10	11†
3D Laser Scanning/Imaging	X	X		X							
Photogrammetry		X		X							
Control Surveying	X	X	X								
Least Squares Adjustments	X	X	X								
Geodesy*	X										
GIS in Water Resources**						X	X	X			
Digital Terrain Modeling	X	X		X							
Oregon Land Survey Law					X						
Property Surveying					X			X	X	X	
Total	5	5	2	3	2	1	1	2	1	1	--

* = This course is offered from the geophysics group in the College of Earth, Ocean, and Atmospheric Sciences at OSU.
** = Numerous graduate courses in GIS are offered from the Geoscience Department and the College of Forestry at OSU. CCE is also developing a GIS course in transportation engineering.
† = Other groups in CCE offer numerous graduate courses in constructing engineering management and civil engineering that helps educate important concepts in this activity.

CONCLUSIONS

Surveyors or geomatics professionals can be involved in a wide range of tasks while working with property owners, geodesists, lawyers, contractors, civil engineers, GIS professionals, geophysicists, geographers, tax assessors, property managers, designers, and more. Hence, it is critical that educational programs prepare students for the diverse opportunities they will have upon graduation. In an effort to define these tasks, FIG (2004) offered eleven detailed activities that surveyors or geomatics professionals may perform in practice. This paper discussed important concepts from each of these eleven activities, and presented a matrix-based approach for identifying potential educational courses that teach those concepts. The matrix format enables visualization of which concepts are taught the most to which are taught the least, which is helpful for designing a well-balanced curriculum.

As an example, the graduate geomatics courses from the School of Civil and Construction Engineering at Oregon State University are evaluated in the matrix format (see Table 1). Results indicated that each of the eleven surveying activities is covered in at least one course. An additional course covering concepts for activities 9 and 10 may be warranted. As OSU's CCE geomatics program experiences further growth, this matrix will help us to determine and prioritize additional course offerings.

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