Three-Dimensional Geographic Information System Applications for Commercial Space Operations

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Abstract: - This research examines GIS training and techniques that can incorporate aeronautical charts and other airport information into a GIS that allows the different airspace classes to form 3-D images depicting their exact dimensions and arrangements. Scenarios of individual approaches, runways, and surrounding infrastructure can be zoomed and rotated in 3-D for optimal viewing. Situational awareness is greatly enhanced by these capabilities, which enable pilots and crew members to better comprehend the complexities of a particular airport, its accompanying airspace, and landing trajectories. Global Positioning System (GPS) data also can be integrated into the GIS, whereby a suborbital space flight can be tracked and plotted in a 3-D environment for visualization. Flights can later be debriefed allowing the crew and support team to replay and analyze the flight from taxi to touchdown. Most importantly, in the event of a return flight diversion, GIS enables the crew to rapidly assess the available alternatives within range and view the airspace and airport in 3-D before committing to the actual approach. Public agencies and private industries at all levels are using GIS technology as a vehicle to create linkages between the diverse disciplines associated with aerospace to maximize the resulting synergy.

Key-Words: - GIS, GPS, 3-D, geospatial, data management, airspace, aerospace, suborbital flight

1 Introduction

In the early days of computing, Burrough (1986) defined a Geographic Information System (GIS) as "a powerful set of tools for storing and retrieving at will, transforming, and displaying spatial data from the real world for a particular set of purposes" [1]. Similarly, Clarke referred to a GIS as an "automated system for the capture, storage, retrieval, analysis, and display of spatial data" [2]. The first modern GIS, the Canada Geographic Information System, was established in the early 1960s by the Canadian government to inventory its natural resources [3]. Many have acknowledged this program as the most important milestone in the development of GIS, which now has evolved into the interdisciplinary field of Geographic Information Science and is applicable as a vocational or academic discipline as well as a tool for education and research [4].

2 The Use of GIS

Initially a tool of geographers, diverse disciplines are developing programs surveying GIS theory and introducing students to the structure, design, and application of database management systems capable of accepting and manipulating large volumes of geospatial data. It can be argued that there are five essential elements of a GIS. The most vital of these are the users who affect the input and output of the GIS. Next, the data must be accurate, accessible, and affordable. The hardware should be the fastest and most sophisticated that is available. The software, consisting of drawing, database, and statistical components, must be reliable and user-friendly. Finally, there must be a consistent set of user defined procedures for achieving precise and reproducible results.

One of the primary advantages of a GIS is its ability to allow the user to conduct a spatial analysis which can be defined as the study of the locations and shapes of geographic features and the relationships between them [5]. Spatial analysis is a valuable approach for assessing suitability and potential, for approximating and calculating, and for interpreting and comprehending problems associated with location [6]. An important GIS tool in a spatial analysis is the thematic layer, which the user can create and manage just like other data in the database. A layer is simply a collection of similar geographic features in a particular area or place referenced together in a database for display on a map.

Because it offers real-time decision-making support, aerospace applications such as air traffic management and safety scientists are using GIS technology. Operational meteorologists and climatologists increasingly utilize GIS in forecasting and analysis as evinced by the first National Weather Service GIS forum in 1999 and the development of a GIS climate atlas by the National Climatic Data Center (Fig.1). However, there is enormous potential for GIS applications in all areas of education and research.

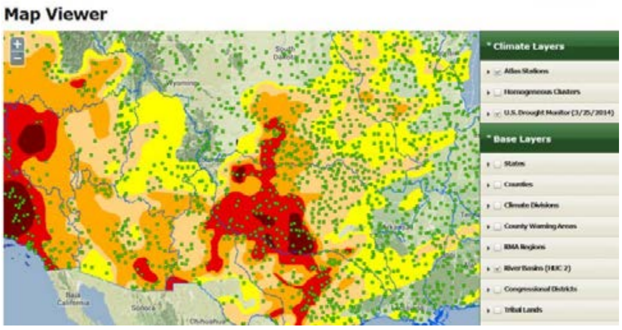

Figure 1. NCDC GIS Climate Atlas

3 GIS Education

College students increasingly are exposed to data about the world, the local community, and their individual disciplines. In order to effectively make use of this information, students and researchers need a system to manage, analyze, and display the data. GIS supplies the tools to meet this challenge, from the business major locating clients to the medical student tracking disease outbreaks. As such, various colleges and universities are developing and implementing courses designed to educate and train students in the concepts, theories, and techniques related to geospatial database management.

The distinction between interpreting statistics in a tabular form and observing data depicted as a graphic, such as a map, is vast because with appropriate training the user can efficiently comprehend the significance of spatial trends and patterns. That is, the manner in which data are presented has a profound influence on the associations and deductions that are drawn, thus enabling the researcher to conduct more effective and rigorous scientific queries.

The expanding use of GIS in government, business, research, and education has created a demand for individuals who are proficient in the principles and procedures of GIS. Gadbow and Hannah claim that the swift development of technology has a major impact on society in both the workplace and in academia [7]. Poole observes that about 22 percent of the workforce have the skills necessary for 60 percent of the new high-tech jobs [8]. Hines suggests that educators should therefore embrace the latest technology in the classroom to help fill this deficiency in the workplace [9]. Kennedy notes that working professionals upgrading their skills or retraining in technology account for a substantial number of the students enrolled in GIS programs [10]. However, the very character of GIS as a technological foundation with numerous applications demands tailored teaching, which is not suited for traditional classroom instruction. According to Longley *et al*. GIS pedagogy requires a combination of methods to adequately account for GIS technical topics, concepts, best practices, administration, and responsibility [11].

In order to explore its true potential, GIS is best taught across all curricula. For example, using an environmental science approach, students can learn how to interpolate air quality based on known quantities of certain aerosols and pollutants. Economists can map the least-cost routes for the shipment of goods while sociologists are able to conduct demographic analyses of local populations, and agricultural researchers can forecast crop yields based on climate, soil, and land resource data. Whatever the context, the student of GIS must always adhere to the scientific method. Typical courses in a GIS specific certificate or degree program include Introduction to GIS, Cartography and GIS, GPS and Field Data Collection, Database Building and Management, Intermediate and Advanced GIS Applications, and Remote Sensing. Many GIS programs involve an internship in local government or business to provide real-world experience.

It is critical to make a distinction between GIS education and training. Lectures are used to emphasize the fundamental principles of GIS, which are applicable across all disciplines and programs. Computer-based laboratory exercises emphasize training, which is largely dependent upon the particular hardware and software being used at a particular time and location. The lead faculty member in GIS education should coordinate the plans, keep the program on the cutting edge, and upgrade/update the hardware and software as GIS technology evolves. Promotion of the program can be achieved through faculty and community workshops.

To implement aerospace GIS courses, an institution needs facilities, trained instructors, a dynamic curriculum, and funding. Fortunately, a number of external sources are available. The United States government offers GIS grants through the National Science Foundation, the National Aeronautics and Space Administration, and the U.S. Geological Survey. Additionally, numerous state, private foundation, partnership, and industry grants are available. A key component of GIS education and research is access to affordable and reliable data. Real time and archived data from a number of sources are compatible with most GIS software. Among these is the Geography Network which provides free data and maps with a range of aerospace themes including business, economics, and transportation. A variety of governmental sites also are available, such as that of the National Oceanic and Atmospheric Administration that include wind, humidity, temperature, and precipitation data from locations around the world (Fig. 2).

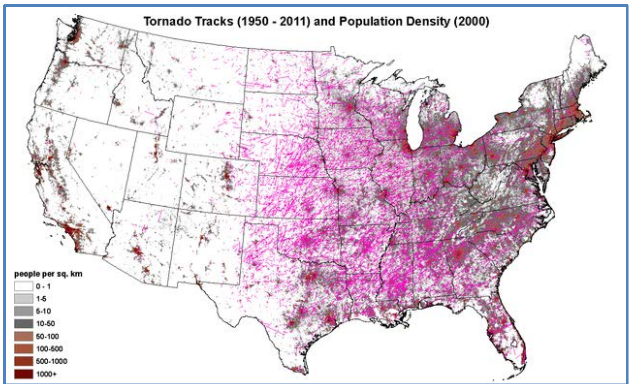

Figure 2. NOAA Map of Tornado Events

Several off-the-shelf GIS software programs are available. In addition to seeking products that are user-friendly, affordable, and compatible with the existing infrastructure, the software should provide data visualization, query, analysis, and integration capabilities along with the ability to create and edit geographic data. Other features should include a catalog for browsing and managing data, on-the-fly coordinate and datum projection, metadata creation, editing and cartographic tools, and the capacity to directly access Internet data.

Due to its interdisciplinary nature, establishing a GIS program presents the potential for turf wars between departments, which best can be overcome through multidiscipline coordination. Questions also might arise concerning where GIS fits into the curriculum. Should it be treated as vocational, academic, or extended education, and should it be taught at the lower division, upper division, or graduate level? Without well-trained instructors and standards concerning course or curriculum content, there could be problems with accreditation. Inadequate planning and a lack of funding to upgrade hardware and software could seriously inhibit growth. Despite the possible perils, the outlook for establishing and maintaining a successful GIS program is highly favorable. Some 3,000 colleges and universities in the U.S. and 4,000 worldwide are incorporating GIS into more than 70 disciplines. Although GIS is high technology, at the heart of the system is basic geographic information that can reveal volumes about the world and our place in it.

4 Aerospace Applications

The visual nature of GIS gives students the chance to interact with and manipulate geospatial data sets in countless ways, which is essential for aviation and aerospace studies that occur across time and space. As Friedrich and Blystone point out, the difference between viewing data on a spreadsheet and seeing it presented graphically on a map is incalculable as humans excel at pattern recognition with proper training [12]. In short, the mode through which one observes data has a profound effect on making connections and drawing conclusions allowing the user to answer the questions of what, where, and why.

There are few aviation and aerospace endeavors that do not involve a spatial component, from the planning of an airport at a particular location and the management of daily operations to routing a flight based on traffic, topography, and weather. As an effective instrument for visualizing tabular data, recognizing emergent patterns, and effectively depicting results, GIS both enhances pedagogy by adding a hands-on component to the process and provides an invaluable contribution to collaborative research among faculty and students of varying aviation and aerospace disciplines.

Lemberg and Stoltman assert that technology has revolutionized Geography as a profession and has had a significant impact on the teaching of the subject in K-12 and higher education [13]. However, there are negative teaching issues involved in the use of multimedia technologies in the classroom, such as those required for GIS instruction. These include the tendency to substitute slide shows for substance and hardware constraints that compel lecturers to stay near the podium [14].

However, positive benefits such as working directly with the computer within the realm of a hands-on, tactile learning environment often preferred by pilots appear to outweigh the disadvantages. As a result, Baker and Case maintain that GIS is emerging as a pedagogical tool for advancing contextually productive student education [15].

One of the most difficult tasks for aviation and aerospace students involves looking at a two-dimensional display and having to translate that image into three dimensions. Using 3-D GIS software, aeronautical charts and other data can be incorporated into a GIS displaying different airspace classes as three-dimensional images depicting their correct dimensions and structures. The software enables the scene to be zoomed and rotated for optimal viewing. As a result, situational awareness is likely to be greatly enhanced enabling student pilots and air traffic managers to better comprehend the complexities of airspace. Approach charts can be added to the GIS, which should prove to be an exceptional aid when debriefing pilots and crew during suborbital space flight training. Global Positioning System (GPS) data also can be integrated allowing a suborbital flight to be tracked and later plotted in a virtual three-dimensional environment. Thus, flights can be analyzed for precision of maneuvers helping pilots and their instructors review and analyze each flight from takeoff to landing. In the event of a return flight diversion, GIS enables the crew to rapidly assess the available alternatives within range and view the airspace and airport in 3-D before committing to the actual approach (Fig. 3).

Figure 3. San Francisco Airport in 3-D

Another possible aerospace application involves the integration of flight routes and corridors into a GIS along with real-time weather information. Using the spatial accuracy of GIS, it is possible to develop individual forecasts for each flight, allowing pilots, air traffic controllers, and meteorologists to work together making course corrections to produce the safest and most efficient flight path. Such a system could save time, money, and lives as flying into inclement weather is a major cause of general aviation accidents and will likely be a hazard for future suborbital space flights.

In order to fully grasp the potential of 3-D GIS for suborbital space flight support, prior geospatial education and training is necessary rather than attempting to query and analyse data on the fly. This could be accomplished by integrating GIS-related laboratory exercises with fieldwork to encourage students to examine scientific concepts related to aviation and aerospace including describing and summarizing spatial data, making generalizations concerning complex spatial patterns, estimating the probability of an outcome, making inferences about a population from a sample, and determining differences in phenomena at various locations. These objectives could be met by the implementation of GIS courses distinctly designed specifically for the aerospace community with the expectation that following the proposed pedagogical approach would multiply the dissemination of new GIS methods across aviation and aerospace institutions of higher learning.

To provide course developers with the necessary data to improve lesson plans and exercises while guiding and motivating students to participate in and direct their education, a formative assessment of the courses would need to be implemented. A classroom assessment technique should be selected that best provides information about what is being learned, the extent to which the courses are achieving their goals, and that enables students to analyze their understanding of the material. Realizing that evaluation directs and drives curriculum development, the chosen assessment instrument would be capable of appraising the students' command of course content while providing the student feedback that is required to govern the educational process.

5 Conclusion

Currently, the prevailing paradigm for education is evolving. As many universities are administered like businesses, businesses are offering, or even requiring, advanced education of their workforce. In a society that is increasingly adept in the use of technology, graduates today must be equipped with the skills necessary to compete. Students enrolled in aerospace institutions expect and deserve to acquire the most sophisticated education available in science, math, engineering, and technology. Adapting, developing, and implementing courses in aerospace GIS will better prepare students to contribute to society's growing technological demands. Without a comprehensive cognition of technology and science there can be no meaningful depiction of data.

Success with GIS arises only through a broad-based education because competency comes through understanding the complex interactions between people, their environments, and technologies. As an interdisciplinary instrument focused on the universal language of maps, GIS offer a means to a more comprehensive understanding of the whole. The expertise acquired in GIS courses is being applied in government, industry, and academia to advance the analysis of spatial data and to enhance decision-making capabilities at all levels. Airport planners employ GIS to analyze the best locations for new runways and other structures, the proper placement of radar units and wind-shear detectors, and to determine how nearby buildings might interfere with aircraft operations. Likewise, airport managers use GIS for a multitude of applications from assessing the condition of pavement to determining optimal flight paths for reducing aircraft noise levels over highly populated areas.

Through the facilitation of data collection and analysis, GIS allows students and teachers to cooperate in the pedagogical process as students seek direction from faculty regarding how best to investigate research interests, collect and analyze data, and make new discoveries. Students who are familiar with advanced cartographic principles and have well-developed GIS laboratory skills are empowered to collaborate in research as they are able to map any aspect of the spatial world. Equipped with the ability to visualize data formerly confined to tables or graphs, students will be placed in a significantly superior position to help modernize the workplace and enhance the global research infrastructure. Together with their cohorts across the globe, they will serve as the seeds of dissemination for widespread applications of GIS.

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