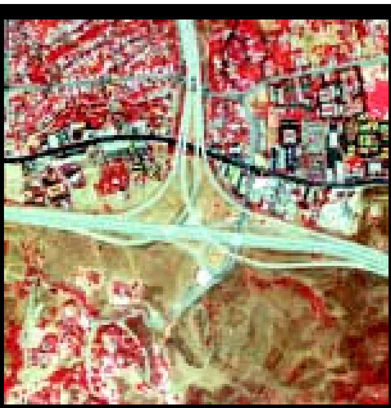
NCRST

NATIONAL CONSORTIA ON REMOTE SENSING IN TRANSPORTATION

REMOTE SENSING AND SPATIAL INFORMATION TECHNOLOGIES IN TRANSPORTATION

Synthesis Report 2001

A Collaborative Research Program

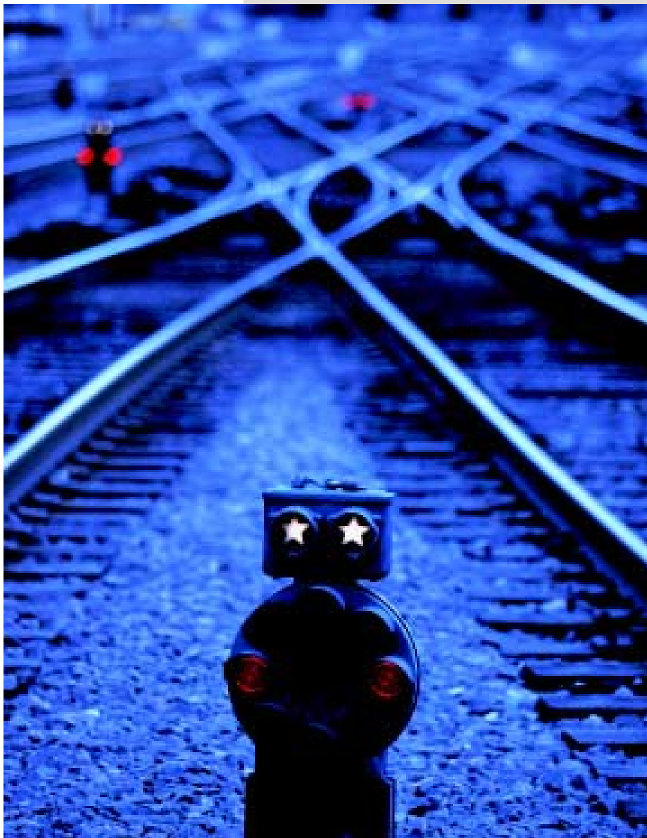
U.S. DEPARTMENT OF TRANSPORTATION
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

TRANSPORTATION *at a* CROSSROADS

Transportation planners have been hearing it for years. The population is increasing, trade barriers are down, the highways and railroads are humming and traffic volume is swelling to record numbers. At the same time, there are new standards for managing the traffic; and more ambitious expectations of transit ridership and emergency service delivery; public review of designs is required and environmental impacts must constantly be monitored. Fortunately, as the challenges for transportation management become more demanding, new tools emerge — from cellular phones to GPS and internet communications, technology is making information more accessible to managers and users. As Intelligent Transportation Systems (ITS) are deployed, a wider variety of technologies will become available.

Geospatial information technologies have made a real difference in a number of management domains, from cadastral mapping to commercial logistics. In the transportation arena, state Departments of Transportation (DOTs) have embraced GIS technology over the last two decades, and reaped significant benefits. While gross budgets may or may not have been reduced, DOTs have produced much more for every dollar spent, by integrating a wider range of variables in planning, and disseminating information better.

Remote sensing is a relatively late entrant in transportation GIS, largely because the technology has only recently started to achieve the sharp resolutions necessary for most transportation applications. With a view to facilitating the transition, the United States Department of Transportation (USDOT) Research and Special Programs Administration (RSPA) and the National Aeronautics and Space Administration (NASA) collaborated to establish the National Consortia on Remote Sensing in Transportation (NCRST), with funding under the Transportation Equity Act for the 21st Century (TEA-21), Section 5113. Four university consortia are pursuing research in applications of remote sensing and spatial information technologies in four focus areas of transportation: (a) environmental assessment, (b) infrastructure management, (c) traffic flow and (d) hazards, safety and disaster assessment. A number of Technology Application Partners, mostly commercial firms, are engaged in a parallel effort to develop recent research into marketable products.



This Synthesis Report from the university consortia marks the end of the first year of the research program. It places the research in the context of the state of the practice as it currently exists. It is presented in three sections. The first is a quick overview of the technology. The second section documents examples of application of the technology in DOTs in the U.S. over the last decade. This sets the stage for the third section, a summary of consortium research in its first year of operation.

This is by no means a comprehensive listing of efforts or offerings. It merely opens a door to a developing area of research and commercial development; and by way of illustration, cites a handful of users and vendors working with the technologies. In that sense this report is part of an evolving project. We will continue to pursue the synthesis effort, compiling use cases and reporting on research findings. Electronic copies of this and other documents are available at our web site, *www.ncgia.ucsb.edu/ncrst/synthesis*. All four consortia have active outreach programs and web sites, and we invite you to keep in touch with our efforts as we explore this exciting area.

TECHNOLOGICAL BACKGROUND

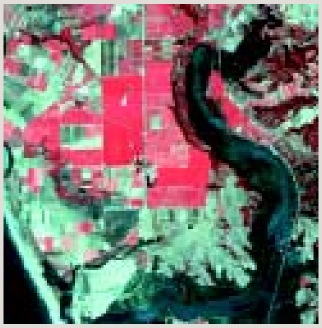
This section offers a thumbnail introduction to some of the most popular remote sensing technologies, and the more pertinent issues regarding data quality. There is a danger that such an instant review of the technology paints an unduly rosy picture and creates inflated expectations, because it does not discuss the extensive image processing steps, pitfalls and implementation costs. For a more complete treatment the reader is referred to text books and Internet resources, notably the Remote Sensing Core Curriculum, accessible from *www.ncgia.ucsb.edu/pubs/core.html* or *www.umbc.edu/rscc*, and the Canadian Center for Remote Sensing, *http://www.ccrs.nrcan.gc.ca/ccrs/eduref/educate.html*.

There is a danger that such an instant review of the technology paints an unduly rosy picture

Sensing Technologies

The earliest documented attempts at remote sensing were in the last century, using cameras carried in tethered hot air balloons. Cameras strapped on pigeons were employed for espionage during the first World War. Aerial photography saw rapid growth thereafter for both military and civilian surveying and mapping. Stereo imagery made it possible to view the earth in three dimensions, and analytical stereo plotters helped to develop elevation maps and to trace contours. By the mid 20th century topographic map production usually employed some degree of aerial compilation. Both black and white (panchromatic) and color photography are still used for mapping.

Multi-spectral The U.S. space program triggered further development of sensing technology, as sensors started to offer insights into the invisible portions of the spectrum. Heat profiles and chemical pollution trails became visible. Healthy vegetation could be distinguished from diseased vegetation. The program received a boost in the mid-1970s, when at the height of the Cold War, the U.S. monitored Russian agricultural activity and detected an impending disaster, setting the stage for early economic and political responses.

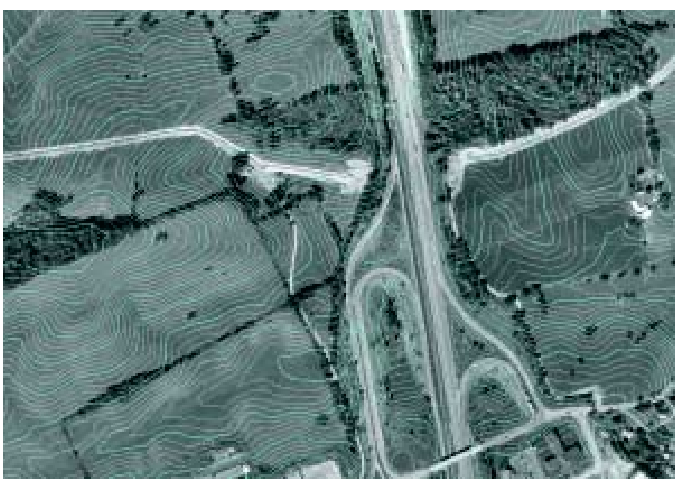

Monterey, California, highlighting near infra-red. 4m resolution multi-spectral product from Space Imaging, www.spaceimaging.com

The Landsat satellites originally employed a sensor called the multi-spectral scanner (MSS), which measured reflected light in green, red and near-infrared. Images were stored and transmitted digitally rather than on film, facilitating reproduction and information exchange. The satellite data are numeric values on each of the 4 bands, and these can be color-coded by an operator to produce "false-color" graphics in which, for example, healthy vegetation may look red. In the early 1980s the MSS was replaced by the Thematic Mapping, a 7-channel system with three visible channels, one infrared, two short-wave infrared and one thermal channel.

Hyper-spectral sensing is an extension of multi-spectral. The visible and infrared spectrum is sliced into narrow intervals, producing detailed readings of spectral characteristics. Compared with the 4–12 bands in a multi-spectral image, there could be more than 200 in hyper-spectral data. This enables one to distinguish for example between fresh asphalt and older oxidized asphalt; or between roofing materials and road construction materials that might look similar in traditional color photographs. Hyper-spectral sensors are typically carried by aircraft at low or high altitudes. A spaceborne sensor called Hyperion was launched in late 2000.

RADAR (Radio Detection and Ranging) imaging is another leap beyond the visible, into microwave energy bands. Active radar systems transmit a radar signal to their target, and recover the reflected beam. Radar is unaffected by cloud and rain; and because it relies on its own energy source, it can sense by day or by night. Visually, a radar image is similar to a panchromatic photograph. Radarsat (*radarsat.mda.ca*) offers high resolution commercial imaging, with a ground resolution of about 3 m. SAR (Synthetic Aperture Radar) is an ingenious adaptation of radar. It uses the trajectory of the sensing platform (aircraft, satellite or spacecraft) to simulate a long antenna (e.g. 4 km long) that would be impossible to construct physically; by analyzing interference patterns from the returns, the distance to the earth's surface is derived. This produces a map of elevation, or a Digital Elevation Model (DEM). The Spaceborne Imaging Radar (SIR, 1994, *www.jpl.nasa.gov/radar/sircxsar/sirc-pkt.html*) and Shuttle Radar Topography Mission (SRTM, Feb 2000, *www.jpl.nasa.gov/srtm/*) are two of the better publicized SAR projects, and produced elevation models at about 30 m resolution for a large part of the globe. Airborne interferometric SAR (IFSAR), with a flying height of 3000-5000 m, covers a smaller area with about 2–3 m vertical accuracy. For a commercial offering see *www.intermaptechnologies.com*.

The UCSB campus, Town of Goleta and City of Santa Barbara CA, viewed from the west. Produced by Jet Propulsion Laboratory from SRTM and land cover data. Credit: NASA



Detailed contours produced from LIDAR. Credit: Virginia Department of Transportation

LIDAR (Light Detection and Ranging) is a simple adaptation of the radar principle. It employs a laser scan in place of the radio wave. This is currently the most dense and accurate method to sample elevation for the production of DEMs. Point spacing on the ground is about 1 m, and vertical accuracy is in the range of 15–20 cm. The beam is so narrow that it can produce returns off telegraph wires, producing useful utility maps. In lightly wooded areas, the beam may penetrate the canopy in places, and it is therefore possible to derive a "bare-earth" surface model. The drawback of LIDAR is that to achieve these high accuracies, the scan must be flown at low altitude, about 600 m, and the area of coverage is therefore narrower.

GPR (Ground-Penetrating Radar) transmits microwaves into the solid earth and receives the reflected signals, producing profiles of the sub-surface strata based on mechanical and electrical properties. It is typically used up to 30 m depths, and can be operated from aircraft or on the ground. GPR may be useful in examining subgrades below highways and railroads. For commercial services see *www.g-p-r.com* and *www.geomodel.com*.

Remote Sensing Data Quality

Remote sensing quality is generally characterized by 4 different kinds of resolution: spatial, spectral, radiometric and temporal.

Spatial resolution has to do with pixel size. In the Landsat sensors of the 1980s, each pixel covered 30x30 m on the ground. Imagery of this resolution was useful to distinguish say forests from agricultural plots, but little use in transportation. With the French SPOT program, resolution improved to 20 m. Today the state of the art is about 1m from space-borne sensors such as Ikonos and the planned Orbview satellites, and as little as about 5–10 cm from low-altitude aircraft.

Some transportation objects like this bridge identifier are not visible from satellites.

Spectral resolution describes color discrimination in the visible and invisible portions of the spectrum. At one end of the scale, panchromatic imagery provides a single intensity value for each pixel. The valves can be visualized as shades of gray, producing a “black and white” image. Multispectral sensors offer intensities in 4–12 spectral bands, producing the range of colors commonly seen on today’s computer monitors. At the high end, hyperspectral sensors slice the visible and invisible portions of the spectrum into 200 or more bands. This allows an analyst to find subtle distinctions between materials, e.g. to detect oxidation in pavement asphalt, and thereby perhaps to assess pavement condition.

Radiometric resolution is the level of detail with which the intensity in each spectral band is represented. An 8-bit pixel offers 256 different intensity values. This aspect of resolution is rarely quoted because relative to other aspects of resolution, it is less likely to mean the difference between a viable and impractical application.

Temporal resolution is the frequency with which an object is sensed. This is a critical aspect that can make or break transportation applications. Satellites typically revisit a scene every two weeks to six months, and it usually takes at least a couple of days before the data are delivered to the customer. Satellites are not always directly overhead, so an object on the ground may be obscured by tall buildings; or the view may be inhibited by shadows, darkness or cloud cover. Therefore in transportation, where the objects of interest move continuously, we have to broaden our outlook to include airborne sensors, uninhabited aerial vehicles (UAVs), video logging vans and fixed cameras.

SUCCESS STORIES OF THE LAST DECADE

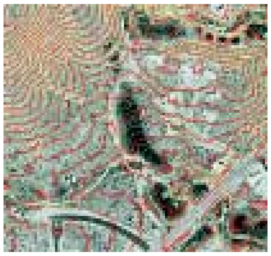
This section presents a selection of use cases of remote sensing and GIS in state and local DOTs and commercial service organizations. These do not necessarily represent the state of the art, but they illustrate the problems to which the technology has been applied, and in some cases address the management hurdles that were overcome.

Among the keys to successful management of new information technology are cooperation and cost sharing

Photogrammetry for Mapping

Holding a map and an aerial photo side by side (e.g. *www.globexplorer.com*, *www.terraserver.com*), there are probably several things one could record that are in the photo and not in the map (e.g. vehicles), and vice versa (most notably, annotation). To an extent, an orthophoto represents a convergence of these representations, making a photograph function more like a map. When a tall building appears in a low altitude photograph, the top of the building is further from the centerpoint of the photograph than is the base of the building, and windows on the face of the building are visible. This is not so in the true "plan" view represented by a map. To give a photograph the geometric fidelity of a map, this and other artifacts of the optical process must be removed. This is possible, using a Digital Elevation Model (DEM) as an independent source of information on height. The U.S. Geological Survey (USGS) produces an inexpensive product called the Digital Ortho Quarter Quad (DOQQ), an orthophoto series that corresponds with the boundaries of USGS topographic quadrangles. Ortho-adjustments are based on USGS DEMs, which have an accuracy of about 30 m. The resulting *x*,*y* accuracy is about 6 m on average. While this is not adequate for design scale transportation applications, it is a useful resource to get started on a limited budget.

Transportation projects require detailed terrain and land cover maps for corridor planning, environmental assessment and engineering design. The applications are so diverse in their requirements that mapping has to be repeated at a number of different scales, from 1:600 for design to 1:50,000 for corridor planning. In many cases, traditional field survey methods have given way to photogrammetry, using either traditional analytical stereo-plotters or modern soft-copy photogrammetry. Photogrammetry from low-altitude photography (flown as low as 150 m) can produce elevation accuracy in the range of 2 cm. This may be used, for example, to calculate the volume of material to be stripped off a road surface. About half of all state and local photogrammetry work is contracted to the private sector, hence these firms face the same pressures as do DOTs to adopt the new technologies.



Topographic mapping by photogrammetry. Credit: Pima Association of Governments, Arizona

Photogrammetry for Asset Management

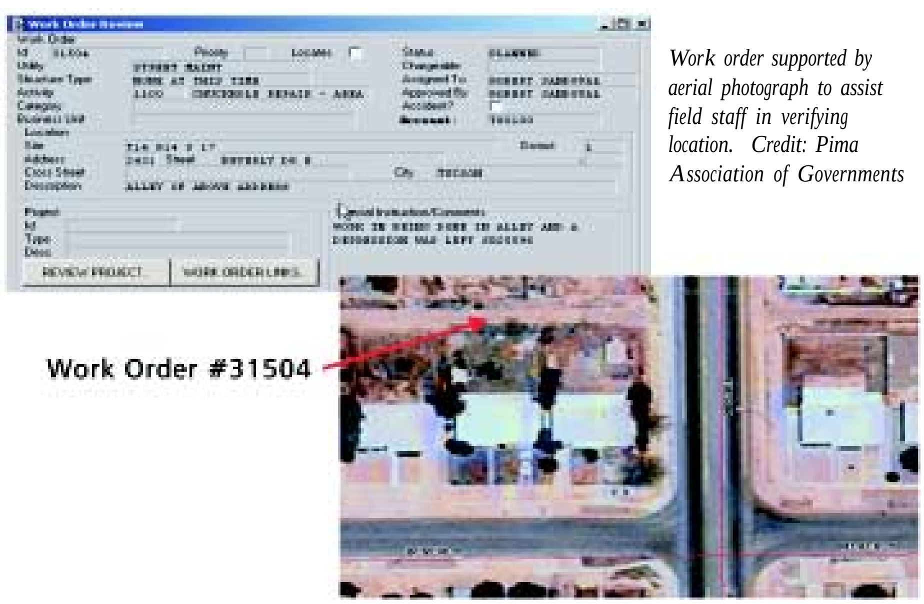
Pima Association of Governments, Arizona

Among the keys to successful management of new information technology are cooperation and cost sharing between departments within the organization, and with neighboring jurisdictions. The story of Pima, Arizona is a good illustration of this.

In April 1998, the Pima Association of Governments (PAG) and local jurisdictions contracted for high quality orthophoto coverage of 578 square miles (1500 km^2) of the Tucson urbanized area. Combined with ground verification, a series of aerial flights at 3,600' (1100 m) above the mean elevation captured the images and related data necessary to create the unified ortho-rectified digital coverage of the region.

Large scale photography used for inventory of street signage. The yellow triangles are yield signs; the red circles are stop signs. Credit: Pima

The total cost of the contract was $2.3 million. Another $132,000 was added to enhance or to add coverage at the request of the Town of Oro Valley, Tucson Airport Authority and the City of Tucson. The resulting products — topographic files, geodetic control points, grayscale and multi-spectral orthophoto imagery at multiple resolutions — were distributed to local jurisdictions and are being used in transportation, air quality analysis, hydrology, land use planning, site development review and permitting. The City of Tucson Department of Transportation has started to use the high resolution orthophoto imagery to inventory transportation-related facilities, such as street lights and traffic control signs. The ability to conduct vast inventories directly from the orthophotos has resulted in significant savings in time and resources.



Work order supported by aerial photograph to assist field staff in verifying location. Credit: Pima Association of Governments

Other applications that are being developed include analysis of impacts from proposed rezonings; matching building permits with tax assessor records; right-of-way and roadway alignment; transportation network inventory and analysis; preliminary design studies; gridded emissions of air pollutants; flood control and hydrology studies; habitat mapping; vegetation classification; land use identification and detection of land development changes. TDOT has also used the multispectral imagery for vegetation analysis and to determine impervious versus pervious ground areas. The City of Tucson has added orthophoto images to street maintenance work orders that are distributed to field crews; this has helped them visually identify the location of specific features of projects in the field. Street centerlines are being adjusted to their precise location on the orthophoto image, allowing greater accuracy in transportation modeling. This undertaking is a joint effort of the City of Tucson and PAG.

The above information is quoted almost verbatim from a handout prepared by PAG. For further information contact Andy Gunning, Regional Planning Director, *agunning@pagnet.org*. PAG offers geographic data and imagery in a publicly accessible interactive mapping system at its web site, *www.pagnet.org/website/pagrdc*.

Florida

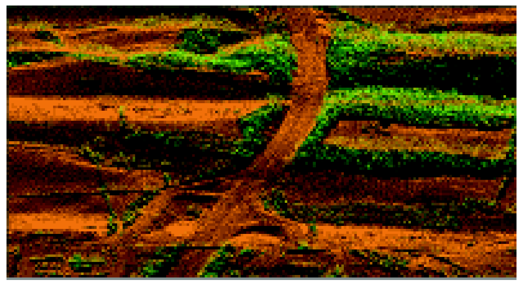
At the Florida Department of Transportation, District Three arranged for high-resolution (3 cm) aerial surveys flown at an altitude of 600 m to support its Roadway Characteristics Inventory (RCI) data base. Ground control points were surveyed with high precision GPS units, and aero-triangulation performed to register the aerial images to the ground, achieving positional accuracy of about 15 cm. Using the specialized *TransView* software, the stereo data were utilized to extract a 3-dimensional roadway centerline, calculate road length, and relate the x, y, and z coordinates to the Department's linear referencing system. Further, the Department's video logs have been linked to the milepost locations within the imagery. This project is in full production with nearly 1500 km of roadway being inventoried using this method. For the future, there are plans to integrate the data with other 3-D data and to serve other functional units within the department. For further information contact Ted Jones at FDOT District Three Planning, *Ted.Jones@dot.state.fl.us*.

Centerline and intersection identified on aerial photography, for linear measurement. Credit: Florida DOT

3-D Surveys for Visualization

Virginia

In late 2000, Virginia DOT (VDOT) contracted with Woolpert LLP, to perform a topographic survey utilizing LIDAR technology. The project was initiated by VDOT in support of a location study to determine the most feasible alternative to improve a heavily trafficked, overlapping interstate in the southwestern part of the state. The LIDAR was flown at an altitude of 1400 m, and utilized both airborne and ground-based GPS to establish control. Photogrammetry was also used for quality assurance purposes. Utilizing LIDAR did improve the timeliness of the deliverables over traditional survey or photogrammety while meeting project accuracies. While accuracies for the LIDAR project met the requirements for the location study, they were minimally lower than traditional photogrammetry. Costs of the LIDAR project were slightly lower when compared to traditional photogrammetry costs due to lesser amounts of data collection time. The greatest benefit realized by VDOT was the quick turnaround and delivery of a finished project that could immediately be used by the preliminary engineers performing the study. For further information contact John Simmers, Virginia DOT, *simmers_jr@vdot.state.va.us*



Intersection of Interstate 77 and Interstate 81, visualized from LIDAR-derived elevation postings (green points). Credit: Virginia Department of Transportation, Woolpert LLP

Texas

The Katy Freeway, a section of Interstate 10 in Houston, is one of the worst traffic bottlenecks in the United States. A 65 km stretch of the freeway is to be widened starting in 2003, and this requires prior evaluation of impact on adjacent urban communities. Public consultation is a mandated step in planning, and visualization of the proposed construction is helpful not only to the public, but also to planners and design staff.

LIDAR generated bare earth, tall buildings and existing elevated intersections of a portion of the Interstate 10 corridor. Published in Earth Observation Magazine, *November 2000, reproduced with permission.*

The Texas DOT used a combination of CAD and LIDAR data, flown at 1000 m for an accuracy of 30–40 cm, to create detailed 3-D representations of the proposed construction. Striping, signage, guard rails and support pilings under raised highways were simulated. Buildings were digitally removed to make room for the wider roadway. Perspective views were streamed to create animated “drive-bys” for presentation at public meetings. The LIDAR approach saved Texas about 3 months in turnaround time, in addition to the cost of field surveys.

For further information contact Jack Hill, Houston Advanced Research Center, *jhill@harc.edu*, or Dan Cotter at TerraPoint, *dancotter@transamerica.com*.

Video Logs

While the foregoing discussion has focused on imaging from space and aerial platforms, an important component of transportation survey takes place at the ground level. Street signs, bridge identifiers and several aspects of road condition are best viewed from the vantage point of the motorist.

The video log van is now standard equipment in many DOTs. There are variations in equipment — vans may carry some combination of GPS, distance measuring instrumentation, road condition sensors and cameras. A mobile laser retroreflectometer, as recently acquired by Iowa DOT, records the condition of pavement striping. By associating a spatial reference (from GPS and/or linear measurement) and a time stamp with video and other observations, users can query the system and retrieve relevant information.

Distance from guard-rail post to edge of pavement is measured in Roadware's Surveyor module. Courtesy: Roadware , www.roadware.com

An emerging enhancement of the video log is mensuration, the ability to make precise measurements from the video or photographic record. Camera position in the vehicle is controlled and calibrated, Inertial Measurement Units (IMUs) record the systematic (forward) and erratic (pitch and roll) camera movement, and apply appropriate corrections. It is then possible to measure distance and lateral dimensions with much better accuracy than is possible with traditional DMI methods — about 15 cm over a viewing distance of about 10 m. In addition, optical character recognition is being applied to road signage for automatic attribution.

For further information on photo mensuration from logging vans, contact Gil Boettcher at Roadware, *info@roadware.com*.

The Fly-by

If the “pretty picture” (colorful GIS output) was the hot attraction in GIS departments of the 1980s, the fly-by movie took over in the late 1990s. Creating a fly-by requires several carefully coordinated steps. First a photograph is orthocorrected, as described in an earlier section. (Alternately, an aerial photograph is simulated using land use and land cover data.) Next this is draped over a DEM, i.e. reflectance values from the photograph are associated with each corresponding value in the DEM. Third, a flight trajectory is set up, either in advance or in real time using a mouse or joystick, and a series of perspective views of the landscape is generated to simulate a bird's eye movie. It is much easier to create a fly-by over a desert than at low altitude over a city. Building facades and elevated highways pose special problems that require laborious manual work. One may use relatively coarse elevation data (e.g. USGS DEMs) for distant viewpoints, and replace them with IFSAR or LIDAR data for close-up views.

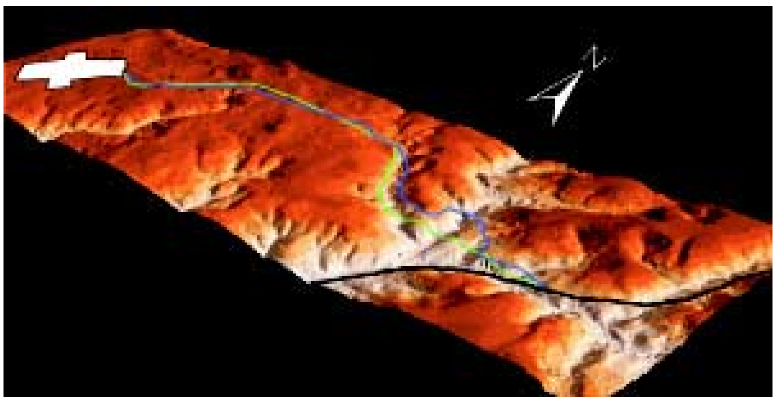
Fly-bys are a powerful tool in public reviews and impact studies for large projects. One effective variant on a construction or upgrade project is to split the screen, with one half showing the scene as it exists prior to construction, and the other showing a simulated future scene (e.g. *www.wilsonbridge.com*). A selection of fly-bys is available for download from the NCRST Synthesis web site, *www.ncgia.ucsb.edu/ncrst/synthesis*. Additional material, not particularly related to transportation, is available from NASA: *esdcd.gsfc.nasa.gov/GLACIER.BAY/movies.flyby.html*.

Planning a Transportation Corridor

The preceding cases addressed the design and operations end of applications, i.e. at scales of 1:10,000 to 1:600. An application with great potential fiscal impact is planning on a broader scale for new transport corridor alignments. This is where one attempts to achieve logistical efficiency by aligning a corridor to take the shortest route between two points, but environmental issues and public resistance have to be factored in as elements of cost. Large construction budgets hinge on these decisions.

The general issue of corridor location has been addressed for at least three decades in the GIS and operations research literature. Some of the data have been available from the lower-resolution sensors of the 1980s, but some types are becoming available now for the first time.

In a recent study, Norfolk Southern Corporation was faced with a corridor location problem, and compared a remote sensing/GIS solution with the visual



3-dimensional view of LIDAR surface with modeled and surveyed routes. Credit: John Jensen analysis of its engineers. The goal was to plan a 5 km stretch of railroad between the main line near Aiken, South Carolina and a new Bridgestone/Firestone Tire plant. A study was conducted in cooperation with the Affiliated Research Center (ARC) at the University of South Carolina. It took into account three cost factors: grade construction (cut/fill cost), road and stream crossings and track construction cost. Because of Norfolk's stipulation that the grade should never exceed 2%, it was necessary to use high resolution elevation data, i.e. LIDAR. The study area was divided into grid cells, each cell was assigned a value for each of the above cost factors, and an optimization model was used to find the best route. As shown in the illustration, on the previous page, the results of the algorithmic approach and the engineers' more traditional approach were largely in agreement.

In Australia, an integrated solution environment for the corridor location problem was developed at CSIRO and is now offered commercially by Quantm (*www. quantm.net*). Over a period of time these tools will inevitably be refined and will take into consideration more complex variables.

FORGING AHEAD: NCRST RESEARCH

This section reports on the research conducted by the NCRST during its first year. It is organized by consortium. There are projects that straddle consortium boundaries, or are duplicated between consortia. This allows different approaches to a problem to be pursued independently, and there are numerous occasions each year when the consortia compare notes and learn from each others' experiences.

Environmental Assessment

Transportation, Development and Land Cover Change in a Coastal Corridor

The three coastal counties in Mississippi have undergone considerable change in land use, population, wildlife habitat, demographics, and socio-economic conditions in the past 30 years. In that time, Interstate 10 (I-10) has been completed, extensive population growth has occurred, and the coastal counties have changed from being mostly small fishing and shrimping communities to communities with a complex mixture of residential, commercial, industrial, urban, resort, and relatively unspoiled coastal wilderness areas. The population has gone from around 240,000 in 1970 to over 350,000 in 2000.

The I-10 and Coastal Corridor project will investigate the changes that have occurred over the previous 30 years in the Mississippi coastal corridor's land cover and land use as well as the change in transportation infrastructure for the area over the same time period. Research objectives will include completion of a baseline study of historic land cover and land use, analysis of land cover and land use change, analysis of the relationships between land cover and land use change and transportation infrastructure development, and assessment of transportation corridor preservation opportunities and priorities in a coastal zone area with sensitive habitat areas and considerable population growth. An important goal of the project is to provide guidance and assistance in the detection of trends and spatial patterns that threaten environmental sustainability in a fragile coastal ecosystem. Work will be coordinated and communicated with resource agencies that have responsibilities in the area to assure the effective transfer of technology and results as well as to provide valuable ground-truthing and verification of the finding of the research components.

Regional-Scale Assessment

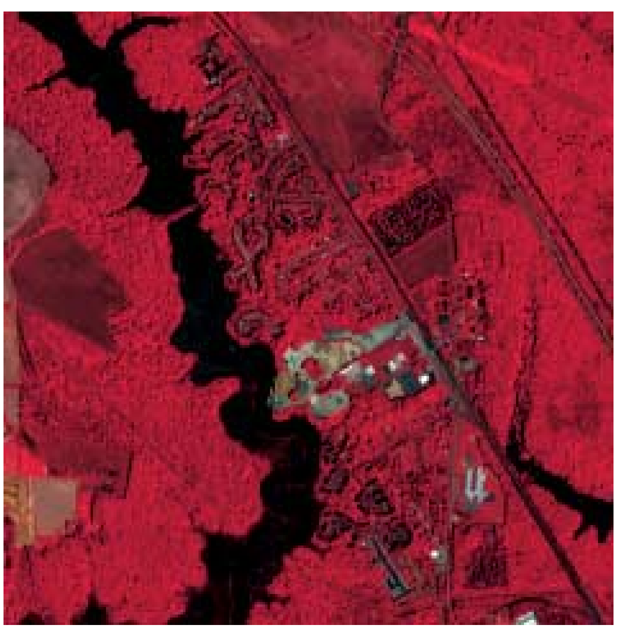
Within the Appalachian region, 55 counties of northeastern Alabama, northwestern Georgia, and south-central Tennessee are included in a regional environmental assessment. This region includes the metropolitan regions of Atlanta, Birmingham, Chattanooga, and Huntsville. The objective of this study is to determine the effect transportation development over the past 25 years has had on the regional-scale environment, including land cover/land use change, runoff, stream flow, socio-economic variables, etc. We expect to gain valuable insight into the relationship between transportation development and long-term environmental changes and possibly even rates of change from this study.

The assessment of regional impacts is being conducted by the Global Hydrology and Climate Center (GHCC), with scientists from Universities Space Research Association (USRA), NASA, the University of Alabama in Huntsville (UAH), Auburn University, and East-West Enterprises, Inc. representing government, academic, non-profit and for-profit commercial businesses. Plans for the coming year include (a) analysis of the transportation development history of the region; (b) analysis of the hydrologic data and identification of trends with respect to development history; (c) analysis of socio-economic data and identification of trends with respect to development history and (d) determination of relationships between transportation development and long-term environmental changes.

Streamlining Environmental Assessment

Since the passage of the National Environmental Policy Review Act of 1969 (NEPA), the Clean Air Act, the Clean Water Act, the Intermodal Surface Transportation Efficiency Act and other related legislation, transportation agencies must follow a time-consuming and costly environmental review process for transportation projects. A major task is investigating the use of remotely sensed data and geospatial technology to streamline processes in the area of regulatory compliance.

In North Carolina, EarthData is working closely with other companies and the state to evaluate opportunities to use remote sensing data and geospatial technology to streamline the environmental assessment process. The research uses remote sensing technologies for detecting environmental features of interest for transportation corridor studies. By providing a synoptic view of the project area, the analyst is able to identify features of interest with reduced need for field investigation. In addition, remote sensing analyses collect information over the entire corridor project area, rather than just specific sample locations, providing a more extensive information base from which to plan.



Credit: Space Imaging. www.spaceimaging.com

Using geospatial and image processing technology, the Ikonos image shown at left was analyzed for the presence of wetland vegetation. Wetland vegetative cover was identified in the image scene and areas shaded in green on the processed version of the image (not shown) indicate locations or areas that have been classified as containing wetland vegetation. By using a geographic information system (GIS) the processed image can be further analyzed to determine the relationship between the vegetative cover and other features that contribute to determine if wetlands exists at a location. Other features such as soils and flood duration are also important in determining if a wetland exists at a specific site. By combining soils data and other information with those areas where wetland vegetation has been identified, it is possible to identify and predict the presence of wetlands that meet some of, most of, or all of the criteria set forth for wetlands by the Corps of Engineers under Section 404 of the Clean Water Act.

Infrastructure Management

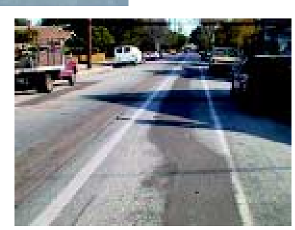
Remote sensing and image processing are only part of the solution in infrastructure management. We envisage these as part of a broader strategy that includes compatibility with legacy data sets, making data available to users when they want it, and integrating data from multiple sources into process models that address management needs (e.g. optimization models for corridor location). The following projects offer a sampling of a developing program in all these areas.

Centerline Geometry

Road centerline vector files are an important information management resource. In many states and local jurisdictions, staff rely on poor quality map files, with positional inaccuracies up to 200 m in places. This inhibits data exchange, and makes it impossible to work towards a future that will inevitably be dominated by GPS and other field locator technologies.

This road is easily detected from the air...

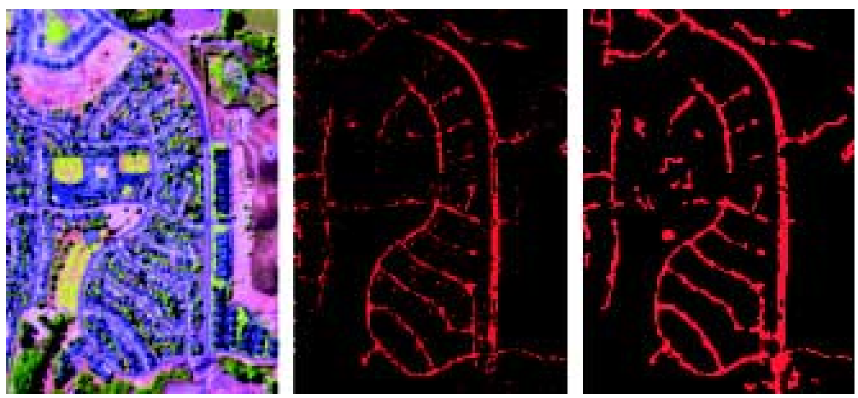
Derivation of centerlines from air photographs and digital imagery is a well established manual practice, a by-product of soft-copy photogrammetry. But photogrammetic extraction is expensive, and performed only when there is a specific project need. If this process can be automated, it would be possible to derive and to update centerlines more frequently. There are 4 steps in an automated solution: (1) find the concrete and asphalt pixels;



...this is not

(2) link the road pixels into vectorized centerline shapes; (3) conflate the centerlines with legacy databases to derive attributes; (4) calculate costs and benefits in comparison to other technologies such as GPS surveys. The first step is the most difficult. Ideally the road surface is completely visible from the air. But often there are patches and mixtures of materials, parked vehicles, shadows and tree overhangs, that obscure the concrete and asphalt pixels. Moreover, concrete and other roofing materials produce false positives.

We are exploring hyperspectral imagery as a solution. Examining infrared spectral signatures, it is possible to distinguish concrete from asphalt, parking lot asphalt from road asphalt, and rooftop concrete from road concrete. A complicating factor is that modern road surfaces are almost never pure concrete or asphalt — materials are mixed and aggregates varied to blend properties of strength, smoothness, traction and water occlusion, and newer materials such as rubberized asphalt are constantly being introduced. We have the algorithms to deal with spectral mixing, and we are developing a spectral library of these materials to assist in identification, but the taxonomy of materials may be the more challenging problem.



Extraction of centerlines. (a) Hyperspectral image (b) Likely road surfaces classified by reference to spectral library; (c) Unconnected pixel clusters rejected and linear patterns isolated.

We have made progress in the second step as well, linking linearly contiguous pixels into lines, omitting isolated pixels that represent rooftops. The third step, conflation, has previously been explored at UCSB. Estimation of relative costs and benefits will be the final step in this research. We are particularly interested in the comparison with GPS survey; not simply a comparison of dollar cost, but also the turnaround time in the event that centerline mapping is required at extremely short notice, e.g. in the aftermath of a disaster.

Pavement Condition

Mainstream aerial and satellite imagery is not yet of sufficient resolution to spot individual cracks and to measure their width — that is still the domain of the video log or pavement analysis vehicle. However, there are gross aspects of pavement condition that can be detected from airborne sensors. There are changes in spectral characteristics of pavement over time, due to the effects of weather and traffic. Although individual cracks may not be detectable in 1 m pixels, a pixel that represents cracked pavement is different from one showing an intact surface. Using interferometric interferometry methods it may be possible to detect subsidence of roadways, particularly differential subsidence that causes loss of cross gradient on cloverleaf ramps.

Bridge Location

States are required to support the FHWA's National Bridge Inventory by recording the latitude and longitude of bridges with 1–2 m accuracy. Traditionally, bridge locations have been recorded as linear measures; when related to rudimentary road centerline files, e.g. from the U.S. Census' TIGER database, there can be significant errors in the calculated latitude and longitude. We have created a simple ArcView extension to integrate imagery, centerlines and bridge locations in a convenient user interface, allowing an operator to observe incorrect locations and to adjust them as required. The software was developed for Wisconsin DOT, but could easily be adapted to work in other states, subject to availability of imagery of appropriate resolution.

Access Management and Accident Analysis

There is a significant correlation between access points on a road (e.g. curb cuts from strip malls) and vehicle accidents, both rear-end and broadside. Aerial photographs yield information on the number and placement of curb cuts and driveways, median strips, length of left turn lanes, obstructions to vision around corners, dimensions of crosswalks, and numerous other aspects of roadway inventory that are useful for micro-level planning. A project at the Iowa Center for Transportation Research and Education is comparing aerial and videolog methods of compiling the required information.

Airport Survey

Airport authorities are adopting digital methods for airspace analysis and layout planning. Three-dimensional Airspace Analysis Programs (3DAAP) and Digital Airport Layout Plans (DALPs) help to identify potential obstructions to aircraft approaches, and barriers that would impair visibility of aircraft from the control tower. LIDAR is proving to be a useful tool in this effort. At Plant City airport in Florida, we have documented LIDAR survey aircraft navigation accuracy in the 5–10cm range, and elevation data accuracy of less than 10cm.

Data Modeling

It seems incredible that there is a dearth of accurate centerline maps, considering that digital design drawings contain road centerlines, curblines, rights of way and signage, accurately and in great detail. The problem is that Computer Assisted Design (CAD) and GIS have historically existed in separate, incompatible worlds — by circumstance, not necessity. Environmental Systems Research Institute (ESRI, *www.esri.com*), a leading vendor of GIS software, sponsored a cost-match project at UCSB to develop a generic data model for transportation. Among other things, this was an opportunity to unify the CAD and GIS views of transportation features by means of an object model. A consortium of about 50 professionals helped define user needs, and in a series of meetings in the U.S. and Europe, and Internet exchanges, the draft model was critiqued and refined. In the context of the NCRST project, the Unified Network for Transportation (UNETRANS) achieves two goals. First, it defines objects in terms of open and recognizable features such as roadways, carriageways and lanes, that inherit properties as appropriate. If our research on centerline extraction creates a flood of new centerline data, the lack of a standard data model will be an impediment to dissemination of the data. Second, the model raises the possibility that CAD data could now be processed into centerlines more easily, and this could prove to be a cost-effective alternative to both GPS and remote sensing.

Transportation professionals need to become familiar with the vocabulary and techniques of remote sensing

Curriculum on Remote Sensing in Transportation

At user consultations and presentations in the course of our first year, we have heard repeated pleas for research findings to be expressed in "plain English." On the other side of the coin, there is a need for transportation professionals to become familiar with the vocabulary and techniques of remote sensing and geospatial information systems. To cater to this user group, we are creating a multi-faceted Internet-accessible education program. A curriculum is under development, that will be tied to the Remote Sensing Core Curriculum (sponsored by NASA, the National Center for Geographic Information and Analysis and the International Society for Photogrammetry and Remote Sensing) and the NCGIA Core Curricula in GIS. Glossaries and short blurbs on several technical topics round out the formal curriculum. Items are accessed via a user interface that offers multiple entry points: applications-oriented, technique-oriented and Frequently Asked Questions.

Traffic Flow

Using Remote Sensing to Monitor Truck Rest Area Availability and Utilization

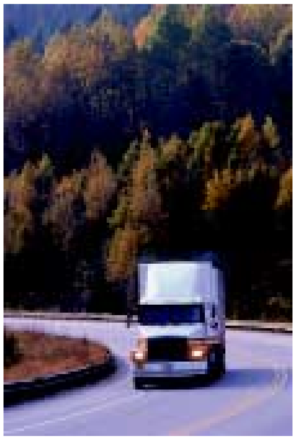
Trucks heavily use rest areas on interstate highways, particularly during the late evening and early morning hours. Most public rest areas on the primary system of highways now lack sufficient truck parking spaces. Consequently, overflow parking of trucks occurs on shoulders of entrance and exit ramps, on travel lane shoulders, and on entrance and exit ramps at nearby interchanges. This practice reduces the available pavement width and sight distance, creating traffic safety hazards. The parking space shortage also raises issues of driver fatigue and safety. In 1996 FHWA estimated a nationwide shortfall of 28,400 truck parking spaces at public rest areas. The shortfall is projected to reach about 36,000 spaces over the next 5 years. FHWA and several states have conducted studies of rest area requirements for commercial vehicles. These studies have relied primarily on field visits to truck stops and on telephone or mail surveys to collect data on the availability and utilization of truck parking spaces.

Remote sensing offers the potential of making such studies more responsive to operational and policy needs, but there is a need to assess the usefulness and practicality of this application. Two public rest areas were selected for field studies. One is located on I-66 west of Washington DC and Fairfax VA, near Manassas. The second is on I-95 south of Washington, near Dumfries VA. From visual analysis of images, we conclude that air photos will be an excellent data source for measuring truck activity at rest areas. Both parking spaces and vehicles are clearly visible in the images. The next step in this phase of the project will be to obtain ground truth data for these two sites and test various image processing algorithms for extracting useful data from the images.

Improving AADT and VMT Estimates

DOTs in many countries are interested in estimating vehicular traffic over their highway networks. The estimates are used to document and forecast trends and serve as inputs to planning and design studies. Many regional and local entities (*e.g.*, metropolitan planning agencies and municipal transportation or traffic divisions) are similarly interested in estimating vehicular traffic in their jurisdiction. Two popular summary measures of vehicular traffic are Average Annual Daily Traffic (AADT) and annual Vehicle Miles Traveled (VMT). The AADT's are estimated by using ground-based traffic recorders (primarily loop detectors and road tubes) to record traffic volumes on sampled segments. Data collection programs that support these estimates involve large equipment and labor expenses. In the U.S., for example, the state DOTs, at the urging of the federal government, attempt to obtain short-term samples of every segment in the network at least once every three years in an attempt to keep the error in the AADT's and VMT estimates low. Covering the networks on this three-year cycle requires substantial effort.

The data collection effort could conceivably be aided by using high-resolution satellite imagery, since it appears that vehicles can be distinguished in such imagery. This additional data source could therefore be used to decrease the error in the AADT and VMT estimates, to obtain the same level of error with less effort on the ground, or both. The difficulty is that high-resolution sensors are carried on satellites in low orbits that do not allow high-frequency temporal sampling of the links. Software was therefore developed to simulate the reduction in errors of AADT and VMT estimates. The results indicate that incorporating data obtained with the coverage pattern associated with high-resolution satellite sensors could markedly improve AADT and VMT estimation. The satellite data could be added to existing ground-based data to reduce the error in AADT and VMT estimates, while decreasing the ground-based sampling effort.



Traffic Flow Variables from Low-Flying Moving Platforms

Loop detectors in the pavement are the most commonly used devices for measuring traffic parameters; some agencies complement loops with other ground-based sensors (usually fixed video cameras). These can produce volume counts, occupancies and, with certain calibrations, average speeds. However, because they are fixed at a certain location, they cannot describe dynamic parameters such as vehicle origins and destinations, travel time, accelerations, decelerations and delays, which depend on the movement of vehicles over time and space. Remotely sensed flow data are of interest because data obtained from airborne platforms (airplanes, helicopters, satellites, tethered balloons, etc.) have the potential of supplying this information that otherwise cannot be acquired from ground-based sensors. Low-flying platforms allow more flexibility than satellites because they can be used at any location at any time of day, and they provide higher image resolution. Also, moving platforms provide the ability to follow sets of vehicles (platoons) as they progress through the network.

For this project, low-flying moving platforms were selected to track individual vehicles and measure traffic flow characteristics over time and space. The work has focused on two main areas: automated vehicle identification and tracking, and evaluation of data needs for measuring traffic flow variables. Vehicle matching can be done using vehicle features like color, shape or size or by estimating the vehicle's expected location in subsequent frames. The major difficulty is that in the case of heavy traffic, vehicles with similar characteristics (color, shape, size) may appear very close to each other in the same frame. The algorithm being developed for tracking vehicles uses a combination of vehicle color, shape, size and location to reduce the probability of having false matches. Once all the coding for frame transformation and vehicle matching is done, the entire process will be integrated to reduce the computational time.

Spectral Library of Civilian Vehicles

The spatial resolution of satellites is too low to identify many objects by their shape or specific detail. In some cases, it is possible to identify such objects by spectral measurements. The basis of multispectral remote sensing is that different types of objects can be distinguished on the basis of differences in their spectral signatures.

A set of spectral measurements of vehicle paints was performed in a parking lot at the University of Arizona. This measurement was repeated for different colors and shades of cars and various pavement types. The reflectance is plotted with respect to the wavelength. The reflectance value for the different colors is markedly different, especially in the wavelength 1500 to 1800 nm.

Hazards, Safety and Disaster Assessment

Over the years, researchers have developed many applications for remotely sensed data for a number of disciplines, including resource management, infrastructure development and maintenance, and urban planning. Many of these applications contain algorithms and methodologies that are applicable to transportation hazards, safety, and disaster assessment. The focus of this research is to survey a wide variety of remote sensing applications in order to build on prior experience. Because the high costs of data, software, and training have traditionally deterred the adoption of remote sensing in other applications, a cost analysis of remote sensing methods designed to weigh the benefits and drawbacks of incorporating these methods into transportation will be conducted. This survey will assist DOT and NASA in developing priorities for future data acquisition and research. An additional benefit will be an interactive resource on the utility and costs of utilizing remotely sensed data to address issues of transportation hazards, safety, and disaster assessment.

Road Trafficability/Safety on Tribal Lands

Native American communities, like many county governments, are typically deficient in basic infrastructure, and are lacking spatially explicit digital databases for managing their transportation networks. In addition to raising significant concerns about road safety and emergency access, absence of adequate road infrastructure severely impedes tribal economic development. Despite efforts to improve road surfaces on Indian reservations, many remain unimproved. Hence, severe weather reduces trafficability and causes roads to become impassable, limiting access to emergency vehicles. Because of the steep terrain and lack of ground cover, flash floods resulting from sudden, intense rains are also common in the region. Low lying road segments become flooded with rapidly rising waters, making some crossings dangerous or impassable. The resulting rutted surfaces remain long after the surface dries up, decreasing use by traffic. Improved roads may become impassable because of mudslides or erosion. Not only do such conditions reduce road safety and response time of emergency services, they make it difficult for local residents, often widely dispersed across the reservation, to reach their jobs and schools. Not surprisingly, road safety and trafficability are among the more significant public issues cited by tribal authorities. The focus of the EDAC research, working with the George Washington University Space Policy Institute, will be on the analysis and application of geospatial technologies that can assist tribal transportation authorities 1) in using remote sensing to help document plans to improve their road systems, and 2) training to use advanced geospatial technologies. The resultant analysis and results will have broad applicability to rural transportation networks off Indian Reservations and outside the Southwest.

Automated Network Extraction

Information on networks is fundamental for all transportation applications. Road network data are needed to dispatch emergency vehicles, plan evacuation routes, formulate transportation strategies, and implement controls for safety improvement or disaster mitigation. Many network databases exist, but for hazards and safety they lack accuracy and currency. In this application, advanced algorithms will be developed that automatically recognize, measure, and attribute urban and rural road networks from Ikonos-2 and similar high-resolution aerial and satellite images to provide accurate and up-to-date information.

Maintaining and Updating E-911 Transportation Networks

Enhanced-911 services are being extended to all Americans with a telephone and an address. In the western states this means that many isolated homes and communities must be mapped to develop the routing required to reach an address once an emergency has been reported. The dominance of low-growing vegetation in much of the Southwest and Intermountain West is conducive to utilizing 5-meter satellite imagery for mapping infrastructure. Well maintained primary and secondary roads, in which edges are clearly defined, are easily detectable on high resolution imagery because of the spectral contrast between the road and adjacent land. The challenge lies in detecting unimproved roads leading to isolated homes. In many cases the dwelling sites are observable on 5-meter imagery, but the roads are difficult to discern because spectral responses of the road surface and the surrounding landscape are very similar. This application will undertake a series of tests in different landscapes to evaluate the potential of remote sensed data in the delineation of unimproved roads.

Loss of Transportation Lifelines Due to Hazards

The focus of this research is to model the potential for losing critical transportation lifelines due to flood, fire, landslide, avalanche, earthquake, or contaminant release. The loss of lifelines can significantly impede travel, evacuation, and the deployment of relief in an emergency. An associated focus area is developing methods and tools for assessing the consequences of losing critical transportation lifelines. This problem is exacerbated in situations that increase a population through attendance at special events. The 2002 Winter Olympics in Salt Lake City are an opportunity to test the impacts of a sharp increase in population on the potential for a significant increase in emergency response time.

Hazard Vulnerability Change Detection

Hazardous areas often evolve into dense urban areas over time, as new homes, commercial activities, and transportation network improvements are developed. Generally, there is little consideration for the increasing hazard vulnerability facing the population in any given area, particularly if the recurrence interval between events is long. The focus of this research area is on developing methods and tools that allow emergency managers to monitor these changing hazard vulnerabilities. Salt Lake City and Las Vegas represent two prime research study areas, as rapid urbanization is occurring in historically hazardous areas in both these cities.

Integrating Remote Sensing with OREMS

Urban and regional emergency evacuation are viable alternatives for responding to natural disasters or human calamities. Evacuation modeling systems (EMSs) have been developed to facilitate evacuation planning, analysis, and execution. They require data from road maps, traffic control characteristics, and population distribution, among others, to delineate emergency zones, estimate the population at risk, and determine evacuation routes. Traditional ways of collecting and integrating data with EMS, however, are time consuming, and in many cases cannot assure data currency. This proposed application will investigate approaches for integrating information from remotely sensed data into OREMS.

Concluding Remarks

Technical Challenges

Transportation has become a viable application of remote sensing only relatively recently, as the resolution of sensors has improved to the 1–5 m range. This raises exciting possibilities in terms of the potential to integrate GIS and vast data resources, as detailed in this and the previous section. On the other hand there are challenges:

First, satellite imagery costs are high, and are likely to remain so until a larger user base develops, and vendors enjoy the benefits of a mass market and return on investment. Second, airborne sensing is expensive, and considerable lead time is required to plan a data acquisition mission. While airborne LIDAR and hyperspectral sensing have been painted as attractive technologies, they are not universally available. Third, it is still impossible for civilian users to obtain real-time imagery from satellites. Turnaround time is at least 48 hours; this places a significant cap on the types of applications that can be addressed. It is reasonable to think strategically about problems in annual and perhaps quarterly time frames (e.g. corridor planning; pavement renewal), but tactical operations, e.g. real time emergency response, are not currently viable.

Implementation Challenges

All this will certainly change as cameras become inexpensive and ubiquitous, ITS technologies place more sensors at our disposable, computers become wearable and wireless data communication becomes the norm. Research into new applications, and cost comparisons against traditional methods, promise to be ongoing activities. It is encouraging to see that transportation managers have not just coped with recent change, but have seen an opportunity in the new technology and responded with cooperative strategies and imaginative projects.

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