Engineering Applications of Airborne Scanning Lasers: Reports From the Field

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Several organizations and private enterprises have undertaken some challenging and unique mapping projects during 1996 and 1997. What distinguishes these projects from standard surveying and mapping operations is that they were performed with scanning airborne laser systems. The focus of these operations is to provide digital elevation information to engineers, scientists and commercial users to perform engineering-related tasks.

THANKS TO PIONEERING efforts by NASA and the ATM (Airborne Terrain Mapper) group at Wallops Island, airborne laser scanning has long been established as a topographic research tool. In the last five years, the airborne remote sensing sector has seen this technology emerge as an extremely rapid and highly accurate terrain-mapping tool. This development has spawned innovative solutions to difficult mapping problems. While there are only a few commercial manufacturers of such systems and little more than a handful of operators of airborne laser scanners, the use of these systems is growing quickly.

The following article discusses some of the innovative uses of airborne scanning lasers as applied to engineering projects. The focus will be on several samples of reports provided by commercial operators and researchers in the fields of Highway, Coastal and Power Line Engineering.

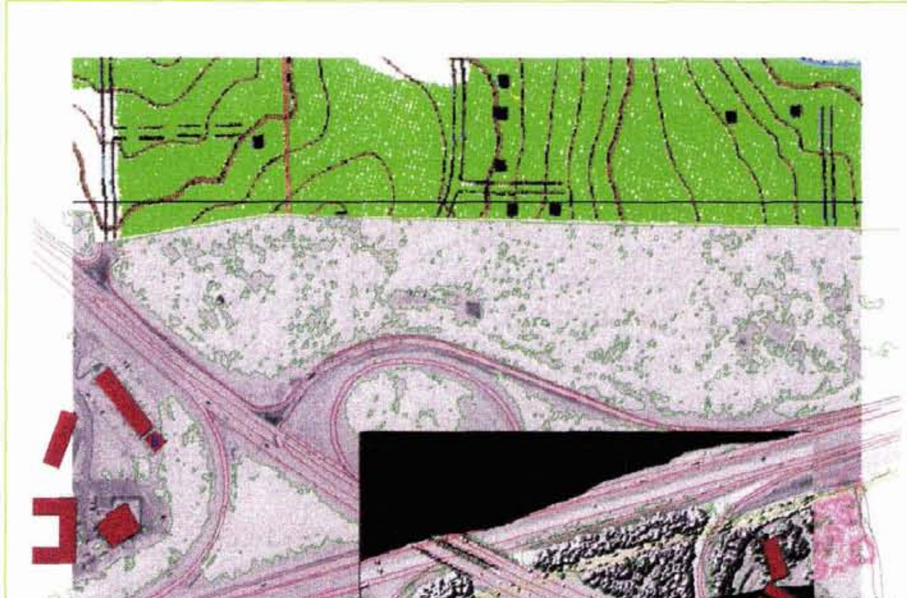

FIGURE 1. The intersection of Interstate Highway 1-10 and State Highway 63 near Tallahassee, FL, mapped by a team of University of Florida researchers and Optech personnel in November 1996.

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Introduction

The basic concepts of airborne laser terrain (ALTM) mapping are simple. A pulsed laser is optically coupled to a beam director which scans the laser pulses over a "swath" of terrain, usually centered on, and co-linear with, the flight path of the aircraft in which the system is mounted. The round trip travel times of the laser pulses from the aircraft to the ground (or objects such as buildings, trees, power lines) are measured with a precise interval timer and the time intervals are converted into a range of measurements using the velocity of light. The position of the aircraft at the epoch of each measurement is determined by phase difference kinematic Global Positioning System (GPS). Rotational positions of the beam director are combined with aircraft roll, pitch and heading values determined with an inertial navigation system, and the range measurements to obtain vectors from the aircraft to the ground points. When these vectors are added to the aircraft locations they yield accurate coordinates of points on the surface of the terrain.

Solid state lasers are now available that can produce thousands of pulses of light per second, each pulse having a duration of a few nanoseconds (10-9 seconds). Light travels approximately 30 centimeters in one nanosecond. By accurately timing the round trip travel time of the light pulses from the laser to a reflecting surface it is possible to determine the distance from the laser to the surface, typically with a precision of one centimeter or better. Errors in the location and orientation of the aircraft, the beam director angle, atmospheric refraction model, and several other sources degrade the coordinates of the surface points to 5 to 10 centimeters, in the current state of the art systems. The width of the "swath" covered in a single pass of the aircraft depends on the scan angle of the laser ranging system and the airplane height. Typical operating specifications permit flying speeds of 200 to 250 kilometers per hour (55 to 70 meters per second), flying heights of 300 to 3,000 meters, scan angles up to 20 degrees, and pulse rates of 2,000 to 25,000 pulses per second. These parameters can be selected to yield a measurement point every few meters, with a footprint of 10 to 15 centimeters, providing enough information to create a digital terrain model (DTM) adequate for many engineering applications, including the design of drainage systems, the alignment of highways, the determination of volumes of earth works, and the design of coastal structures.

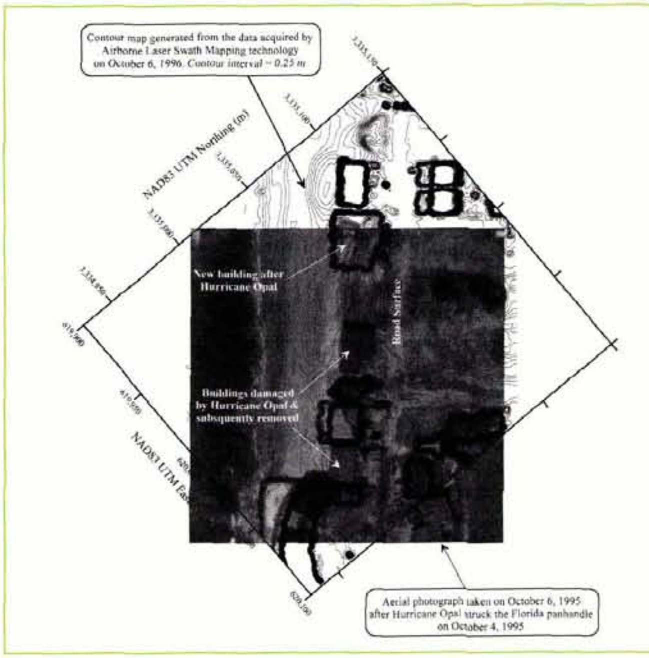

FIGURE 2. An example of one product produced from the data covering a few hundred meters of beach area in which a number of buildings were severely damaged.

Highway Engineering

ALTM is particularly well suited to mapping lineal areas such as the right of ways of highways. The aircraft can be flown directly along the centerline of the highway, resulting in the mapping only of the area of interest, and providing a digital terrain map with high spatial resolution, capturing information about the pavement, drainage system, and vegetation.

Figure 1 at the intersection of Interstate Highway 1-10 and State Highway 63 near Tallahassee, Florida, mapped by a team of University of Florida researchers and Optech personnel in November 1996. A digitized version of the US Geological Survey quad sheet (based on 1967 photography and revised in 1976 to include some new photography collected by Florida state agencies) was overlaid with a strip of 0.5 meter resolution digital photographs collected as part of the University research program in 1997. Features such as the edges of pavement and buildings were delineated using the 1997 digital photography, and a DTM created from the laser swath mapping data was then overlaid on a portion of the digital photograph to show how these various types of data can be combined into a single product that can be used by highway engineers.

Coastal Engineering

On October 4, 1995, Hurricane Opal struck the panhandle region of Florida doing severe damage to the beaches and buildings. In October 1996 researchers from the University of Florida, supported by Optech personnel, surveyed the beach area using an Optech 1020 ALTM system, mounted in a Florida Department of transportation aircraft. More than 200 kilometers of shoreline were mapped twice, in opposite directions of flight, in just over two hours. Figure 2 is an example of one product produced from the data covering a few hundred meters of beach area in which a number of buildings were severely damaged.

The laser data were used to generate a contour map, which is shown as an overlay on an aerial photograph taken on October 6, 1995, just two days after the storm. In the thirteen months between the date of the photograph and the date of the laser contour map two of the more severely damaged buildings were torn down and a new building was erected on previously undeveloped beachfront property. The laser contour map provides footprints of the buildings at the time of the survey, and surface of the land after removal of the storm damaged buildings.

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We have been watching with great interest the activities of airborne scanning lasers since the First International Airborne Remote Sensing Conference in Strasbourg in September 1994. In the summer of 1997 we had the opportunity to become more closely acquainted with Optech Inc. after our company Opten Ltd., whose major area of business is the design and installation of fiber optic communication lines, purchased the laser sensor ALTM 1020 for power transmission line precision surveys. We started with a large airborne survey project along Ulan-Ude - Blagoveshensk line and within 10 days surveyed over 5,000 km of transmission lines using a local Mi-8 helicopter. Complete installation of on-board equipment only took us two days.

Trying to determine the exact location of each support tower is extremely difficult. Available information about the towers and their location and also as-built drawings, are either very scarce or altogether non-existent. Therefore, the complete Trans-Siberian powerline corridor needed to be surveyed to obtain detailed information regarding the tower locations. In addition to tower location, accurate topographic information about the terrain in proximity to the lines and towers was required to establish routes to the towers as well as possible encroachment by vegetation. Figure 3 shows a profile view of a section of powerline corridor. Clearly visible are the "conductors" as well as parts of the tower structure. Below the lines and towers are vegetation and terrain. The data in this image are the results of a "decimation" process applied to the data set. All points were first classified as "vegetation," "terrain," "wires," or "intersection points" (support towers). Then a "removal" algorithm is applied that eliminates approximately 70-90% of all points, leaving the majority of points that fall on the terrain below the wires, the wires themselves, or the towers.

The results of laser scanning are especially impressive when compared with traditional methods of power lines survey. Along with tremendous productivity — around 500-600 km per day, the method also provides accuracy of 15-20 cm for ground objects' geometric parameters, that is completely unattainable for traditional stereo photogrammetric methods. Here we have first gotten the opportunity to directly analyze the 3-dimensional observance that significantly increased efficiency of survey results interpretation and consequent topical decoding.

The other remote sensing methods that were tested and evaluated were aerial photo, thermal IR, SAR, high-resolution video and low-altitude digital aerial photo. A combination of airborne laser scanning and video seems to be the most reliable and efficient means of gathering digital elevation and imagery information about the lines and towers.

The reason Opten requires this detailed geographic information about the towers, is that the shield or "ground" wire will be replaced on the powerline with specially shielded high-speed fiber optic communication cable. Since fiber optic cable is quite expensive, a substantial savings is realized by having precise information regarding the location and height of existing lines and towers. This allows "cut-lengths" to be prepared at the factory and then delivered directly to the installation site without additional alteration of the cable, other than splicing.

We certainly do not limit application of the technology to only power lines surveys. ALTM applications, along with modern digital airborne cameras for creating general-purpose topographic maps, appear to hold much prospect. Such an approach shall first allow us to make labor intensive and expensive processes like orthorectification and photomaps synthesis completely automatic.

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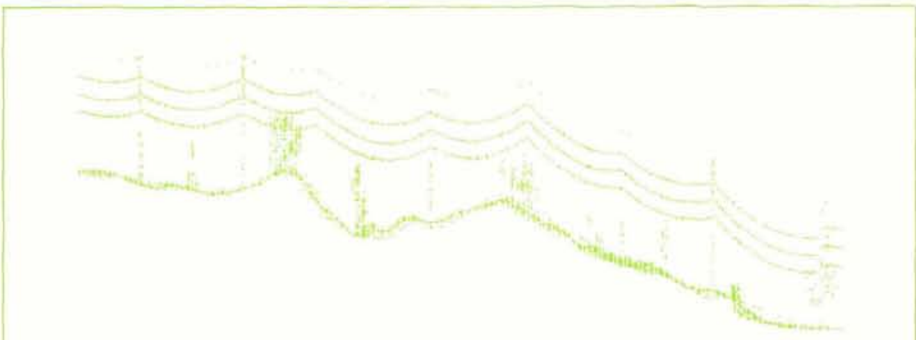
Over the last three years, the Bureau of Economic Geology (BEG) and Center for Space Research (CSR) at the University of Texas at Austin have monitored Galveston Island and Bolivar Peninsula on the Texas Gulf coast. With the support of the NASA Topography and Surface Change Program, the BEG and CSR are developing new techniques for studying coastal processes using

FIGURE 3. A profile view of a section of powerline corridor. Clearly visible are the "conductors" as well as parts of the tower structure. Below the lines and towers are vegetation and terrain. The data in this image are the results of a "decimation" process applied to the data set.



conventional ground surveys, ground Global Positioning System (GPS) surveys, and NASA's Topographic Airborne Synthetic Aperture Radar (TOPSAR). This fall our research group began using airborne laser terrain mapping (ALTM). On November 8, 1997, we flew over Galveston Island and Bolivar Peninsula with an Optech ALTM-1020 airborne laser terrain mapping system. With the instrument installed in a single-engine Cessna 206 (Figure 4), we mapped over 163 sq. km in one day with a laser ground point spacing of 2 to 6 m. The Optech engineers processed the raw data on a laptop computer and had a preliminary ALTM data set available the next day.

ALTM data from adjacent flightlines over Bolivar Peninsula were merged together without any adjustments and then gridded to create a smooth digital terrain model (DTM). Figure 5 is a shaded relief topographic image of the Port Bolivar area, the west end of Bolivar Peninsula. This image has a spatial resolution of five meters and is constructed from approximately 3.2 million laser ground points distributed over the 5 km x 7 km area. Vegetation and cultural features (roads, buildings, ships, jetties) are clearly discernible in the topographic image. The Intracoastal Waterway with barge traffic is visible along the upper left-hand edge of the image.

Identifiable geomorphic features include the shoreline, beach and foredunes, a series of accretionary spits, relict beach ridges, and small tidal creeks. A kinematic, differential GPS ground survey was conducted across the west end of Bolivar Peninsula; note the line A to A' on the topographic image. Figure 6 is a plot comparing the ground GPS survey (+) to the topography measured by the ALTM laser system (o). The laser profile is noisier than the GPS, nevertheless, the ALTM profile closely matches the ground GPS profile in all significant details.

Figure 7 is an oblique, hand-held aerial photograph of Fort Travis, a 100-year-old fortification on Bolivar Peninsula. This photo was taken during the ALTM flight. Figure 8 is a three-dimensional, elevation contour plot of Fort Travis computed from the laser DTM. The contour interval is 0.5 m and vertical exaggeration is 2X. This contour plot demonstrates the near-photographic resolution of airborne laser terrain mapping. The low seawall around the fortification is discernible, and roads, trees, and small buildings are all recognizable on the plot and easy to correlate with the identical features on the photograph.

In Figure 9, the dunes and seawall are visible, looking in an easterly direction along the Galveston city shorefront. Figure 10 is a three-dimensional, elevation contour plot of the Galveston city shorefront derived from a single, 300m-wide mapping swath flown at an altitude of 470 m

FIGURE 4. An Optech ALTM-1020 airborne laser terrain mapping system was installed in this single-engine Cessna 206 to map over 163 sq. km in one day over Galveston Island and Bolivar Peninsula.

(AGL). The contour interval is 0.25 m and the vertical exaggeration is 2x. On the left are shorefront buildings in downtown Galveston; in the center are Seawall Boulevard (with cars) and the Galveston seawall. Projecting from the seawall is a low groin and various hotels and restaurants on piers. Contour lines in front of the seawall define a gently sloping artificial beach and more chaotic contour lines seaward of the beach reflect wave heights in the surf zone.

Our experience with the ALTM system convinces us that airborne laser mapping has the potential to revolutionize coastal geology and engineering. Until now, observations of coastal processes have been restricted to either detailed surveys at widely distributed points along a coastline or regional studies using maps, aerial photography, or remote sensing systems of relatively low resolution. Airborne laser mapping combines the resolution of ground surveys with large area coverage. The accuracy of GPS positioning and the high resolution of airborne laser mapping will allow us to compare coastal surveys conducted years apart and identify areas of change. By monitoring such changes, we will be able to delineate areas at risk from storms, land subsidence, and beach erosion with unprecedented accuracy. With detailed geomorphologic information we can estimate sediment transport rates along the entire Texas Gulf coast and relate variations in wind and wave regime, currents, and river flow to coastal patterns of beach accretion or erosion.

Conclusion

Employing airborne scanning lasers as terrain and object mapping tools will continue to grow as an aid in the analysis carried out by scientists and engineers. For example, Figure 11 is a DTM of a spillway structure. Gathering data about the condition of constructions that are engineered to prevent flooding disasters is imperative to maintaining these structures.

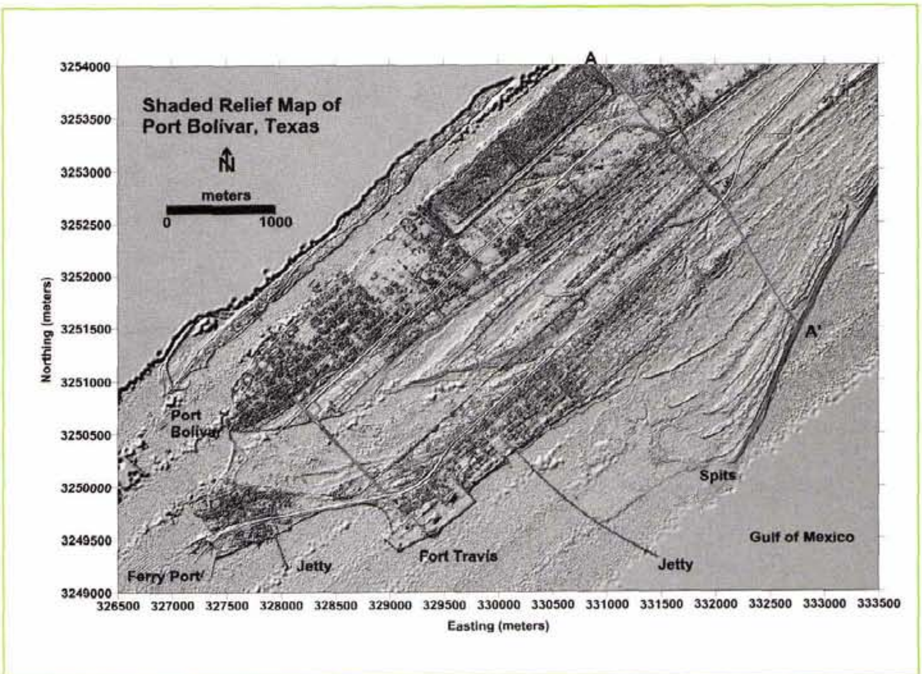
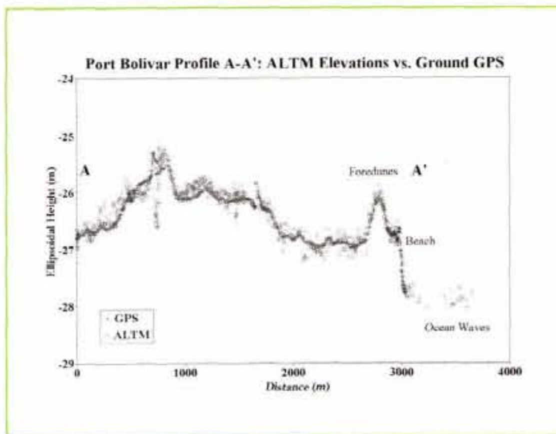


FIGURE 5 (ABOVE). A shaded relief topographic image of the Port Bolivar area, the west end of Bolivar Peninsula.

FIGURE 6 (RIGHT). A plot comparing the ground GPS survey (+) to the topography measured by the ALTM laser system (o).

FIGURE 7 (BELOW). An oblique, hand-held aerial photograph of Fort Travis, a 100 year-old fortification on Bolivar Peninsula. This photo was taken during the ALTM flight.



Laser scanning can be used more effectively than many standard methods since it can be mobilized rapidly and provide data almost instantaneosly. Following a storm event, engineers often need to acquire data at night or in poor weather. This means that almost all other methods of remote sensing cannot fulfil the requirement. Laser scanners can be flown in the dark and in bad weather, thereby providing a powerful remote sensing tool.

In an effort to gather elevation data about the 40% of land that is below sealevel, the Rijkswaterstaat in Holland has recently mandated that the entire country be mapped using airborne laser scanners. The engineers in the Rijkswaterstaat certainly know the benefit of having detailed knowledge about the terrain elevation in their flood-prone environment.

References

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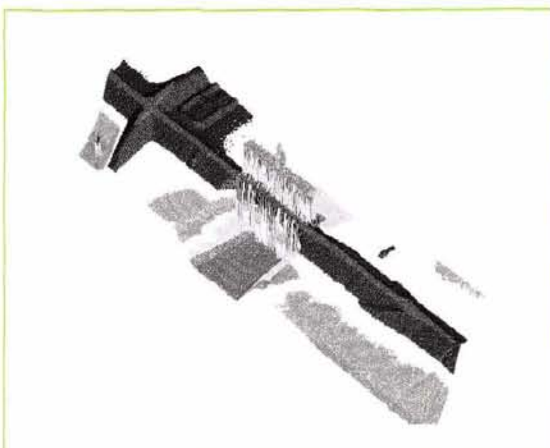

FIGURE 8 (TOP). A three-dimensional, elevation contour plot of Fort Travis computed from the laser DTM.

FIGURE 9 (ABOVE). *The dunes and seawall from an easterly direction* along the Galveston city shorefront.

FIGURE 10 (FAR LEFT). A three-dimensional, elevation contour plot of the Galveston city shorefront.

FIGURE 11 (LEFT). A DTM of a spillway structure.