# EVALUATION OF AIRBORNE LIDAR DIGITAL TERRAIN MAPPING FOR HIGHWAY CORRIDOR PLANNING AND DESIGN

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## ABSTRACT

This paper presents some results of a recent study that has evaluated data accuracy, efficiency, and cost-effectiveness of this remote-sensing LIDAR technology as compared to the conventional aerial photogrammetry and ground total station methods for terrain data acquisition and mapping. An overview of airborne laser mapping technology for producing digital terrain models and digital databases for highway planning and design applications are presented. Airborne LIDAR (Light Detection And Ranging) permits elevation accuracy of 15 cm (6 in.) and up to 0.3-m (1-ft) contours. There are no operating constraints, such as cloud and vegetation cover, traffic and usage, or time of day. Spaceborne remote sensing imagery from modern satellites is relatively inexpensive and rapid. Appropriate data analysis of modern high-resolution imagery can provide up-to-date spatial information on highway corridors and surrounding areas. This can be a cost-effective alternative for conventional aerial photography and an excellent base layer for overlaying digital LIDAR elevation data and contours.

## INTRODUCTION

Accurate terrain mapping is important for highway corridor planning and design, environmental impact assessment, and infrastructure asset management. As discussed in depth by Hudson, Haas, and Uddin (1997), the management of transportation infrastructure assets can be more efficient and cost-effective by using a geographical information system (GIS) for defining georeferenced locations, storing attribute data, and displaying data on maps. Collecting good-quality geographical coordinate data by traditional ground-based manual methods may require a substantial investment depending upon the size of the assets. In the case of natural or orchestrated disasters, the assessment of damage and re-building can be costly and time-consuming if the inventory and terrain model data are not easily available. Safe and efficient mobility of goods and people requires periodic monitoring and maintenance of all transportation infrastructure components within the right-of-way including the following: pavements, bridges, tunnels, interchanges, roadside safety structures, and drainage structures. These data collection activities require time- and labor-intensive efforts. In many parts of the world, highway data are collected at highway speed using noncontact photography, video, laser, acoustic, radar, and infrared sensors. These terrestrial noncontact technologies may suffer limitations resulting from time of day, traffic congestion, and proximity to urban locations. Additionally, traditional terrestrial ground surveys can be quite hazardous, especially in the areas of maintenance work zones. Modern airborne and spaceborne remote-sensing technologies offer cost-effective terrain mapping, inventory, and monitoring data collection (Al-Turk and Uddin, 1999).

## OVERVIEW OF REMOTE SENSING TECHNOLOGIES

Remote-sensing earth observations from aircraft (airborne) or satellites (spaceborne) are used to assess ground topography and provide the data and/or derived information to users. Traditionally, high-altitude (about 3,000 m or 10,000 ft above ground) commercial aerial photogrammetry (passive sensor) has been used to produce orthorectified photos and digital elevation models for most transportation and landuse planning and engineering studies. The new innovative airborne laser survey missions (active sensors) are flown at about 500 m or 1,500 ft above ground level. Several key components on airside and landside operations are similar in these airborne technologies. Table 1 compares operating characteristics and data resolution of several remote sensing technologies (Uddin and Al-Turk, 2001).

Table 1. Comparison of the new 'high resolution' spaceborne and airborne remote sensing technologies (Uddin and Al-Turk, 2001)

| Satellite/ Airborne | Spatial Resolution | Spectral Resolution | Temporal Resolution (days) | Footprint (km x km) |
|---|---|---|---|---|
| Landsat 7 | 15 m | 7 bands | 16 | 185 x 185 |
| IKONOS | 1 m | 3 bands | 3.5 -5 | 11 x 11 |
| QuickBird2 | 0.62 m | 3 bands | 1.5- 4 | 16.5 x 16.5 |
| ASTER | VNIR: 15 m<br>IR: 30-90 m | 14 bands | In Space Shuttle | Variable |
| Obrview4 | 1m | 4 bands | 3 | 8 x 8 |
| SPOT 5 (A,B) | 2.5 m<br>20 m (Mid IR) | 4 bands | 1- 4 | 60 x 60 |
| **Aerial** Photo | Up to 0.15 m | Visible band | On Demand | 2 x 2 at 3,000 m |
| **Airborne** LIDAR | Up to 0.15 m | NIR band | On Demand | Very Dense * |

IR = Infrared, NIR = Near Infrared, VNIR = Very Near Infrared

* LIDAR measurement at 500 m above terrain level: about 1 m x 1 m on ground

Spaceborne satellite remote sensing offers relatively inexpensive and unprecedented amounts of high-resolution data collected several times a year, particularly at regional and national levels. Appropriate imagery data analysis can provide up-to-date information on transportation corridors and surrounding areas. This capability can assist in studying the type and extent of land and space use, as well as their effects on the transportation network, environment, and quality of life (TRB, 2001). Satellites orbiting several hundred kilometers above the Earth have provided low-resolution images and sensor data.

Modern commercial spaceborne imagery has high spatial resolution, as shown in Table 1. Examples are: IKONOS-2 satellite remote-sensing system, launched by Space Imaging, Inc. in 1999, which is a good source of high-resolution 1 x 1-m panchromatic and 4 x 4-m multispectral digital imagery data and related value-added products.

The DigitalGlobe's Quickbird2 satellite is now providing the highest resolution submeter imagery. However, these images do not provide this accuracy in altitude data, which is needed for accurate terrain mapping applications of highway corridor planning and design. Airborne LIDAR survey provides digital elevation data at an accuracy of 15-20 cm.

Highway planning and integration of asset management systems, using GIS by a highway agency and municipal or metropolitan authority, provides a cost-effective approach to share common georeferencing and attribute data and reduce demand on computer workstations and related resources. The data can be accessed by all agency users and can be utilized for public outreach using Internet sources. Most of the GIS databases and maps are based upon the United States Geographic Survey (USGS) 7.5-minute quadrangle maps (scale 1:24,000), and minimal conventional survey data at 6-m (20-ft) or 3-m (10-ft) contours. The lack of accuracy and inherent low resolution of USGS data limit their use to conduct solid engineering analysis and develop cost-effective designs for large-scale networks. Appropriate analysis of the radiometrically and geometrically calibrated modern remote-sensor data provides much needed and useful information for transportation and environmental planners (examples: digital elevation models, accurate mapping of buildings and roads, and planimetric products).

## AIRBORNE LIDAR TECHNOLOGY

### Principles

LIDAR is an acronym for LIght Detection And Ranging. The electromagnetic spectrum is defined in terms of wavelength. The wavelength of the light range is from about 1mm for the far infrared to about 10 nm for the extreme ultraviolet. The remote- sensing LIDAR pulse measurements in the near-infrared band use laser pulses from a low-altitude aircraft to transmit and receive electromagnetic radiations. By knowing the time of returns and the speed of light, vertical distances from the aircraft to the ground are calculated.

The airborne LIDAR survey, also called Airborne Laser Terrain Mapping (ALTM) technology, is a cost-effective, efficient method for creating high-resolution digital terrain models (DTM) and contours for transportation and environmental applications. This airborne remote-sensing technology is used in conjunction with Global Positioning System (GPS) receivers and aerial photography.

### Operating Protocols

The LIDAR technology has few constraints typical to conventional topographic survey methods. It can survey day and night, at altitudes between 300 and 900 m (1,000 to 3,000 ft) above ground, over any terrain, and through most vegetation and canopy. Most of the highway application surveys are conducted at a height of 500 m (1,500 ft) above ground level, as illustrated in Figure 1. The flexibility of day and night missions is subjected to usual constraints of flying aircraft at relatively low altitudes due to applicable aviation rules. An airborne platform provides non-intrusive operation and no interference with highway traffic. A twin-turbo-prop Cessna aircraft is used for ALTM missions. Before a flight, a ground-based GPS is set up on a known point in the survey area. Flight planning determines optimal LIDAR settings and aircraft parameters. A typical survey can collect data at a rate of up to 81 sq. km (20,000 acres) per day.

From an aircraft flying a pattern over the survey area, a focused infrared laser (eye-safe at survey altitudes) sends up to 5,000 pulses per second to the ground. A high-accuracy scanner sweeps the laser pulses across the flight path and collects the reflected light. By varying the aircraft altitude, the aircraft speed, the scanner angle, and the scanner frequency, the operator is able to program ground point spacing to fit the particular survey mission. All this information is stored on an 8- mm tape and tied to the GPS time tags.

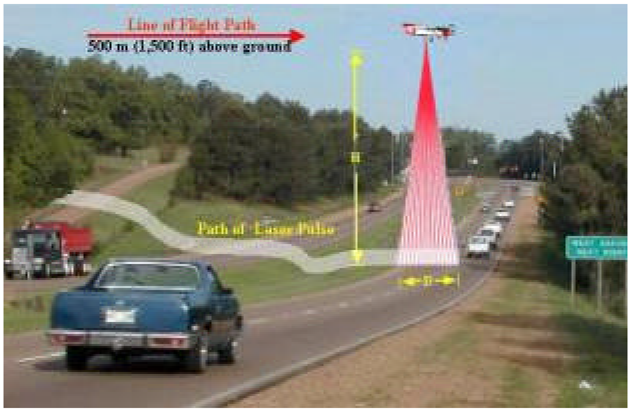

Figure 1. Principle of airborne LIDAR terrain mapping survey

### Processing of LIDAR Data

Following the flight, the data tapes are transferred to a ground-based computer station where a display of the recorded data is immediately made available. When the data processing of x, y, and z coordinates is complete, a color-coded map is generated. Examples of the color-coded map of contours at 0.3-m (1-ft) intervals are presented by Uddin and Al-Turk (2001) for the I-55 interchange in Ridgeland near Jackson, Mississippi.

### GIS Applications

GIS software has the ability of displaying data in different layers. Each layer displays sorted information. Thus the complicated highway and airfield planning and design data can be displayed in different layers. In a conceptual design of a GIS product for highway corridor planning and design, each layer represents one aspect of the design, and one or more attribute tables can be related to this layer to store inventory and other text information.

Three-dimensional digital LIDAR coordinate data are directly loaded into terrain mapping, GIS, or CAD software. This computerized data collection and transfer leads to efficient, error-free data processing, map generation, and asset management databases. Conventional ground based topographic surveys are slow. They are limited by operating constraints and time-consuming data processing.

## LIDAR EVALUATION STUDY FOR RALEIGH BYPASS ALIGNMENT

### Study Site and Field Evaluation

The results of a recent airborne remote-sensing technology evaluation study funded by the National Atmospheric and Space Administration (NASA) Stennis Space Center through the Mississippi Space Commerce Initiative (MSCI) and supported by the Mississippi Department of Transportation (DOT) are presented. The airborne LIDAR remote sensing digital mapping technology, in conjunction with GPS receivers and aerial photography, was evaluated by the Center for Advanced Infrastructure Technology (CAIT) at the University of Mississippi (UM). The study is focused on an 8-km (5.9-mile) long highway alignment project of the Raleigh Bypass near Jackson, Mississippi. Figure 2 shows the study site and control GPS locations used for LIDAR survey.

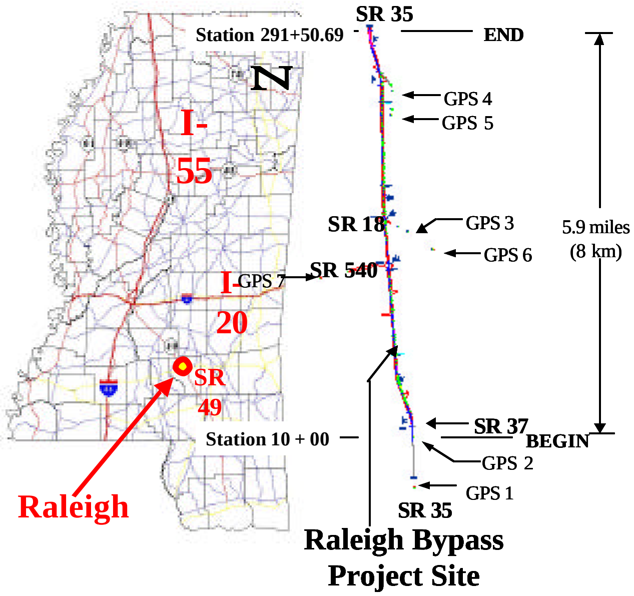

Figure 2. Location of LIDAR study area – Raleigh Bypass, Smith County, Mississippi

The LIDAR survey was conducted during a two-hour flight, and all laser and GPS data were stored on a one-GB 8-mm tape. The conventional topographical survey was completed in several months just for data collection because of the presence of thick forest and farmland.

The immense benefit of airborne LIDAR is the speed of collecting and processing data, which is being accurately documented and validated in this first independent study of airborne LIDAR. Some examples of LIDAR data collection equipment, orthorectified georeferenced raster digital images, and vector contour maps from LIDAR data have been presented by Uddin et al (2001). A bare-earth terrain model was developed after filtering the data through a vegetation-removal software. Subsequently 0.3 m (1-ft) interval contours were generated through CAD software. The digital maps produced by processing laser data can be superimposed on orthorectified digital aerial photo images for highway alignment design and other numerous civil and environmental applications, as shown in Figure 3.

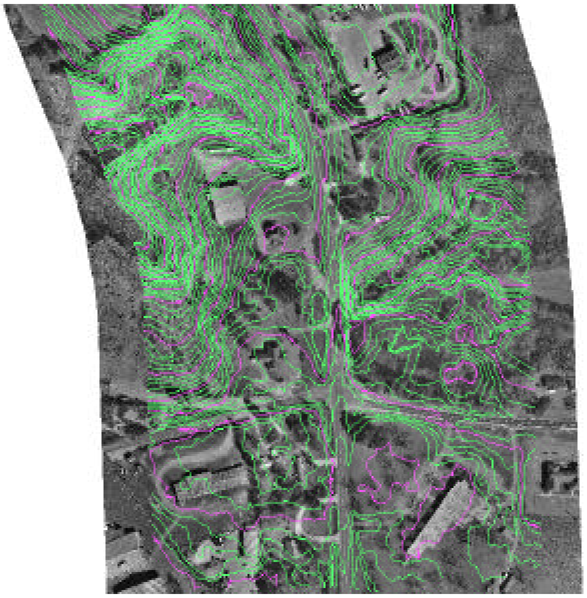

Figure 3. Overlay of LIDAR contour map on orthorectified aerial photo image
for a section of Raleigh Bypass project site, Mississippi

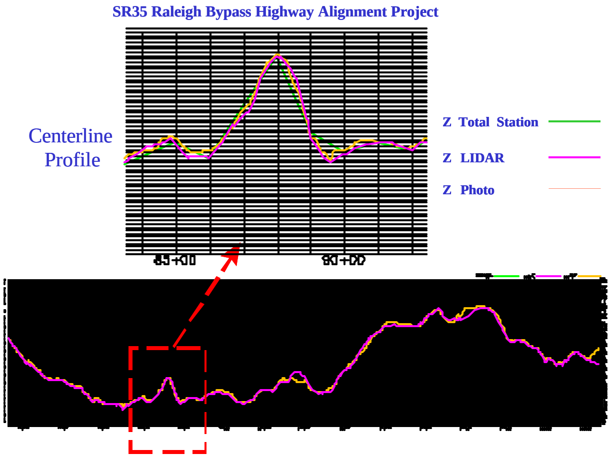

Figure 4. Comparison of centerline profiles from the three topographic survey methods

### Data Accuracy and Cost Savings

The elevation data of the centerline profile and cross-sections of the Raleigh Bypass highway project were compared using all three methods (airborne LIDAR, aerial photogrammetry, and ground total station). There is no statistically significant difference in the mean elevation data from the three methods at a 95 percent confidence level. Figure 4 compares the centerline profile data in a partial view. The RMSE value calculated from a comparison of the LIDAR and ground total station data was 15 to 18 cm depending upon the location of this wooded and rolling terrain. This site has about 45 m (150 ft) maximum difference in elevation, as shown in Figure 5.

The combined costs of LIDAR for contour maps and the ground-based total station for the layout and staking is almost half of the cost of the conventional total station survey without LIDAR data for Raleigh Bypass study. However, cost savings will be substantially higher for larger areas, difficult terrain, and heavily populated and congested urban areas (Uddin and Al-Turk, 2001). The results of Raleigh Bypass study show that a combination of airborne LIDAR survey and total station for wooded and difficult areas and staking out centerline and cross-sections provide the most accurate, efficient and cost-effective strategy for highway alignment and subsequent roadway design applications.

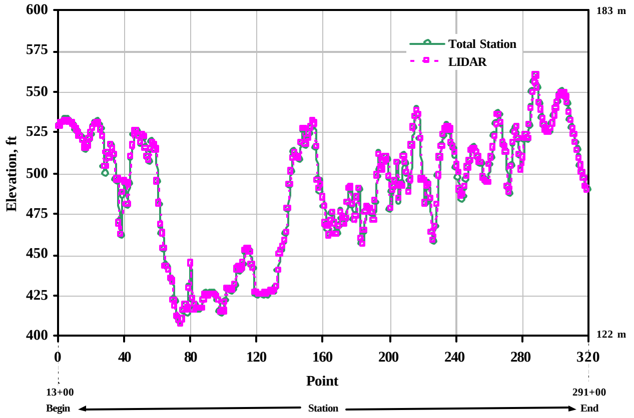

Figure 5. Centerline elevation profile of LIDAR and total station data – Raleigh Bypass project

## AIRBORNE LIDAR TERRAIN MAPPING FOR OXFORD ITS PROJECT

Airborne LIDAR and color aerial photo missions were completed in March-April 2001 in the Oxford area of Lafayette County in Northern Mississippi as a part of the on-going City of Oxford's Intelligent Transportation System (ITS) project, funded by the US DOT and conducted by the University of Mississippi. Several high-resolution GPS markers were established in the Oxford area to ensure high accuracy of future terrain mapping surveys. The aerial color photography survey was conducted in about four hours in daytime at a high altitude of 3,000m (10,000 ft). The airborne LIDAR mission was completed in two 4-hours flights in daytime and nighttime. The remote-sensing data is being used to develop a comprehensive GIS of the Oxford area. This is important considering the high accuracy of distance calculations on digitized road and highway maps for ITS traffic flow improvement studies and their use for air quality analysis (CAIT, 2001).

## EXPECTED BENEFITS AND OUTPUTS OF LIDAR TERRAIN MAPPING SURVEYS

The enhanced accuracy and efficiency of using airborne LIDAR and conventional surveying combined to digital terrain mapping and digital elevation model versus conventional topographic surveying and photogrammetry procedures, either singularly or jointly, in an operational environment are important contributions. Traditional photogrammetry methods utilizing aerial photographs involving photo and ground plots has worked well for open areas, but does not have the accuracy or efficiency of the new sensor/image analysis technology for wooded and vegetative areas. Translating research results to acceptable operation procedures, within cost and accuracy constraints, will be the decisive factor in utilizing the new LIDAR technology.

There are many additional benefits of using LIDAR and conventional ground surveying combination. The data can produce a bare-earth, digital terrain model of the surveyed area to be used for future planning and design of any highway facilities or improvement, as well as flood mapping and drainage analysis. The canopy modeling can be used to identify the extent of wooded areas and obstructions piercing through the airport obstruction-free space today, as well as future needs. The noninvasive airborne LIDAR survey can be conducted without worrying about the usual hurdles faced by the ground survey crews and can save months of delays due to site obstructions, disputes with property owners, weather conditions, and traffic congestions.

## CONCLUSIONS

Traditional topographic survey and photogrammetry methods utilizing aerial photographs involving photo and ground plots have worked well for open areas, but do not have the accuracy or efficiency of the new sensor/image analysis technology for wooded and vegetative areas. The airborne LIDAR laser mapping data collection system offers several unique advantages over conventional ground survey methods. Three-dimensional digital LIDAR coordinate data are directly loaded into bare-earth terrain mapping, GIS, or CAD software. This computerized data collection and transfer leads to efficient, error-free data processing, map generation, and asset management databases. In essence a template of the imaginary roadway surface can be constructed and accurate quantities of cut and fill be calculated so that the best alignment alternative can be selected. With the speed, safety, efficiency, and digital formats of this airborne remote-sensing method for topographic surveying, LIDAR can truly revolutionize the future of surveying, digital mapping and accurate GIS databases, and their applications for highway corridor planning and design, ITS and infrastructure asset management.

Spaceborne remote sensing imagery from modern satellites is relatively inexpensive and rapid. Appropriate data analysis of modern high-resolution imagery can provide up-to-date spatial information on highway corridors and surrounding areas. This can be used cost-effectively as a base layer for overlaying digital LIDAR elevation data and contours. The use of airborne and spaceborne remote sensing technologies will accelerate huge data-collection and processing efforts, which are essential for full and timely implementation of GIS-based infrastructure asset management systems.

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