Final Report

FWHA/INDOT/JTRP-2006/23

CORRIDOR MAPPING USING AERIAL TECHNIQUE

By

James S. Bethel
Professor of Civil Engineering

Boudewijn H.W. van Gelder
Professor of Civil Engineering

Ali Fuat Cetin
Graduate Research Assistant

and

Aparajithan Sampath
Graduate Research Assistant

School of Civil Engineering
Purdue University

Joint Transportation Research Program
Project No: C-36-17RRR
File No: 8-4-70
SPR-2851

Conducted in Cooperation with the
Indiana Department of Transportation and the
U.S. Department of Transportation
Federal Highway Administration

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Purdue University
West Lafayette, IN 47907
August 2006

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. FHWA/IN/JTRP-2006/23	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle Corridor Mapping Using Aerial Lidar Technique		5. Report Date August 2006	
		6. Performing Organization Code	
7. Author(s) James S. Bethel, Boudewijn H.W. van Gelder, Ali Fuat Cetin, Aparajithan Sampath		8. Performing Organization Report No. FWHA/INDOT/JTRP-2006/23	
9. Performing Organization Name and Address Joint Transportation Research Program School of Civil Engineering Purdue University 550 Stadium Mall West Lafayette, IN 47907-2051		10. Work Unit No.	
		11. Contract or Grant No. SPR-2851	
12. Sponsoring Agency Name and Address Indiana Department of Transportation State Office Building 100 North Senate Avenue Indianapolis, IN 46204		13. Type of Report and Period Covered Final Report	
		14. Sponsoring Agency Code	
15. Supplementary Notes			
16. Abstract <p>With properly designed LIDAR control, assessment of 3D as-builts is attainable with an average over-all horizontal (planimetric) error of 0.324 ft (9.9 cm). Specifically, with an RMS error of 0.284 ft (8.7 cm) in Northing, and 0.255 ft (7.8 cm) in Easting. The average over-all vertical (height) error is 0.003 ft (0.1 cm) with a 0.108 ft (3.3 cm) RMS error. Lidar recognizable control (2m x 2m chevrons) was spaced at approximately 200m parallel to the direction of the axis of the project corridor, and at 60m sideway intervals. The project corridor was about 6 km long. Least Squares Image matching software was developed. The internal accuracy proved to be 0.027 ft (8mm). The strip width was approximately 111m and overlap between the Lidar strips changes from 55 to 90m sideways. Each flight line was flown twice in opposite directions showing 55 % overlap in two strips and 75 % in other two. The overall conclusion about the usage of Lidar aerial surveys for corridor mapping projects is that this technique is an efficient, cost cutting alternative to classical terrestrial and aerial survey techniques. However, at this point of the research it is felt that that the design of the LiDAR control plays a critical role to the success of the deployment of aerial LiDAR surveys. Augmentation of ground-based LiDAR and classical surveys proves necessary because of shielding of the airborne laser signals (e.g. underpasses). Comparison of the Lidar based model against the photogrammetric model obtained from low flying aerial photography (helicopter) should be made once the latter model becomes available.</p>			
17. Keywords Airborne Lidar, Accuracy Assessment, Edge of Pavement Feature Extraction, Evaluation		18. Distribution Statement	
19. Security Classf. (of this report)	20. Security Classf. (of this page)	21. No. Of Pages 89	22. Price

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Accurate terrain mapping is important for highway corridor planning and design, environmental impact assessment, and infrastructure asset management. 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 non-contact photography, video, laser, acoustic, radar, and infrared sensors. These terrestrial non-contact 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 [115].

Recently Airborne Laser Scanning (ALS) systems are preferred more and more for collecting topographic data since it provides quick and accurate data for large areas.

Laser scanning systems available on the market are presently in a fairly mature state of art, where most of technical hardware difficulties and system integration problems have been solved. The systems are very complex, being more a ‘geodetic’ system on the data acquisition part and more a ‘photogrammetric’ system on the data processing part. What very much remains is the development of algorithms and methods for interpretation and modeling of laser scanner data, resulting in useful representations and formats for an end-user [100].

1.2 AIRBORNE LASER SCANNERS

Airborne laser mapping is an emerging technology in the field of remote sensing that is capable of rapidly generating high-density, geo-referenced digital elevation data with an accuracy equivalent to traditional land surveys but significantly faster than traditional airborne surveys.

Airborne laser mapping offers lower field operation costs and post-processing costs compared to traditional survey methods. Point for point, the cost to produce the data is significantly less than other forms of traditional topographic data collection making it an

attractive technology for a variety of survey applications and data end-users requiring low cost, high-density, high accuracy geo-referenced digital elevation data.

Airborne laser mapping use a combination of three mature technologies; rugged compact laser rangefinders (LIDAR), highly accurate inertial reference systems (INS) and the global positioning satellite system (GPS) (Figure 1.1) . By integrating these subsystems in to a single instrument mounted in a small airplane or helicopter, it is possible to rapidly produce accurate digital topographic maps of the terrain beneath the flight path of the aircraft.

Figure 1.1 A typical LIDAR system sensor configuration

The absolute accuracy of the elevation data is 15 cm; relative accuracy can be less than 5 cm. Absolute accuracy of the XY data is dependent on operating parameters such as flight altitude but is usually 10's of cm to 1 m.

The elevation data is generated at 1000s of points per second, resulting in elevation point densities far greater than traditional ground survey methods. One hour of data collection can result in over 10,000,000 individually geo-referenced elevation points. With these high sampling rates, it is possible to rapidly complete a large topographic survey and still generate DTMs with a grid spacing of 1 m or less.

The technology allows for extremely rapid rates of topographic data collection. With current commercial systems it is possible to survey one thousand square kilometers in less than 12 hours and have the geo-referenced DTM data available within 24 hours of the flight. A 500 kilometer linear corridor, such as a section of coastline or a transmission line corridor can be surveyed in the course of a morning, with results available the next day.

Airborne laser mapping instruments are active sensor systems, as opposed to passive imagery such as cameras. Consequently, they offer advantages and unique capabilities when compared to traditional photogrammetry. For example, airborne laser mapping systems can penetrate forest canopy to map the floor beneath the treetops, accurately map the sag of electrical power lines between transmission towers or provide accurate elevation data in areas of low relief and contrast such as beaches.

Airborne laser mapping is a non-intrusive method of obtaining detailed and accurate elevation information. It can be used in situations where ground access is limited, prohibited or risky to field crews.

Commercial airborne laser mapping systems are now available from several instrument manufacturers while various survey companies have designed and built custom systems. Similar to aerial cameras, the instruments can be installed in small single or twin-engine planes or helicopters. Since the instruments are less sensitive to environmental conditions such as weather, sun angle or leaf on/off conditions, the envelope for survey operations is increased. In addition, airborne laser mapping can be conducted at night with no degradation in performance.

A number of service providers are operating these instruments around the world, either for dedicated survey needs or for hire on a project basis. Some organizations are starting to survey areas on speculation and then offering the laser-generated data sets for resale similar to the satellite data market.

1.2.1 The Technology

While the core technologies for airborne laser mapping have been in development for the past 25 years, the commercial market for these instruments has only developed significantly within the last five years. This commercial development has been driven by the availability of rugged, low-cost solutions for each of the core subsystems and the growing demand for cheap, accurate, timely, digital elevation data.

In operation, a pulsed laser rangefinder mounted in the aircraft accurately measures the distance to the ground by recording the time it takes a laser pulse to reflect back to the aircraft from the ground or from objects such as buildings, trees or power lines. Since the speed of light is known, the elapsed time is converted to an accurate distance or slant range. Some instruments record multiple returns from a single laser pulse to capture a vertical profile along the slant range. A scanning or rotating mirror is used to provide coverage across the path of the aircraft with swath widths dependent on scan angle and operating altitude. Simultaneously the INS subsystem records the roll, pitch and heading of the aircraft to determine its orientation in space, while the GPS subsystem provides the precise location of the aircraft through a differential kinematic solution. During post-processing the INS orientation and GPS position solutions are combined with the laser slant ranges to calculate accurate XYZ co-ordinates for each laser return.

The technology does not provide a real-time solution; it requires additional post-processing after the field operations and data collection are completed to generate the final XYZ data points. Post-processing is based on proprietary software developed by each instrument manufacturer but has significantly faster turn-around times than conventional survey techniques, on the order of 10's of hours compared to 10's days for traditional methods.

In addition to directly generating digital XYZ data points, post-processing software modules for the automatic analysis and classification of various features are being developed. Software modules already exists for such activities as vegetation classification

and removal while other modules are being developed for automatic feature extraction, building recognition or automatic power wire detection and modeling.

1.2.2 Applications

Depending on the application, airborne laser mapping technology is either a complementary or a competitive technology when compared to existing survey methods. For many survey applications airborne laser technology is currently deployed in conjunction with other more traditional sensors including standard aerial cameras, digital cameras, multispectral scanners or thermal imagers. However, in certain applications, such as forestry or coastal engineering, it offers capabilities not achievable with any other technology.

The most active application areas are:

1. DTM Generation for a Variety of GIS/Mapping Related Products.

Airborne laser mapping is a rapid, cost-effective source of high-accuracy, high-density elevation data for many traditional topographic mapping applications. The technology allows large area topographic surveys to be completed significantly faster and at a reduced cost compared to traditional survey methods.

2. Forestry.

The use of airborne laser mapping in the forestry industry was one of the first commercial areas investigated. Accurate information on the terrain and topography beneath the tree canopy is extremely important to both the forestry industry and natural resource

managers. Accurate information on tree heights and densities is also critical information that is difficult to obtain using conventional techniques. Airborne laser technology, unlike radar or satellite imaging, can simultaneously map the ground beneath the tree canopy as well as the tree heights. Post-processing of the data allows the individual laser returns to be analyzed and classified as vegetation or ground returns allowing DTMs of the bare ground to be generated or accurate representative tree heights to be calculated. Consequently, airborne laser mapping is an extremely effective technique for forestry companies when compared to photogrammetry or extensive ground surveys.

3. Coastal Engineering.

This is another area where airborne laser technology offers state-of-the-art type performance with significant advantages over other survey techniques. Since traditional photogrammetry is difficult to use in areas of limited contrast, such as beaches and coastal zones, an active sensing technique such as airborne laser mapping offers the ability to complete surveys that would be too costly to contemplate using other methods. In addition, highly dynamic environments such as coastal zones often require constant updating of baseline survey data. Airborne laser mapping offers a cost-effective method to do this on a routine basis. It is also used for mapping and monitoring of shore belts, dunes, dikes and coastal forests.

4. Corridor or Right-of-Way Mapping.

Airborne laser mapping allows rapid, cost-effective, accurate mapping of linear corridors such as power utility right-of-ways, gas pipelines, or highways. A major market is

mapping power line corridors to allow for proper modeling of conductor catenary curves, sag, ground clearance, encroachment and accurate determination of tower locations. For example data acquired through airborne laser surveys can be combined with simultaneous measurements of air and conductor temperature and load currents to establish admissible increases in load-carrying capacity of power lines.

5. Construction.

Timely and accurate digital, geo-referenced elevation data is useful in a variety of construction and engineering activities. Examples include highway corridors, open-pit mines or daily surveying of large construction sites.

6. Flood Plain Mapping

Accurate and updated models of flood plains are critical both for disaster planning and recovery and flood insurance purposes. Airborne laser mapping offers a cost-effective method of acquiring the topographic data required as input for various flood plain modeling programs.

7. Urban Modeling.

Accurate digital models of urban environments are required for a variety of applications including telecommunications, wireless communications, law enforcement and disaster planning. An active remote sensing system such as a laser offers the ability to accurately map urban environments without shadowing.

8. Disaster Response and Damage Assessment.

Major natural disasters such as hurricanes or earthquakes stress an emergency response organization's abilities to plan and respond. Airborne laser mapping allows timely, accurate survey data to be rapidly incorporated directly in to on going disaster management efforts and allows rapid post-disaster damage assessments. It is particularly useful in areas prone to major topographic changes during natural disasters; areas such as beaches, river estuaries or flood plains.

9. Wetlands and Other Restricted Access Areas

Many environmentally sensitive areas such as wetlands offer limited ground access and due to vegetation cover are difficult to asses with traditional photogrammetry. Airborne laser mapping offers the capability to survey these areas. The technology can also be deployed to survey toxic waste sites or industrial waste dumps.

Since airborne laser mapping is a relatively new technology, applications are still being identified and developed as end-users start to work with the data. There are on going efforts to identify areas where this technology allows value-added products to be generated or where it offers significant cost reductions over traditional survey methods [118].

1.3 RESEARCH OBJECTIVES AND METHODOLOGY

LIDAR (LIght Detection And Ranging) systems are complex multi-sensory systems and incorporate at least three main sensors, GPS and INS navigation sensors, and the laser-scanning device. The complexity of the system results in possible error sources that can

degrade the accuracy of the acquired LIDAR data. The errors in laser scanning data can come from individual sensor calibration or measurement errors, lack of synchronization, or misalignment between the different sensors [101]. [102] presents an overview of basic relations and error formulas concerning airborne laser scanning.

As laser scanners have a potential range accuracy of better than 1 dm, the position and orientation system (POS) should allow at least one order of magnitude better accuracy. Such accuracy can be achieved only by an integrated POS consisting of a DGPS and an inertial measurement unit (IMU)/INS. After a surveying flight, basically two data sets are available: the POS data and the laser ranges with the instantaneous scanning angles. Assuming that the accuracy of POS data is better than 1 dm in position and 0.028 in orientation, already very precise laser measurement points in an earth-fixed coordinate system can be calculated. However, some systematic parameters must be considered. These are e.g., the three mounting angles of the laser scanner frame, described by the Euler angles roll, pitch and yaw, with respect to the platform-fixed coordinate system usually with origin at the IMU, the position of the laser scanner with respect to the IMU, and the position of the IMU with respect to the GPS. This so-called calibration data can be derived from laser scanner surveys, whereby certain reference areas are flown-over in different directions. Reference areas are e.g., flat terrain like large sport fields or stadiums, buildings and corner of buildings. From the relative orientation and position of the different surveys and their absolute orientation and position with respect to an earth-fixed coordinate system, calibration data can be derived [103].

Each component requires calibration and the offsets between the components needs to be determined. GPS/INS and range finders are usually calibrated in the lab; thus this research will concentrate on scanner and misalignment (bore sight) values. The misalignment between the INS system and the scanner is the largest source of systematic error in an ALS and must be addressed before the sensor can be effectively deployed. It has been observed empirically that these misalignment errors are often relatively small (0.1 – 3 degrees), but their effect on the recorded ground points will depend on flying height and the scanner field of view (maximum scan angle) [104].

Most of these errors are systematic and can be corrected. To eliminate the effect of the systematic errors, several procedures have been proposed so far. One group can be categorized as data driven. The motivation is to correct the laser points by transforming them so that the difference between their values and the reference control information is minimized. Another approach is based on recovering the systematic system errors. Several authors report recovering the errors by conducting different flight patterns over flat, locally horizontal surfaces and “flattening” the surface as a function of the systematic errors. Others base their calibration procedure on control, height, and tie points, in a fashion similar to photogrammetric block adjustment, or propose to reconstruct the elevation model around distinct landmarks to tie the overlapping strips which is called strip adjustment [110].

Although many systems require the calibration for each survey flight there are also some other systems [112] claiming no need for any calibration except any major component replacement.

Currently the most common method of calibrating an ALS sensor is also the least rigorous: profiles of overlapping strips are compared and an experienced operator manually adjusts the misalignment angles until the strips appear to visually fit. Although pragmatic, this approach is time consuming and labor intensive; and the results do not immediately provide any statistical measure on the quality of the calibration.

Several strip adjustment models have been proposed by [104], [105], [106], [107], [108], [109], [111]. All of these strip adjustment methods are based on the observed vertical or three-dimensional discrepancies between the overlapping LIDAR strips. Systematic planimetric errors are often much larger than height errors of the LIDAR data, and therefore, a three-dimensional strip adjustment is the desirable solution. Some of the strip adjustment methods work only with tie points (without any ground control information), however, the use of some type of ground control is desirable, since eliminating the relative discrepancies between overlapping strips does not provide an absolute check of the dataset. Applications demanding the highest accuracy require the elimination of absolute errors, which cannot be achieved without the use of absolute control information. Ground control information can be used in the strip adjustment process or after strip adjustment to correct the remaining absolute errors in the corrected strips. Many times after the strip adjustment, a horizontal surface with a known elevation is used

to correct remaining vertical shifts in the data. However, remaining absolute errors after strip adjustment can be more complex than just a vertical shift. Three-dimensional ground control information, buildings, known roof structures, etc., are often used. However, this type of control information is not always available. Furthermore, due to the characteristics of laser data, the identification of distinct points of buildings and roof structures in LIDAR data can result in a biased position, which could affect the accuracy of the corrected LIDAR data. Therefore, for applications with high accuracy requirements, such as corridor mapping, well-identifiable LIDAR-specific ground control targets are necessary [101].

Accurate terrain data is needed for highway corridor mapping and relocating existing or locating new infrastructures. Besides, the data should be collected in as fast as possible considering the personnel safety issues. Currently traditional field surveying and photogrammetric mapping processes require early collection and processing of data for design purposes. However the accuracies provided by these methods may be needed at the final stages of the process and they require too much time and cost. Lidar technology can provide data at the required accuracy level for early stages of the process. The current research aims to achieve the required accuracy level for the final stages of the design process. Currently Lidar data vendors specify a height precision of 15 cm and above 50 cm horizontal accuracies for their systems.

For the last few years it has been shown in many research papers that automated feature extraction from Lidar data is a very promising issue. However achieving the required

accuracies for design stages using the automated technologies is a challenging issue. But the quality and the quantity of the Lidar data may provide a high accuracy 3D feature extraction environment.

In this research we used a novel approach which uses LIDAR detectable ground control targets. “L” shaped targets are used along the strips in the project area which were applied by painting the inside of a template. This proposal describes the matching of the targets in the LIDAR intensity images using Least Squares Image Matching (LSIM) technique and the least squares method to remove the systematic errors from the uncalibrated data set.

Highway corridor mapping is an important task for most DOTs in the U.S. which is mainly done for evaluation of the existing infrastructure. In this research, the edge of pavements on the roads will be extracted from the Lidar data and the accuracy for the extracted features along the project area will be compared with the ones derived from aerial photogrammetry, and ground total station.

The report is organized as follows. The next section describes the error budget for Lidar technology, a brief description of the least squares image matching technique, test results and adjustment method for misalignment correction. The following section describes feature extraction for highway edge of pavements, and comparison of the extracted features using the all three methods mentioned above.

CHAPTER 2

EVALUATION AND ADJUSTMENT OF LIDAR DATA

One of the goals of the project is to evaluate the planimetric and the vertical accuracy, as well as the internal consistency of the lidar data. However, the nature of lidar data collection made it challenging to devise a strategy for such a task. Unlike photogrammetry, Lidar technology does not generate continuous data. Therefore, it is impossible to ensure that control points are directly scanned as it is not possible to point the laser scanner to a particular spot, and then measure its coordinates. The point cloud is a series of discrete, albeit very close, three dimensional coordinates. It was finally decided that control points in the study area be painted such that they are visible in the lidar dataset.

Before going into details of the analysis, the error sources in an airborne lidar system is going to be presented.

2.1 ERROR SOURCES

Digital elevation models (DEMs) or triangulated irregular networks (TINs) produced from lidar observations are created from lidar returns labeled as “ground” observations. These lidar-derived “ground” elevations contain error from three categories of sources:

- *elevation error* from the sensor system measurement,
- *horizontal error* from the sensor system measurement, and
- *labeling error* process of identifying a “ground” return from other types of returns (e.g., canopy top, intermediate vegetation, building top).

The error in the measured elevation of a lidar point is the cumulative product of the sensor/platform sources, such as analysis of waveform, identification of the return position in the pulse length, and position error in the GPS/INU control. Horizontal error is a function of the same factors but often dominated by flying height. Horizontal error is often reported to be approximately 1/1000th of the flying height AGL on most systems. The horizontal error will introduce additional elevation error in the use of the observations. The lidar “ground” return set contains both omission and commission errors. Some points in the set are incorrectly labeled as “ground” returns, and some true “ground” returns are omitted. From a user’s perspective, the point set is treated as if there are no errors or occasionally as if there are only elevation errors. The use of lidar observations typically involves the interpolation of an irregular point set to a DEM, which may introduce additional elevation error. Finally, any assessment of elevation error with reference data introduces additional “apparent” error from the surveying of the reference data [119].

2.1.1 Sources of Positional (X-Y-Z) Error

The primary sources of positional error in the lidar collection process are associated with the Global Positioning System (GPS) equipment onboard the aircraft, the inertial navigation unit (INU) for estimating positions between GPS fixes, and the inertial measurement unit (IMU) for monitoring the pointing direction of the laser. The horizontal (X-Y) error is typically much greater than the vertical error. Assessing the horizontal accuracy of lidar observations is also problematic. Conventional assessments of horizontal error involve multiple over-flights over building corners with flat roofs. Most lasers used in the commercial lidar sensors are similar and have a divergence from 0.2 to 0.33 mr. This divergence, along with scan angle and flying height, defines the lidar

footprint (typically between 24 cm to 60 cm). Smaller footprints are more likely to pass through breaks in forest canopy [119].

2.1.1.1 Range Errors

The range accuracy is the most complicated among the major accuracy factors. In practice, however, if the necessary measures and precautions are taken, the contribution of range errors to 3D coordinate errors is the minimum among the major error sources, with the exception of low flying heights and small scan angles, where its relative importance with respect to the total error budget increases [102]. Under normal operating conditions the range error from a typical laser rangefinder that is properly calibrated can be expected to be between 2" to 3". However, the atmosphere acts to distort the path of the laser pulse as it travels to the target and back again, introducing a timing error that needs to be corrected. These corrections become critical at higher altitudes. These atmospheric affects are usually minimized but not eliminated by incorporating an appropriate atmospheric model in the post-processing of the LiDAR data. A surveyor needs to pay close attention as specified operational altitudes increase [120].

2.1.1.2 Position Errors

This depends mainly on the quality of the DGPS postprocessing. Other factors: GPS hardware, GPS satellite constellation during flight, number, distribution and distance of ground reference stations from (aircraft values of 10–100 km have been reported), accuracy of offsets and misalignment between GPS and INS, and INS and laser scanner (depending on the used computation method less information might be sufficient, e.g., offset between GPS and laser and misalignment between INS and GPS, or offset and

misalignment between laser and INS), and the accuracy of the laser beam direction scanner accuracy . The GPS error varies over time, but it is bounded (exceptions can occur during GPS outage), and through integration of GPS with INS, the temporal variability is smoothed [102]. It is important for surveyors to have a good understanding of GPS-related errors that fall into several broad categories. Sources of error include satellite geometry (PDOP), orbital biases, multipath, antenna phase center modeling, integer resolution and atmospheric errors. Compounding some of these errors is the operational distance from the ground GPS stations. It is important to remember that for every GPS-related error source, a method can be employed to detect, eliminate or minimize that error. In general, when properly taken into account and with proper project planning, GPS error contributes on the order of 2" to 4" of position error to the final product [120].

2.1.1.3 Orientation Errors

This depends on the quality of the INS, the INS frequency (i.e., interpolation error) , the method of postprocessing and integration with the GPS. Heading accuracy in addition depends on latitude. The effect of attitude errors on the 3D accuracy increases with the flying height and the scan angle [102]. Knowing the correct orientation or pointing direction of the Lidar sensor is necessary for calculating an accurate spot location on the ground. In practice, the orientation of the platform is recorded by an on-board inertial measurement unit (IMU)/INS that is hard mounted to the Lidar sensor. While a variety of IMUs are available commercially, a typical specification for the price/performance levels common in most commercial Lidar sensors would be 0.005° pitch/roll, 0.008° heading (POS/AV 510 from Applanix, Richmond Hill, Ontario, Canada post-processed solution)

although some systems perform to a 0.0025° pitch/roll accuracy. A 0.005° angular error corresponds to a 0.87 foot error from 10,000 feet and a 1.70 foot error from 20,000 feet. However, there are additional contributions to the angular pointing error including contributions from the scanning subsystem. Many of these additional errors can be minimized but not eliminated by proper system calibration prior to data collection and proper system modeling during post-processing.

2.1.1.3.1 Boresight Misalignment

Figure 2.1 shows the usual sensor configuration of airborne LIDAR systems. The navigation sensors are separated the most since the GPS antenna is installed on the top of the fuselage while the INS sensor is attached to the LIDAR system, which is down in the aircraft. The spatial relationship between the sensors should be known with high accuracy. In addition, maintaining a rigid connection between the sensors is also very important since modeling any changes in the sensor geometry in time just would further increase the complexity of the system model and thus may add to the overall error. The INS frame is usually considered as the local reference system; thus the navigation solution is computed in this frame. The spatial relationship between the laser scanner and the INS is defined by the offset and rotation between the two systems. The critical component here is the rotation since the object distance amplifies the effect of an angular inaccuracy, while the effect of an inaccuracy in the offset does not depend on the flying height. The description of the effects of the different boresight misalignment angles is omitted here; for details see e.g. ([102]).

The coordinates of a laser point are a function of the exterior orientation of the laser sensor and the laser range vector. The observation equation is:

$$r_{M,k} = r_{M,INS} + R_{INS}^M (R_L^{INS} \cdot r_L + b_{INS}) \quad (1)$$

where

$r_{M,k}$	—	3D coordinates of point k in the mapping frame
$r_{M,INS}$	—	3D INS coordinates in the mapping frame
R_{INS}^M	—	rotation matrix between the INS frame and mapping frame, measured by GPS/INS
R_L^{INS}	—	boresight matrix between the laser frame and INS frame
r_L	—	3D object coordinates in laser frame
b_{INS}	—	boresight offset component

To obtain the local object coordinates of a LIDAR point, the laser range vector has to be reduced to the INS system by applying the shift and rotation between the two systems, which results in the coordinates of the LIDAR point in the INS system. The GPS/INS-based navigation provides the orientation of the INS frame, including position and attitude; thus the mapping frame coordinates can be subsequently derived. In our discussion, the automated determination of the rotation component, the boresight matrix between the INS and the laser frame, is addressed.

The boresight rotation can be described by three rotation angles, ω rotation around the x-axis, ϕ rotation around the y-axis, and κ around the z-axis in the laser sensor frame. The approximate values of the three rotation angles between the INS and the laser frames are known from the mechanical alignment. The actual angles differ slightly from these nominal values. The boresight misalignment problem is to determine these three misalignment angles. Any discrepancy in their values results in a misfit between the LIDAR points and the ground surface; the calculated coordinates of the LIDAR points are not correct. In case the ground surface is unknown, the effect of the misalignment can be seen if different overlapping LIDAR strips are flown in different directions.

Figure 2.1. Sensor configuration of airborne LIDAR systems

Boresight misalignment has to be determined to obtain correct surface from the LIDAR data. The unknown boresight misalignment angles can be found with ground control or without it by using overlapping LIDAR strips flown in different directions. Since the true ground surfaces are not always available preference should be given to techniques that do not require a priori knowledge of the surface [111].

The misalignment between the INS system and the scanner is the largest source of systematic error in an ALS and must be addressed before the sensor can be effectively deployed. It has been observed empirically that these misalignment errors are often relatively small (0.1 – 3 degrees), but their effect on the recorded ground points will depend on flying height and the scanner field of view (maximum scan angle). When

comparing data from overlapping strips on an un-calibrated system, the effects of these errors will be seen as in Figure 2.2.

Figure 2.2 Boresight Induced Errors

On systems using an oscillating scanner (such as the Leica ALS40 and the Optech ALTM), additional errors can be visible when comparing strips (Figure 2.3).

These additional effects are caused by errors in the angle encoder. As the mirror accelerates and decelerates across its swath, the angle encoder undergoes small amounts of torsion. This torsion causes a small, but systematic misreading of the angle, which is manifested by the ends of the scan rising too high or dropping too low. Due to the systematic nature of this error, it can be modeled and removed during the calibration process.

Figure 2.3. Scanner Induced Errors

To determine the calibration parameters empirically, data from overlapping strips must be collected. Alternatively, data from one strip can be compared to a known surface. The misalignment errors and scanner errors described above are all correlated with the direction of flight. If strips are flown in opposite directions, then the induced errors will be maximized and more importantly de-correlated. This will allow for a least-squares approach to the problem. [104].

2.1.1.4 Time Offsets

For accurate 3D positioning, orientation, position, and range are required to be taken at the same time. If there is a time offset and this is not known precisely, it will cause a variable error. The error increases with increasing change rate of the related measurements, e.g., while a time offset between range and rotation angles can have a

small effect for a calm flight (rotation angles remain fairly stable) , it can influence the 3D accuracy a lot for a turbulent flight [102].

Concluding, the total error consists of a variable part that is dependent on major parameters like flying height, scan angle, terrain topography, and land cover referring to object geometry and reflectivity and a constant part 5–10 cm in good cases that is independent of the previous parameters, e.g., pulse detection accuracy, GPS accuracy, etc.

2.1.2 Lidar Point Labeling Error

A single lidar pulse of approximately 200 cm in length is emitted toward a surface location at some 10,000 to 70,000 times per second. Most lidar sensors record the return energy as a waveform of multiple pulses, and then unique returns are identified (e.g., four or five returns). In some instances, the magnitude of the pulse is also recorded and is referred to as intensity. From this set of lidar returns, both automated and manual methods are used to identify or label each return as a “ground” return, “vegetation” return, “building” return, or other. This process is sometimes referred to as “vegetation removal.” Automated methods are based on neighborhood operators that iteratively identify the lowest points within each neighborhood and add them to a candidate set of “ground” returns. Subsequent iterations refine the candidate set by adding additional returns that are also “low” or exhibit some angular deflection from a surface modeled by the current candidate set of points. The exact neighborhood operators and parameters vary by lidar mapping vendor and are proprietary information [119].

2.1.3 Mapping Sources of Error

A well-known characteristic of observed elevation error for terrain mapping is the relationship with terrain slope. Even if the elevation of a surface observation is measured without error, the horizontal error in the observation may introduce “apparent” error in the elevation value from a user’s perspective. The introduction of elevation error based on horizontal error is only true for inclined slopes (Figure 2.4). The maximum amount of elevation error introduced is a function of surface slope: i.e.,

$$\text{Elevation Error} = \tan \alpha * \text{Horizontal Displacement.}$$

For instance, the additional elevation error introduced for a point with a 100-cm horizontal error on a 10° slope can be up to ± 18 cm. The maximum error will only occur if the displacement is perpendicular to the contour line. The error will be zero for displacement parallel with the contour. In practice, the displacement direction for any single point is unknown and assumed to be random for the entire set of points. Early work in topographic mapping has demonstrated the relationship between observation point density and the accuracy of the derived DEM. As the density of observation points increases, the accuracy of the resulting DEM increases. The density of lidar “ground” returns depends on the nominal posting (i.e., spacing between lidar pulses at nadir), land-cover type, and point-labeling approach. This density concept resulted in a maximum 5-m posting criteria within FEMA’s guidelines for using lidar data to construct DEMs in the floodplain mapping process. FEMA also suggested a minimum percentage of “data voids,” areas where the distance to the nearest lidar observation is greater than some threshold [119].

Figure 2.4 Illustration of the effects of terrain slope on observable elevation error.

While a general understanding of the relative accuracy of lidar is known, too few empirical studies exist for assessing the accuracy of digital elevation models (DEMs) created from these data. During the initial years of lidar mapping efforts (i.e., 1995 to 2000), most aeroservice companies would routinely quote accuracies of 15 cm RMSE. Most would now agree such accuracy is only achievable under the most ideal circumstances (e.g., low altitude collections, flat terrain, minimal or no surface vegetation or obstructions, much human analysis, etc.). A few empirical studies have been conducted to date and suggest accuracies of 26 cm to 153 cm root-mean-squared error (RMSE) for large-scale mapping applications [119].

2.2. DATA DESCRIPTION

This research is funded by Joint Transportation Research Program (JTRP Project Number: C-36-17RRR, File Number: 8-4-70, SPR-2851) for Indiana Department of Transportation (INDOT) under the name of “Corridor Mapping Using Aerial Lidar Technique”. The project area selected for this research is on an approximately 8 km portion of I-70 highway in Marion County, Indiana as seen in Figure 2.5. 4 parallel flight paths are used to get 8 strips having 4 flights in opposite directions (Figure 2.6). The strip width was approximately 111m and the overlap between the strips changes from 55 to 90m. Figure 2.6 shows the flight paths and 73 ground control points used in the project.

Figure 2.5 Project Area

Data was collected by the service provider company using a Leica Geosystems ALS50 system on October 22, 2004. The data was collected with a 12 degree field of view at 70 Hz scan frequency, and 52.3 kHz pulse rate from an altitude of 610m. The point density obtained for this area was 25 points/m² having approximately 10 million points in each

strip. Approximate aircraft (N404CP) speed was 110 knots. Besides the range data intensity values were collected at the same time. The mission started at 6:20pm and ended at 10:00 pm. The weather was hazy with dry surface and no precipitation. For the same project area aerial images were collected before this flight. The control points used for this aerial imagery were investigated and the ones that are suitable and fall in the LIDAR data collection corridor are selected evenly throughout the project area. Out of 73

Figure 2.6 Flight paths and control points.

control points 3 of them were not used because of the surface conditions and three points fell just outside of the data strip. These points were already GPS surveyed and we had the coordinates of these points just after the data collection. Each of the points was painted with to an L shape. The shape and the dimensions were chosen so that they are visible in the dataset. Since the x-y point spacing is around 20 cm, the dimensions of the control point markings make sure that more than one point in the point cloud would lie on the markings. One of the L shaped targets used for LIDAR detection is shown in Figure 2.7,

which has the control point at the intersection of the legs. The picture on the top left shows the aerial imagery target and the one on the top right is the design template which shows the target dimensions and the ones on the bottom are the actual painted targets for LIDAR detection. The targets are painted on the surface using a wooden template.

Figure 2.7 LIDAR detectable targets.

Figure 2.8 shows some more painted targets. Looking at this figure gives us some idea about how to select the location of a lidar detectable target. For this project, since the aerial survey has been done before collecting lidar data, we decided to use the already

surveyed control points and these locations came up when we wanted to use these targets for painting. This figure shows the most extreme cases but it gives a pretty good picture of how a lidar target should be. In case that the targets will be made by painting,

- there should not be any different materials within the target boundaries which will affect the reflectance inside the target and prevent the detection of the target,

Figure 2.8 Painting Lidar detectable targets

- there should not be any elevation difference inside the target boundaries,
- wherever required contrast should be made.

Figure 2.9 The Dataset with Point spacing for a Lidar flight line, along the two opposing flight directions.

A few characteristics of the data, such as point distribution, geometry, and point spacing are shown in Figure 2.9 The final output given by the service provider company can be seen in Figure 2.10 as an intensity image. This image was created by using the **calibrated** data which is done by an experienced operator comparing the roof tops in the overlapping

strips. The operator adjusted the misalignment angles until the strips appear to visually fit. Figure 2.11 shows a portion of the data as intensity and height images with a 3D view of the same area. The pixel size for this data was 1 ft.

Figure 2.10. Final output as a Lidar intensity image from operator adjusted data.

Figure 2.11 Lidar Intensity and Depth image of a portion of the study area with a 3D view

2.3. LEAST SQUARES LOCATION MODEL

One of the goals of the project is to evaluate the planimetric and the vertical accuracy, as well as the internal consistency of the lidar data. To achieve this goal Lidar detectable targets were designed and used in this project. These targets are then identified in the Lidar dataset using Least Squares Image Matching technique.

In the conventional approach to least squares image matching, we model the correspondence between two image fragments by a geometric model (six parameter transformation) and a radiometric model (two parameter transformation). Pixel gray values in one image are arbitrarily chosen to be the observables, while pixel gray values in the other image are chosen to be constants [113]. Figure 2.12 shows ideal image of a

Figure 2.12 The template and the target in the intensity image for LSM

template, with the pixel boundaries delineated for clarity and another depiction of the same L-shaped target having been transformed by scale, rotation, and translation in the intensity image. This image pair, although simulated, will be used to illustrate the least squares matching techniques between, for example, fragments from the left and right

images of a stereo pair. And the one on the left shows the end result from the LSM application.

Experience has shown that the alignment/correspondence between two images to be matched generally has to be within a few pixels or the process will not converge. This is more restrictive than other matching methods, and therefore forces one to use least squares methods only for refinement rather than from scratch processing of new imagery. On the other hand, performing least squares matching at the high (small) end of the image pyramid and working progressively downward could provide a way to process images with poorer alignments. If for some reason the geometric relationship between the images is not consistent with the usually applied six parameter model, then the model would have to be expanded. Up to now this has not proven necessary in photogrammetric applications.

Also note that nothing in the conventional approach to least squares matching enforces any constraints from the, possibly known, photogrammetric orientation. One could, for example, constrain the shift parameters so that they are only allowed to move in the epipolar direction. [113].

A simplified condition equation, considering only the geometric parameters would be,

$$g(x, y) = h(x', y') \quad (2.1)$$

in which the two coordinate systems are related by the six parameter transformation,

$$\begin{aligned} x' &= a_1x + a_2y + a_3 \\ y' &= b_1x + b_2y + b_3 \end{aligned} \quad (2.2)$$

An extended model including two radiometric parameters for contrast and brightness (or equivalently gain and offset) would be,

$$g(x, y) = k_1 h(x', y') + k_2 \quad (2.3)$$

Written in the form of a condition equation it becomes,

$$F = g(x, y) - k_1 h(x', y') - k_2 = 0 \quad (2.4)$$

in which the parameters are $a_1, a_2, a_3, b_1, b_2, b_3, k_1$, and k_2 , g represents the observation, x, y are constants, and h is a constant. This equation can be linearized into the form,

$$\mathbf{v} + \mathbf{B}\mathbf{\Delta} = \mathbf{f} \quad (2.5)$$

The coefficients of the B matrix will consist of the partial derivatives of Equation (2.4). The resulting normal equations may be formed sequentially, avoiding the actual formation of the full condition equations. They are then solved for the parameter corrections. For the second and subsequent iterations, we resample the right image, $h(x', y')$ using the inverse transformation defined by the updated six parameters. This is necessary because, as mentioned earlier, transformation effects on the resampling grid produce the opposite effects on the objects visible after resampling. After several iterations and resamplings, the two images should appear to be aligned and registered [113].

2.3.1 LSIM Analysis Results

One of the painted control points is shown in Figure 2.13 in the intensity image. When the known elevation of this control point is compared to the LIDAR derived elevation the difference between two values is 0.079 ft (2.4cm). These Lidar derived elevations are

given by the service provider company. These elevations are produced by comparing the calibrated lidar data with a TIN created by using the control points and adding an average value of 0.69 ft difference to the calibrated data set. This way the adjusted data set is produced. Appendix A shows the elevation comparison for the unadjusted data set. The results for the comparison of all the control points in the adjusted data set (Appendix B) shows a signed average Δz as 0.003 ft (0.09cm), max $|\Delta z|$ as 0.54 ft (16.45cm), min $|\Delta z|$ as 0.004 ft(0.12cm), average $|\Delta z|$ as 0.081 ft (2.46cm) and with an RMS of 0.108 ft (3.29cm). The service provider did this comparison for the first time with such LIDAR detectable ground control points.

Figure 2.13. One of the control points in the intensity image.

In this research our aim is to calibrate and adjust the uncalibrated data set using the Lidar detectable targets by finding them with LSIM.

For planimetric comparison a least squares image matching algorithm is applied to this operator-calibrated data. Figure 2.14 shows one of the control points, this time the template was used as rotated due to the convergence issue. The results from this analysis

can be seen in Table 2.1 where Nc is Northing for GPS surveyed control points, Nl for Northing for Lidar derived control points and E represents Easting. The coordinate errors shown in Table 2.1 indicate a good quality of output in horizontal and vertical coordinates but certainly there are some control points which gave around 1 ft error indicates a further investigation of the original uncalibrated data and a different approach for data calibration.

Figure 2.14. Least squares image matching of control points.

Table 2.1 Planimetric comparison of Lidar data with GPS surveyed control points

Average Planimetric discrepancy	0.324 ft	9.87 cm
Maximum Planimetric discrepancy	1.013 ft	30.87 cm
Minimum Planimetric discrepancy	0.028 ft	0.85 cm
Average Nc-Nl	0.160 ft	4.88 cm
Average Ec-El	-0.052 ft	-1.58 cm
N_rms	0.284 ft	8.66 cm
E_rms	0.255 ft	7.77 cm

Figure 2.15 shows the planimetric error directions for the control points. There is a bias in the errors which can be seen from this figure.

Figure 2.15. Error distribution for operator-calibrated data

After performing the LSIM analysis, the elevation values for the control points are computed from Lidar data by selecting the points 1ft. around the LSIM derived control point. Figure 2.16 shows the Lidar points around the control point 267. Comparing all these values with the actual surveyed elevations gives us a difference of 0.539 ft. Appendix C shows all the values for the control points.

To do the same analysis for the **un-calibrated** data the binary files are converted to ASCII files using the ASPRS LIDAR Data Exchange Format Standard Version 1.0 May 9, 2003. Intensity images are produced from the ASCII files using ERDAS Imagine software. The strips are divided into 6-7 parts because of the RAM (1Gb) limitations.

LSIM approach is used for the un-calibrated data and the results for the horizontal coordinates are given in Table 2.2. The columns in Table 2.2 are the strip name showing the direction of the flight and the number of strip, mean distance between the actual horizontal coordinates and LSIM derived coordinates from un-calibrated LIDAR data, maximum distance, minimum distance, mean values for the difference between northing

Figure 2.16 Lidar points around the control point 267

Table 2.2 Control point comparison in horizontal coordinates

Strip	meanDIST	maxDIST	minDIST	Avg_Nc-NI	Avg_Ec-EI	nRMS	eRMS	#c.pts
a1	81.1650	83.6017	71.5062	-75.9819	28.5059	76.0304	28.5784	13
a2	82.2839	84.8512	79.8052	-76.6667	29.8573	76.6801	29.8928	25
a3	84.2599	86.7470	79.8857	-70.5806	28.9670	78.5291	30.6131	21
a4	85.4990	86.5733	82.3717	-79.5989	31.1909	79.6073	31.2287	5
b1	84.0760	85.4474	81.6091	82.9946	-13.4152	83.0038	13.4491	13
b2	83.3062	86.1751	80.7676	82.1148	-13.9690	82.1255	14.0378	26
b3	82.8520	86.9376	78.9945	68.8829	-10.2560	81.3769	15.6811	26
b4	80.9037	82.4256	79.1451	79.7094	-13.8242	79.7163	13.8552	9
Mean	83.0432	85.3449	79.2606	1.3592	8.3821	79.6337	22.1670	17.25
Strip	meanDIST	maxDIST	minDIST	Avg_Nc-NI	Avg_Ec-EI	nRMS	eRMS	#c.pts
a1	81.1650	83.6017	71.5062	-75.9819	28.5059	76.0304	28.5784	13
a2	82.2839	84.8512	79.8052	-76.6667	29.8573	76.6801	29.8928	25
a3	84.2599	86.7470	79.8857	-70.5806	28.9670	78.5291	30.6131	21
a4	85.4990	86.5733	82.3717	-79.5989	31.1909	79.6073	31.2287	5
Mean	83.3020	85.4433	78.3922	-75.7070	29.6303	77.7117	30.0782	16.00
Strip	meanDIST	maxDIST	minDIST	Avg_Nc-NI	Avg_Ec-EI	nRMS	eRMS	#c.pts
b1	84.0760	85.4474	81.6091	82.9946	-13.4152	83.0038	13.4491	13
b2	83.3062	86.1751	80.7676	82.1148	-13.9690	82.1255	14.0378	26
b3	82.8520	86.9376	78.9945	68.8829	-10.2560	81.3769	15.6811	26
b4	80.9037	82.4256	79.1451	79.7094	-13.8242	79.7163	13.8552	9
Mean	82.7845	85.2464	80.1291	78.4254	-12.8661	81.5556	14.2558	18.50

and easting coordinates and the RMS values for northing and easting values. The last column shows the number of control points that fall in each strip. The strips can also be seen in Figure 2.17 with the strip names and directions. Table 2.2 clearly shows a boresight misalignment error existing in the data. All the units in Table 2.2 are in US

Survey foot. The errors in the Easting range from 71.5 ft (21.79m) to 86.93 ft (26.50m). In the next section an adjustment method is explained to remove this boresight misalignment error. Appendix D shows all the comparisons for all strips.

Figure 2.17 LIDAR data strips showing the overlaps and the directions.

The directions of errors can be seen in Figure 2.18, which clearly shows the boresight misalignment with some of the error magnitudes shown in feet.

Figure 2.18. Error directions due to Boresight misalignment

2.4 ADJUSTING THE UNCALIBRATED DATA

LSIM analysis gives us the locations of the ground control points in the Lidar data. We can use these values to adjust the uncalibrated Lidar data which has a major boresight misalignment and elevation error. The research on methodologies of adjusting the data is ongoing, and will be published as part of the doctoral research of the second author (A.F.C.) of this report.

CHAPTER 3

EDGE OF PAVEMENT EXTRACTION AND EVALUATION

Accurate terrain mapping is important for highway corridor planning and design, environmental impact assessment, and infrastructure asset management. 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 [121].

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 3.1 compares operating characteristics and data resolution of several remote sensing technologies [121].

Table 3.1. Comparison of the new ‘high resolution’ spaceborne and airborne remote sensing technologies

Satellite/ Airborne	Spatial Resolution	Spectral Resolution	Temporal Resolution days	Footprint (km x km)
Landsat 7	15m	7 bands	16	185x185
IKONOS	1 m	3 bands	3.5-5	11x11
Quickbird2	0.61m	3 bands	1.5-4	16.5x16.5
ASTER	VNIR:15m IR: 30-90 m	14 bands	In Space Shuttle	Variable
Orbview3	1m	4 bands	3	8x8
SPOT5	2.5m Mid IR:20 m	4 bands	04-Jan	60x60
Aerial Photo	Upto 0.15m	Visible band	On Demand	2x2 at 3000m
Airborne Lidar	Upto 0.15m	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

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 [122].

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. A typical survey can collect data at a rate of up to 81 sq. km (20,000 acres) per day [121].

For the last few years it has been shown in many research papers that automated feature extraction from Lidar data is a very promising issue. However achieving the required accuracies for design stages using the automated technologies is a challenging issue. But the quality and the quantity of the Lidar data may provide a high accuracy 3D feature extraction environment.

Highway corridor mapping is an important task for most DOTs in the U.S. which is mainly done for evaluation of the existing infrastructure. In this research, the edge of pavements on the roads will be extracted from the Lidar data and the accuracy for the extracted features along the project area will be compared with the ones derived from aerial photogrammetry, and ground total station.

Before getting into the feature extraction the next section will introduce the highway cross-section elements. The features that will be extracted this research are edge of pavements.

3.1 Highway Cross-Section Elements

The principal elements of a highway cross-section consist of the travel lanes, shoulders, and medians (for some multilane highways). Marginal elements include median and roadside barriers, curbs, gutters, guard rails, sidewalks, and side slopes. These are typical elements of cross sections of two-lane highways or multilane highways.

Shoulders

Travel lane widths usually vary from 10 ft to 12 ft. One of the elements of a section of a highway cross-section are those designated as shoulders. The shoulder is contiguous with the traveled lane and provides an area along the highway for vehicles to stop, particularly during an emergency. Shoulders are also used to laterally support the pavement structure. The shoulder width is known as either *graded* or *usable*, depending on the section of the shoulder being considered. The graded shoulder width is the whole

width of the shoulder measured from the edge of the traveled pavement to the intersection of the shoulder slope and the plane of the side slope. The usable shoulder width is that part of the graded shoulder that can be used to accommodate parked vehicles. The usable shoulder width is the same as the graded width, when the side slope is equal to or flatters than 4:1, as the shoulder break is usually rounded to a width between 4 ft and 6 ft, thereby increasing the usable width.

When a vehicle stops on the shoulder, it is desirable for it to be at least 1 ft and preferably 2 ft from the edge of the pavement. Based on this, American Association of State Highway and Transportation Officials (AASHTO) recommends that usable shoulder widths of at least 10 ft and preferably 12 ft be used on highways having a large number of trucks and on highways with high traffic volumes and high speeds. However, it may always be feasible to provide this minimum width, particularly when the terrain is difficult or when traffic volume is low. A minimum shoulder width of 2 ft may therefore be used on the lowest type of highways, but 6 to 8 ft widths should preferably be used. The width for usable shoulders within the median for divided arterials having two lanes in each direction, however, may be reduced to 3 ft, since the drivers rarely use the median shoulder for stopping on these roads. The usable median shoulder width for divided arterials with three or more lanes in each direction should be at least 8 ft, since drivers in difficulty on the lane next to the median often find it difficult to maneuver to the outside shoulder.

Medians

A median is the section of a divided highway that separates the lanes in opposing directions. The width of a median is the distance between the edges of the inside lanes, including the median shoulders. Medians can either be raised, flush, or depressed. Raised medians are frequently used in urban arterial streets. Flush medians are commonly used on urban arterials. They can also be used on freeways, but with a median barrier. Depressed medians are generally used on freeways. Median widths vary from a minimum of 2 ft to 80 ft or more. AASHTO recommends a minimum width of 10 ft for four-lane urban freeways, which is adequate for two 4 ft shoulders, and a 2 ft median barrier. A minimum of 22 ft, preferably 26 ft, is recommended for six or more lanes of freeway.

Median and Roadside Barriers

AASHTO defines a median barrier as a longitudinal system used to prevent an errant vehicle from crossing the portion of a divided highway separating the traveled ways for traffic in opposite directions.

Curbs and Gutters

Curbs are raised structures made of either Portland cement concrete or bituminous concrete (rolled asphalt curbs) that are used mainly on urban highways to delineate pavement edges and pedestrian walkways. Gutters or drainage ditches are usually located on the pavement side of a curb to provide the principal drainage facility for the highway.

Guard Rails

Guard rails are longitudinal barriers placed on the outside of sharp curves and sections with high fills. Their main function is to prevent vehicles from leaving the roadbed.

Sidewalks

Sidewalks are usually provided on roads in urban areas, but very seldom are they provided in rural areas.

Cross Slopes

Pavements on straight sections of two-lane and multilane highways without medians are sloped from the middle downward to both sides of the highway. The cross slopes on divided highways are provided by either crowning the pavement in each direction, or by sloping the entire pavement in one direction.

Side Slopes

Side slopes are provided on embankments and fills to provide stability for earthworks. They also serve as a safety feature by providing a recovery area for out-of-control vehicles

Right of Way

The right of way is the total land area acquired for the construction of the highway [116].

3.2 Feature Extraction

For the last few years it has been shown in many research papers that automated feature extraction from Lidar data is a very promising issue. However achieving the required accuracies for design stages using the automated technologies is a challenging issue. But the quality and the quantity of the Lidar data may provide a high accuracy 3D feature extraction environment.

Both intensity and height information will be used for the extraction of road surfaces and delineation of the edge of pavements in the project area. First of all non-terrain objects such as vegetation, buildings, cars, etc. should be identified. To investigate the

separability of these objects a clustering analysis will be performed. And then fusing the elevation information with the intensity will help extraction of road surfaces from the data. Using edge operators edge of pavements will be delineated and applying Hough transform will give us the coordinates of points lying on the edge of pavements.

To see the intensity range for the features inside the data, clustering is performed using MultiSpec data analysis software (ISODATA algorithm, number of classes 8, convergence threshold 98%). A portion of the data (Figure 3.1) is used for this analysis for testing purposes. After several attempts 8 clusters found to represent the data better.

Figure 3.1 Intensity Image used for clustering

Figure 3.2 Clustering Results

Figure 3.3 Closer look at the clustered image

Looking at figures 3.2 and 3.3 we can see that cluster #1 represents mainly buildings, cluster #2 represents the grass, cluster #3 represents mainly vegetation but it also has buildings and roads, cluster #4, 5, and 6 represents mainly roads and parking lots but it also has building and vegetation, cluster #7 represents roads and buildings and cluster #8 represents water and buildings. This analysis shows us that by applying only some threshold values to the intensity image it is impossible to extract any object from the Lida data. But fusing the height values with the intensity and using the first-last return analysis for the Lidar data can be the solution for road surface extraction problem.

To use the elevation information for the separation of the roads a bare earth Digital Terrain Model of the area should be determined, which means the removal of the non-terrain objects from the data.

An inherent source of information for the segmentation of Lidar data is the analysis of height texture defined by local variations of height. The following results show the application of the standard deviation filter to the intensity and height data. Energy, Entropy, Contrast statistics derived from co-occurrence matrices will also be derived to be used for clustering and a possible multi-spectral edge detection process.

To apply the standard deviation filter to the intensity and height image a block of the data which has highway, streets, buildings, and vegetation is cropped. Figure 3.4 shows the intensity image for this area. Figure 3.5 shows the result of the application of the standard

Figure 3.4 Intensity image for standard deviation filter

deviation filter. When Standard Deviation Filter is applied to the intensity image each output pixel contains the standard deviation of the 3-by-3 neighborhood around the corresponding pixel in the input image.

Figure 3.5 Standard deviation filter applied intensity image

Another texture measure, Entropy filter is also applied to the intensity image and the result is presented in Figure 3.6. Looking at the results of this filter for the intensity image gives us some idea about the edge of pavements, especially the standard deviation filter but this is not enough. We decided to apply the standard deviation filter to the height image (Figure 3.7). Height image itself is a very good texture measure to identify some objects in the scene such as high buildings and vegetation.

Figure 3.6 Entropy filter applied intensity image

Figure 3.7 Height image

Figure 3.8 Standard deviation filter applied height image

Looking at Figure 3.8 we can easily identify the non-terrain objects (buildings, trees, cars. Applying a 90% threshold value to this image gives us a binary image showing the non-terrain objects (Figure 3.9). To delineate the pixels defining the non-terrain objects some morphological operations are performed on the threshold applied filtered height image. A closing operation is followed by an opening operation and then filling up the holes gives us the non-terrain objects which can be seen in Figure 3.10. We can clearly see the cars, buildings and trees in this image. To obtain the bare earth DTM we take a compliment of this image which gives the roads, surrounding grass and earth pixels (Figure 3.11).

Figure 3.9 Threshold application

Figure 3.10 Non-terrain objects

Figure 3.11 Bare Earth pixels

By removing the non-terrain pixels from the intensity image we get output which has only the bare earth pixels in Figure 3.12. Now we can cluster this image to separate the road surfaces from the Lidar data as in Figures 3.13 and 3.14. After performing opening and closing morphological operations on the separated road surfaces (Figure 3.15) we can clearly see the road surfaces which include the parking lots in Figure 3.16. And finally, applying an edge detection algorithm (Canny Edge detection method) to the final image gives us the edge of pavements for the area.

Figure 3.12 Intensity image without non-terrain objects

Figure 3.13 Clustered image showing road surfaces

Figure 3.14 Separated road surfaces

Figure 3.15 Opening and closing operation on road surfaces

Figure 3.16 Road surfaces over intensity image

Figure 3.17 Application of Canny edge detection over Road surfaces

When we look at the figures 3.16 and 3.17 we see that the method does not give a very good result for edge of pavements. The trees block some of the road surfaces, so the last return data for the surfaces should be included where the trees are removed. The railroad inside the image also included as a road feature and it has to be removed, too. The surface under the vehicles should be interpolated. The median on the highway should be identified and the highway edge of pavements should be clearly delineated. The feature extraction and evaluation is not finished yet but the research is continuing. The following steps are to be done;

- Deriving other texture measures for clustering and multi-spectral edge detection
- Extraction of edge of pavements using Hough Transform
- Comparison of the results with the data collected for INDOT for the same project area.

CHAPTER 4

FIELD TRIP TO ODOT

A visit to ODOT (Ohio Department of Transportation) is planned and done on Dec.16, 2005 to discuss our findings in the project and to see how they compare to their experience. It was a very helpful trip. This section summarizes the observations during that trip.

After investigating their options ODOT bought a Lidar system to operate themselves for faster processing of large linear jobs. Selection of a Lidar system depends on criteria such as functionality, cost, upgrade potential, maintenance program, and other options. The department preferred a fixed wing aircraft (Cessna Grand Caravan) since it is better than a helicopter when the vibration, maintenance costs and flying time is considered although the flying height for helicopters can be as low as 80m when compared to 300m for fixed wing (Figure 4.1).

Figure 4.1 Cessna Grand Caravan Lidar instrumentation

But then the swath width for the flight decreases due to the lower heights. The other items that are considered for the selection of the airplane were cabin floor area, fuel duration, cost, safety record, operating characteristics and payload capacity. After selection of the aircraft the interior design should be made to put all the instruments. ODOT has Optech ALTM 30/70 Lidar equipment.

Besides the systems onboard the aircraft there has to be data storage systems which should store terabytes of data. There has to be an archival, and an expansion plan for the units. Multiple hard drives, lots of memory and dual processors are some of the requirements for the workstations.

The software packages that are used for the data management purposes are:

- Geomedia – Plan mapping extents
- ALTM NAV – Plan and conduct flights
- POSPAC – GPS/INS solution
- Realm – Point cloud generation
- GeoCue – Review coverage, create working segments, LiDAR ortho's, manage workflow
- Microstation V8 – CAD software

- TerraScan – classification, thinning, smoothing
- TerraMatch – Rectify flight lines if necessary
- QT Modeler – 3D visualization
- TerraPhoto – AT and orthophoto production
- ISAT – Auto AT
- OrthoPro – Orthophoto production
- GeoPac – Microstation Design software

Selection of the software should be done according to the application/products, goal/design quality, and approach/Lidar for the surface and photogrammetry for the planimetrics.

One of the softwares is GeoCue which can use other softwares for several purposes. GeoCue is applicable to just about any production or task management scenario that follows the paradigm of input of data, dividing the data into production “segments” and then processing the data into products (<http://www.niirs10.com/Products/geocue.htm>).

QT Modeler is the software used for visualization purposes which is now being marketed by Applied Imagery (www.appliedimagery.com). The story of Applied Imagery begins at the Johns Hopkins University's Applied Physics Lab (APL).

Another visualization software is PointVue LE. PointVue LE is a 3-D LIDAR visualization tool which can be used to visualize LIDAR data in ASPRS LAS Version 1.1 format (<http://www.niirs10.com/Products/pointvue.htm>).

The data extraction software form the Lidar equipment is Realm Survey.

POSPac software is used for fully exploit data collected with the company's Position and Orientation System (POS), Digital Sensor System (DSS), as well as LIDAR and camera systems (http://www.applanix.com/products/pospac_airborne_index.php).

For processing laser-scanning points Terrascan is used. Processing includes error calibration, point classification, removal of unnecessary points, profile extraction and digitizing features by snapping onto laser points (http://www.terrasolid.fi/ENG/Tuote_kuvaukset/TScan.htm).

The main output from their system is a Digital Terrain Model of the project area. By only producing this data the system paid of itself in one year.

Some of the conclusions from ODOT projects are:

- Vertical accuracy needed for planning stages is ± 1.0 ft and ± 0.1 ft for design stages. The planimetric accuracy that is asked is 0.2-0.3ft.
- LiDAR can be used with existing softcopy photogrammetry
- LiDAR can meet planning level mapping needs with little processing
- LiDAR can meet design level mapping if appropriate control and processing is performed
- Survey control must be obtained as accurately as possible
- High point density is essential for design level mapping
- Photogrammetry is used for small jobs; Lidar is used for DTM generation on moderate and large jobs, special projects [123].

The project area is shown in Figures 4.2, 4.3 which are produced using QT Modeler software.

Whole project area

Another oblique view the project area

Figure 4.2 Scenes from the project area produced using QT Modeler with elevation values

Figure 4.3 Scenes from the project area produced using QT Modeler with intensity values

CHAPTER 5

CONCLUSIONS

With properly designed LIDAR control, assessment of 3D as built is attainable at the over-all average horizontal (planimetric) error of 0.324 ft (9.9 cm); more specifically with a 0.284 ft (8.7 cm) RMS error in Northing, and a 0.255 ft (7.8 cm) RMS error in Easting. The over-all average vertical (height) error was 0.003 ft (0.09 c,m). The RMS error in height was 0.108 ft (3.29cm).

Lidar recognizable control (2m x 2m chevrons) was spaced at approximately 200m parallel to the axis of the project corridor, at a 60m spacing sideways. The corridor project was about 6 km long.

Least Squares Image matching software was developed. The internal accuracy proved to be 0.027 ft (8mm).

The strip width was approximately 111m and overlap between the Lidar strips changes from 55 to 90m sideways. Each flight line was flown twice in opposite directions showing 55 % overlap in two strips and 75 % in other two.

The overall conclusion about the usage of Lidar aerial surveys for corridor mapping projects is that this technique is an efficient, cost cutting alternative to classical terrestrial and aerial survey techniques. However, at this point of the research it is felt that the design of the LiDAR control plays a critical role to the success of the deployment of aerial LiDAR surveys. Augmentation of ground-based LiDAR and classical surveys

proves to be necessary because of shielding of the airborne laser signals (e.g. underpasses).

Comparison of the Lidar based model against the photogrammetric model obtained from low flying aerial photography (helicopter) should be made once data of the latter model become available.

CHAPTER 6

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APPENDIX A

Control Comparison Unadjusted

Number	Easting	Northing	Known Z	Laser Z	Dz

130	199378.650	1655755.703	744.780	744.020	-0.760
132	199818.110	1656139.531	749.530	748.940	-0.590
133	200093.884	1655807.529	752.340	751.430	-0.910
134	200165.720	1656508.201	753.700	753.010	-0.690
135	200408.865	1656281.570	779.820	779.210	-0.610
136	200597.350	1656957.308	756.440	755.780	-0.660
137	200927.969	1656627.696	757.740	757.120	-0.620
138	201297.810	1656870.779	775.950	775.290	-0.660
139	201173.775	1657308.593	771.050	770.460	-0.590
140	201916.774	1657138.177	772.950	772.420	-0.530
142	202374.944	1657418.569	777.879	777.170	-0.709
143	202651.589	1657810.773	771.001	770.370	-0.631
144	202959.425	1657405.944	777.017	776.210	-0.807
145	203365.627	1657822.824	777.155	776.560	-0.595
146	203626.829	1657284.615	780.807	780.160	-0.647
147	204088.429	1657593.231	782.757	782.030	-0.727
148	204306.485	1657128.402	783.227	782.630	-0.597
149	204953.999	1657124.773	787.410	786.630	-0.780
150	204818.667	1657388.081	788.001	787.210	-0.791
151	205638.790	1656992.112	790.833	790.050	-0.783
152	205638.167	1657427.201	787.235	786.590	-0.645
153	206194.353	1657306.696	777.047	776.230	-0.817
154	206221.467	1657459.828	776.203	775.390	-0.813
155	206795.422	1657610.299	789.357	788.650	-0.707
156	206842.996	1657780.449	791.214	790.490	-0.724
157	207457.213	1657954.471	795.351	794.700	-0.651
158	207495.574	1658117.305	795.891	795.370	-0.521
159	208086.918	1658279.805	798.760	798.020	-0.740
160	208134.598	1658449.065	799.458	798.810	-0.648
161	208737.930	1658611.096	801.479	800.880	-0.599
162	208771.294	1658769.990	804.370	803.610	-0.760
163	209368.246	1658802.822	804.183	803.410	-0.773
164	209415.091	1658967.989	808.337	807.800	-0.537
165	209817.782	1658831.914	804.258	803.490	-0.768
166	210208.320	1658684.342	812.967	812.150	-0.817
167	210109.513	1659061.581	808.134	807.420	-0.714
168	210953.873	1658714.346	833.407	832.750	-0.657
169	210842.340	1659212.160	821.699	821.020	-0.679
170	211668.528	1658739.419	813.631	813.020	-0.611

171	211642.217	1659210.645	817.384	816.760	-0.624
172	212307.276	1658936.437	823.325	822.670	-0.655
173	212362.023	1659111.245	820.578	819.960	-0.618
174	212973.544	1659144.455	833.684	833.020	-0.664
175	213015.607	1659304.426	835.255	834.410	-0.845
176	213643.317	1659229.457	828.313	827.680	-0.633
177	213642.210	1659681.140	828.950	828.200	-0.750
178	214317.586	1659585.845	843.452	842.670	-0.782
179	214345.924	1659732.160	842.923	842.340	-0.583
180	214978.990	1659803.845	840.876	840.200	-0.676
181	215008.129	1659947.921	841.440	840.860	-0.580
182	215659.345	1660026.767	852.686	852.170	-0.516
183	215665.613	1660163.881	853.500	852.980	-0.520
184	216326.614	1660107.239	839.700	839.030	-0.670
185	216322.186	1660586.939	846.319	845.650	-0.669
186	217027.529	1660456.252	854.760	854.000	-0.760
187	217022.241	1660596.252	857.720	857.120	-0.600
188	217715.412	1660644.605	852.060	851.300	-0.760
189	217838.357	1660489.146	850.980	850.330	-0.650
190	218329.201	1660511.872	867.100	866.450	-0.650
191	218526.100	1660106.246	853.460	852.750	-0.710
192	218826.737	1660258.473	881.450	880.760	-0.690
193	219118.197	1659821.622	881.860	881.330	-0.530
195	219306.505	1660091.852	857.510	856.820	-0.690
232	199420.595	1656032.097	742.080	741.320	-0.760
233	199994.044	1656806.731	745.870	745.300	-0.570
236	200302.321	1657122.825	753.530	752.860	-0.670
237	200612.192	1657401.508	754.000	752.770	-1.230
238	201215.212	1656296.602	761.610	761.020	-0.590
240	201674.727	1656553.373	766.760	766.240	-0.520
242	202353.978	1656826.049	772.979	772.220	-0.759
244	202834.360	1657146.020	775.546	774.850	-0.696
246	203288.890	1657034.452	779.447	778.780	-0.667
247	203770.077	1658054.986	777.655	777.100	-0.555
248	203957.593	1656912.639	782.926	782.210	-0.716
249	204327.256	1657944.902	781.203	780.560	-0.643
251	204834.544	1657692.793	783.819	783.090	-0.729
253	205465.056	1657688.295	787.212	786.390	-0.822
254	205688.559	1657699.373	787.459	786.800	-0.659
256	209949.694	1658121.393	800.264	799.570	-0.694
257	210487.958	1658144.452	805.273	804.420	-0.853
259	211050.863	1658167.265	838.857	838.090	-0.767
262	212004.749	1659237.037	816.873	816.230	-0.643
263	211984.705	1659578.542	817.768	817.200	-0.568
264	213644.530	1658759.639	832.929	832.080	-0.849
265	213866.100	1658737.988	833.964	833.070	-0.894

266	213798.339	1660103.339	831.636	830.960	-0.676
267	216269.311	1659858.646	835.760	835.130	-0.630
269	216553.703	1659731.064	837.665	837.070	-0.595

Average dz	-0.687
Average magnitude	0.687
Root mean square	0.695
Std deviation	0.109

APPENDIX B

Control Comparison Adjusted

Number	Easting	Northing	Known Z	Laser Z	Dz

130	199378.650	1655755.703	744.780	744.710	-0.070
132	199818.110	1656139.531	749.530	749.630	+0.100
133	200093.884	1655807.529	752.340	752.120	-0.220
134	200165.720	1656508.201	753.700	753.700	+0.000
135	200408.865	1656281.570	779.820	779.900	+0.080
136	200597.350	1656957.308	756.440	756.470	+0.030
137	200927.969	1656627.696	757.740	757.810	+0.070
138	201297.810	1656870.779	775.950	775.980	+0.030
139	201173.775	1657308.593	771.050	771.150	+0.100
140	201916.774	1657138.177	772.950	773.110	+0.160
142	202374.944	1657418.569	777.879	777.860	-0.019
143	202651.589	1657810.773	771.001	771.060	+0.059
144	202959.425	1657405.944	777.017	776.900	-0.117
145	203365.627	1657822.824	777.155	777.250	+0.095
146	203626.829	1657284.615	780.807	780.850	+0.043
147	204088.429	1657593.231	782.757	782.720	-0.037
148	204306.485	1657128.402	783.227	783.320	+0.093
149	204953.999	1657124.773	787.410	787.320	-0.090
150	204818.667	1657388.081	788.001	787.900	-0.101
151	205638.790	1656992.112	790.833	790.740	-0.093
152	205638.167	1657427.201	787.235	787.280	+0.045
153	206194.353	1657306.696	777.047	776.920	-0.127
154	206221.467	1657459.828	776.203	776.080	-0.123
155	206795.422	1657610.299	789.357	789.340	-0.017
156	206842.996	1657780.449	791.214	791.180	-0.034
157	207457.213	1657954.471	795.351	795.390	+0.039
158	207495.574	1658117.305	795.891	796.060	+0.169
159	208086.918	1658279.805	798.760	798.710	-0.050
160	208134.598	1658449.065	799.458	799.500	+0.042
161	208737.930	1658611.096	801.479	801.570	+0.091
162	208771.294	1658769.990	804.370	804.300	-0.070
163	209368.246	1658802.822	804.183	804.100	-0.083
164	209415.091	1658967.989	808.337	808.490	+0.153
165	209817.782	1658831.914	804.258	804.180	-0.078
166	210208.320	1658684.342	812.967	812.840	-0.127
167	210109.513	1659061.581	808.134	808.110	-0.024
168	210953.873	1658714.346	833.407	833.440	+0.033
169	210842.340	1659212.160	821.699	821.710	+0.011
170	211668.528	1658739.419	813.631	813.710	+0.079
171	211642.217	1659210.645	817.384	817.450	+0.066

172	212307.276	1658936.437	823.325	823.360	+0.035
173	212362.023	1659111.245	820.578	820.650	+0.072
174	212973.544	1659144.455	833.684	833.710	+0.026
175	213015.607	1659304.426	835.255	835.100	-0.155
176	213643.317	1659229.457	828.313	828.370	+0.057
177	213642.210	1659681.140	828.950	828.890	-0.060
178	214317.586	1659585.845	843.452	843.360	-0.092
179	214345.924	1659732.160	842.923	843.030	+0.107
180	214978.990	1659803.845	840.876	840.890	+0.014
181	215008.129	1659947.921	841.440	841.550	+0.110
182	215659.345	1660026.767	852.686	852.860	+0.174
183	215665.613	1660163.881	853.500	853.670	+0.170
184	216326.614	1660107.239	839.700	839.720	+0.020
185	216322.186	1660586.939	846.319	846.340	+0.021
186	217027.529	1660456.252	854.760	854.690	-0.070
187	217022.241	1660596.252	857.720	857.810	+0.090
188	217715.412	1660644.605	852.060	851.990	-0.070
189	217838.357	1660489.146	850.980	851.020	+0.040
190	218329.201	1660511.872	867.100	867.140	+0.040
191	218526.100	1660106.246	853.460	853.440	-0.020
192	218826.737	1660258.473	881.450	881.450	+0.000
193	219118.197	1659821.622	881.860	882.020	+0.160
195	219306.505	1660091.852	857.510	857.510	+0.000
232	199420.595	1656032.097	742.080	742.010	-0.070
233	199994.044	1656806.731	745.870	745.990	+0.120
236	200302.321	1657122.825	753.530	753.550	+0.020
237	200612.192	1657401.508	754.000	753.460	-0.540
238	201215.212	1656296.602	761.610	761.710	+0.100
240	201674.727	1656553.373	766.760	766.930	+0.170
242	202353.978	1656826.049	772.979	772.910	-0.069
244	202834.360	1657146.020	775.546	775.540	-0.006
246	203288.890	1657034.452	779.447	779.470	+0.023
247	203770.077	1658054.986	777.655	777.790	+0.135
248	203957.593	1656912.639	782.926	782.900	-0.026
249	204327.256	1657944.902	781.203	781.250	+0.047
251	204834.544	1657692.793	783.819	783.780	-0.039
253	205465.056	1657688.295	787.212	787.080	-0.132
254	205688.559	1657699.373	787.459	787.490	+0.031
256	209949.694	1658121.393	800.264	800.260	-0.004
257	210487.958	1658144.452	805.273	805.110	-0.163
259	211050.863	1658167.265	838.857	838.780	-0.077
262	212004.749	1659237.037	816.873	816.920	+0.047
263	211984.705	1659578.542	817.768	817.890	+0.122
264	213644.530	1658759.639	832.929	832.770	-0.159
265	213866.100	1658737.988	833.964	833.760	-0.204
266	213798.339	1660103.339	831.636	831.650	+0.014

267	216269.311	1659858.646	835.760	835.820	+0.060
269	216553.703	1659731.064	837.665	837.760	+0.095

Average dz +0.003
 Average magnitude 0.081
 Root mean square 0.108
 Std deviation 0.109

APPENDIX C

ELEVATION COMPARISON WITH CALIBRATED DATA

GCP #	Northing	Easting	Elevation	Northing	Easting	Avg. elev	CNT	Δ Elevation
137	1656627.696	200927.969	757.740	1656627.482	200927.989	757.285	4	0.455
138	1656870.779	201297.810	775.950	1656870.809	201297.800	775.356	4	0.594
139	1657308.593	201173.775	771.050	1657308.461	201173.226	770.464	2	0.586
140	1657138.177	201916.774	772.950	1657138.061	201916.919	772.587	4	0.363
142	1657418.569	202374.944	777.879	1657418.480	202374.848	777.400	17	0.479
143	1657810.773	202651.589	771.001	1657810.858	202651.688	770.458	5	0.543
144	1657405.944	202959.425	777.017	1657405.530	202959.035	776.407	3	0.610
145	1657822.824	203365.627	777.155	1657822.711	203365.621	776.682	3	0.473
148	1657128.402	204306.485	783.227	1657128.295	204306.263	782.649	3	0.578
149	1657124.773	204953.999	787.410	1657124.605	204954.048	786.741	3	0.669
150	1657388.081	204818.667	788.001	1657387.870	204818.628	787.356	4	0.645
151	1656992.112	205638.790	790.833	1656992.285	205638.337	790.022	1	0.811
152	1657427.201	205638.167	787.235	1657427.297	205638.158	786.764	28	0.471
153	1657306.696	206194.353	777.047	1657306.860	206194.311	776.563	3	0.484
154	1657459.828	206221.467	776.203	1657460.018	206221.306	775.527	6	0.676
155	1657610.299	206795.422	789.357	1657609.948	206795.798	788.690	2	0.667
156	1657780.449	206842.996	791.214	1657780.887	206843.094	790.694	3	0.520
157	1657954.471	207457.213	795.351	1657954.445	207456.980	794.785	4	0.566
158	1658117.305	207495.574	795.891	1658117.540	207495.295	795.391	2	0.500
159	1658279.805	208086.918	798.760	1658279.605	208086.758	798.132	7	0.628
160	1658449.065	208134.598	799.458	1658449.013	208134.829	799.072	4	0.386
161	1658611.096	208737.930	801.479	1658611.290	208738.031	800.969	3	0.510
162	1658769.990	208771.294	804.370	1658770.060	208771.370	803.861	9	0.509
163	1658802.822	209368.246	804.183	1658802.440	209367.913	803.506	2	0.677
164	1658967.989	209415.091	808.337	1658967.526	209415.242	807.721	2	0.616
165	1658831.914	209817.782	804.258	1658831.678	209817.836	803.636	3	0.621
166	1658684.342	210208.320	812.967	1658684.363	210208.180	812.250	3	0.717
167	1659061.581	210109.513	808.134	1659061.072	210109.801	807.630	8	0.504
168	1658714.346	210953.873	833.407	1658714.283	210954.312	832.935	2	0.472
169	1659212.160	210842.340	821.699	1659212.075	210842.299	821.199	7	0.500
170	1658739.419	211668.528	813.631	1658738.837	211668.927	813.095	3	0.536
171	1659210.645	211642.217	817.384	1659210.065	211642.151	816.819	3	0.565
172	1658936.437	212307.276	823.325	1658935.889	212307.511	822.788	5	0.537
173	1659111.245	212362.023	820.578	1659110.398	212362.579	820.113	4	0.465
174	1659144.455	212973.544	833.684	1659144.155	212973.655	833.112	3	0.572
175	1659304.426	213015.607	835.255	1659304.103	213015.877	834.672	18	0.583
176	1659229.457	213643.317	828.313	1659229.148	213643.496	827.696	2	0.617
177	1659681.140	213642.210	828.950	1659681.070	213642.441	828.337	4	0.613
178	1659585.845	214317.586	843.452	1659585.762	214317.555	842.871	19	0.581
179	1659732.160	214345.924	842.923	1659731.797	214346.052	842.514	3	0.409
180	1659803.845	214978.990	840.876	1659803.859	214978.925	840.453	3	0.423
181	1659947.921	215008.129	841.440	1659947.614	215008.267	840.987	3	0.453
182	1660026.767	215659.345	852.686	1660026.575	215659.807	852.193	3	0.492
183	1660163.881	215665.613	853.500	1660163.994	215665.546	853.110	6	0.390

184	1660107.239	216326.614	839.700	1660107.035	216327.437	839.171	3	0.529
185	1660586.939	216322.186	846.319	1660586.890	216321.958	845.788	5	0.531
186	1660456.252	217027.529	854.760	1660456.053	217027.542	854.300	8	0.460
187	1660596.252	217022.241	857.720	1660596.313	217022.468	857.316	3	0.404
188	1660644.605	217715.412	852.060	1660644.209	217715.746	851.554	12	0.506
189	1660489.146	217838.357	850.980	1660489.176	217838.413	850.408	3	0.572
190	1660511.872	218329.201	867.100	1660511.485	218329.401	866.590	4	0.510
191	1660106.246	218526.100	853.460	1660106.204	218526.414	852.911	5	0.549
192	1660258.473	218826.737	881.450	1660257.821	218826.584	880.824	3	0.626
195	1660091.852	219306.505	857.510	1660091.382	219306.332	856.975	4	0.535
233	1656806.731	199994.044	745.870	1656806.618	199994.299	745.397	5	0.473
240	1656553.373	201674.727	766.760	1656553.243	201674.957	766.313	5	0.447
242	1656826.049	202353.978	772.979	1656825.918	202353.783	772.454	4	0.525
244	1657146.020	202834.360	775.546	1657145.954	202834.726	775.049	19	0.497
246	1657034.452	203288.890	779.447	1657033.940	203289.315	778.927	3	0.520
249	1657944.902	204327.256	781.203	1657944.925	204327.271	780.654	3	0.549
251	1657692.793	204834.544	783.819	1657692.637	204834.420	783.166	3	0.653
253	1657688.295	205465.056	787.212	1657688.251	205465.218	786.678	7	0.534
254	1657699.373	205688.559	787.459	1657699.450	205688.257	786.844	3	0.615
262	1659237.037	212004.749	816.873	1659236.809	212004.740	816.390	2	0.484
263	1659578.542	211984.705	817.768	1659578.317	211984.435	817.271	4	0.498
267	1659858.646	216269.311	835.760	1659858.435	216269.499	835.209	4	0.551
269	1659731.064	216553.703	837.665	1659731.007	216553.609	837.216	5	0.449

Average Elevation Diff.= 0.539

APPENDIX D

CONTROL POINT COMPARISON FOR EACH STRIP

STRIP A1 (East To West)

#	Northing	Easting	Northing	Easting	Sigma_a3	Sigma_b3	distance(ft)	Nc-NI	Ec-EI	xDIFF^2	yDIFF^2
139	1657308.593	201173.775	1657386.869	201144.834	0.000675	0.000554	83.455	-78.276	28.941	6127.084	837.584
142	1657418.569	202374.944	1657496.154	202347.151	0.000761	0.000653	82.413	-77.585	27.793	6019.380	772.465
143	1657810.773	202651.589	1657878.312	202628.102	0.000623	0.000555	71.506	-67.539	23.486	4561.521	551.613
145	1657822.824	203365.627	1657899.452	203334.106	0.000700	0.000735	82.857	-76.628	31.521	5871.776	993.551
249	1657944.902	204327.256	1658022.117	204297.370	0.000500	0.000697	82.797	-77.215	29.886	5962.153	893.171
162	1658769.990	208771.294	1658847.604	208740.824	0.000799	0.000514	83.381	-77.614	30.470	6023.999	928.422
164	1658967.989	209415.091	1659046.576	209386.572	0.000543	0.000386	83.602	-78.587	28.520	6175.878	813.366
167	1659061.581	210109.513	1659138.851	210081.905	0.000382	0.000310	82.053	-77.270	27.607	5970.611	762.165
169	1659212.160	210842.340	1659288.758	210812.464	0.000571	0.000519	82.219	-76.598	29.876	5867.298	892.601
263	1659578.542	211984.705	1659654.079	211953.931	0.000324	0.000359	81.565	-75.537	30.773	5705.896	947.005
185	1660586.939	216322.186	1660661.674	216294.760	0.000394	0.000386	79.608	-74.735	27.425	5585.352	752.154
187	1660596.252	217022.241	1660671.204	216995.523	0.000491	0.000490	79.572	-74.952	26.719	5617.763	713.892
188	1660644.605	217715.412	1660719.834	217687.853	0.000513	0.000530	80.117	-75.229	27.558	5659.350	759.457
							Avg	Avg			
							meanDIST	_Nc-NI	Ec-EI	75148.060	10617.446
							maxDIST	-75.982	28.506	13.000	13.000
							minDIST	13.000	13.000	nRMS	eRMS
										76.030	28.578

STRIP A2 (East To West)

#	Northing	Easting	Northing	Easting	Sigma_a3	Sigma_b3	distance(ft)	Nc-NI	Ec-EI	xDIFF^2	yDIFF^2
138	1656870.779	201297.810	1656949.746	201267.962	0.000623	0.000600	84.420	-78.967	29.849	6235.748	890.937
140	1657138.177	201916.774	1657217.063	201886.617	0.000840	0.000832	84.454	-78.886	30.158	6222.965	909.478
142	1657418.569	202374.944	1657496.665	202344.096	0.000274	0.000206	83.968	-78.096	30.848	6098.994	951.606
144	1657405.944	202959.425	1657484.681	202929.273	0.000689	0.001917	84.313	-78.737	30.153	6199.551	909.190
159	1658279.805	208086.918	1658356.738	208055.437	0.001000	0.000623	83.125	-76.933	31.481	5918.680	991.032
160	1658449.065	208134.598	1658526.031	208103.288	0.000884	0.000666	83.091	-76.966	31.310	5923.777	980.326
161	1658611.096	208737.930	1658688.164	208706.666	0.000690	0.000707	83.168	-77.068	31.264	5939.544	977.423
163	1658802.822	209368.246	1658879.716	209336.784	0.000608	0.000344	83.082	-76.894	31.462	5912.666	989.881
165	1658831.914	209817.782	1658909.272	209787.128	0.000571	0.000458	83.210	-77.358	30.654	5984.213	939.680
171	1659210.645	211642.217	1659286.589	211610.696	0.000429	0.000461	82.225	-75.944	31.521	5767.423	993.546
177	1659681.140	213642.210	1659757.032	213611.047	0.000530	0.000469	82.041	-75.892	31.163	5759.628	971.114
178	1659585.845	214317.586	1659661.375	214289.347	0.000399	0.000321	80.636	-75.530	28.239	5704.743	797.427
179	1659732.160	214345.924	1659807.702	214318.502	0.000929	0.000746	80.365	-75.542	27.422	5706.588	751.945
180	1659803.845	214978.990	1659880.063	214950.803	0.000751	0.000487	81.263	-76.218	28.186	5809.254	794.458
181	1659947.921	215008.129	1660023.335	214979.983	0.000598	0.000568	80.495	-75.414	28.146	5687.231	792.200
182	1660026.767	215659.345	1660101.737	215631.138	0.000593	0.000390	80.101	-74.970	28.206	5620.507	795.604
183	1660163.881	215665.613	1660239.133	215637.437	0.000594	0.000481	80.354	-75.252	28.176	5662.925	793.895
184	1660107.239	216326.614	1660183.158	216298.973	0.000352	0.000438	80.794	-75.919	27.641	5763.659	764.045
186	1660456.252	217027.529	1660530.943	216999.278	0.000484	0.000425	79.855	-74.691	28.251	5578.722	798.115
189	1660489.146	217838.357	1660564.365	217808.998	0.000505	0.000447	80.746	-75.219	29.360	5657.864	861.987
190	1660511.872	218329.201	1660586.279	218300.349	0.000453	0.000485	79.805	-74.407	28.852	5536.417	832.457
233	1656806.731	199994.044	1656885.470	199962.424	0.000953	0.000686	84.851	-78.739	31.620	6199.882	999.849
244	1657146.020	202834.360	1657225.250	202804.876	0.001295	0.000785	84.538	-79.230	29.484	6277.448	869.280
251	1657692.793	204834.544	1657770.384	204803.324	0.000988	0.001018	83.636	-77.591	31.220	6020.352	974.676
262	1659237.037	212004.749	1659313.242	211972.980	0.000605	0.000605	82.562	-76.205	31.769	5807.216	1009.260
								Avg_Nc-	Avg_Ec-		
						meanDIST	82.284	NI	EI	146995.997	22339.414
						maxDIST	84.851	-76.667	29.857	25.000	25.000
						minDIST	79.805	25.000	25.000	nRMS	eRMS
										76.680	29.893

STRIP A3 (East To West)

#	Northing	Easting	Northing	Easting	Sigma_a3	Sigma_b3	distance(ft)	Nc-NI	Ec-EI	xDIFF^2	yDIFF^2
137	1656627.696	200927.969	1656708.253	200895.789	0.000738	0.000556	86.747	-80.557	32.180	6489.482	1035.553
148	1657128.402	204306.485	1657209.216	204275.045	0.000643	0.000671	86.715	-80.814	31.440	6530.951	988.494
150	1657388.081	204818.667	1657468.279	204786.710	0.000516	0.000460	86.331	-80.198	31.957	6431.795	1021.240
152	1657427.201	205638.167	1657507.024	205604.451	0.000867	0.000595	86.652	-79.823	33.716	6371.750	1136.739
155	1657610.299	206795.422	1657689.507	206764.330	0.000511	0.000383	85.092	-79.208	31.092	6273.934	966.699
156	1657780.449	206842.996	1657860.542	206811.625	0.000671	0.000491	86.018	-80.093	31.371	6414.938	984.134
157	1657954.471	207457.213	1658034.476	207426.527	0.000921	0.000640	85.687	-80.005	30.685	6400.748	941.598
168	1658714.346	210953.873	1658791.046	210921.602	0.000394	0.000401	83.212	-76.700	32.271	5882.853	1041.449
170	1658739.419	211668.528	1658817.290	211636.852	0.000593	0.000632	84.067	-77.871	31.676	6063.969	1003.367
172	1658936.437	212307.276	1659013.449	212276.406	0.000493	0.000391	82.968	-77.012	30.870	5930.806	952.950
173	1659111.245	212362.023	1659188.913	212331.640	0.000504	0.000412	83.399	-77.668	30.382	6032.325	923.089
174	1659144.455	212973.544	1659221.366	212943.918	0.000436	0.000419	82.420	-76.911	29.626	5915.345	877.723
176	1659229.457	213643.317	1659305.492	213611.356	0.000746	0.000799	82.479	-76.035	31.961	5781.277	1021.518
191	1660106.246	218526.100	1660181.451	218495.306	0.000601	0.000430	81.265	-75.205	30.794	5655.767	948.271
192	1660258.473	218826.737	1660331.976	218795.448	0.000836	0.000628	79.886	-73.503	31.289	5402.700	979.032
240	1656553.373	201674.727	1656634.257	201644.008	0.000728	0.000451	86.521	-80.884	30.718	6542.191	943.622
242	1656826.049	202353.978	1656907.395	202323.302	0.000609	0.000713	86.938	-81.346	30.676	6617.100	941.044
246	1657034.452	203288.890	1657114.875	203258.309	0.001424	0.000934	86.041	-80.423	30.581	6467.795	935.204
253	1657688.295	205465.056	1657767.917	205432.444	0.000047	0.000042	86.042	-79.622	32.612	6339.685	1063.573
254	1657699.373	205688.559	1657778.906	205654.855	0.000577	0.000436	86.380	-79.533	33.704	6325.536	1135.957
267	1659858.646	216269.311	1659935.548	216241.888	0.000690	0.000780	81.645	-76.902	27.424	5913.904	752.057
269	1659731.064	216553.703	1659808.306	216526.254	0.000375	0.000392	81.974	-77.242	27.449	5966.349	753.443
							Avg_Nc-NI	Avg_Ec-EI			
							meanDIST			135751.200	21346.758
							maxDIST	-78.525	31.113	22.000	22.000
							minDIST	22.000	22.000	nRMS	eRMS
										78.553	31.150

STRIP A4 (East To West)

#	Northing	Easting	Northing	Easting	Sigma_a3	Sigma_b3	distance(ft)	Nc-NI	Ec-EI	xDIFF^2	yDIFF^2
149	1657124.773	204953.999	1657204.346	204921.516	0.000551	0.000684	85.948	-79.573	32.483	6331.861	1055.156
151	1656992.112	205638.790	1657072.190	205606.551	0.000471	0.000389	86.324	-80.078	32.239	6412.523	1039.327
153	1657306.696	206194.353	1657387.004	206162.817	0.000857	0.000548	86.278	-80.308	31.535	6449.418	994.472
154	1657459.828	206221.467	1657540.477	206189.992	0.000891	0.000464	86.573	-80.649	31.475	6504.254	990.686
195	1660091.852	219306.505	1660169.238	219278.283	0.000854	0.000752	82.372	-77.386	28.222	5988.591	796.506
								Avg_Nc-	Avg_Ec-		
							meanDIST	NI	EI	31686.648	4876.147
							maxDIST	-79.599	31.191	5.000	5.000
							minDIST	5.000	5.000	nRMS	eRMS
										79.607	31.229

STRIP B1 (West To East)

#	Northing	Easting	Northing	Easting	Sigma_a3	Sigma_b3	distance(ft)	Nc-NI	Ec-EI	xDIFF^2	yDIFF^2
139	1657308.593	201173.775	1657224.481	201186.624	0.000833	0.000499	85.088	84.112	-12.849	7074.886	165.096
142	1657418.569	202374.944	1657334.790	202389.204	0.001159	0.000763	84.984	83.779	-14.260	7018.932	203.352
143	1657810.773	202651.589	1657726.575	202666.147	0.000526	0.000633	85.447	84.198	-14.558	7089.318	211.940
145	1657822.824	203365.627	1657738.961	203380.672	0.000844	0.000785	85.202	83.863	-15.046	7033.064	226.369
249	1657944.902	204327.256	1657860.959	204341.811	0.000571	0.000915	85.195	83.943	-14.555	7046.421	211.847
162	1658769.990	208771.294	1658686.446	208784.456	0.000949	0.000592	84.574	83.544	-13.162	6979.540	173.228
164	1658967.989	209415.091	1658884.855	209429.493	0.000592	0.000357	84.372	83.134	-14.402	6911.247	207.406
167	1659061.581	210109.513	1658977.599	210122.568	0.000552	0.000370	84.991	83.982	-13.055	7053.034	170.444
169	1659212.160	210842.340	1659129.229	210854.766	0.000946	0.000647	83.857	82.931	-12.426	6877.631	154.407
263	1659578.542	211984.705	1659495.749	211997.302	0.000343	0.000339	83.745	82.793	-12.597	6854.618	158.681
185	1660586.939	216322.186	1660506.136	216334.960	0.000451	0.000447	81.806	80.803	-12.775	6529.103	163.194
187	1660596.252	217022.241	1660515.551	217034.384	0.000534	0.000566	81.609	80.701	-12.142	6512.605	147.439
188	1660644.605	217715.412	1660563.458	217727.982	0.000542	0.000500	82.115	81.147	-12.571	6584.823	158.021
							Avg_Nc-NI	Avg_Ec-EI			
							meanDIST			89565.223	2351.423
							maxDIST	82.995	-13.415	13.000	13.000
							minDIST	13.000	13.000	nRMS	eRMS
										83.004	13.449

STRIP B2 (West To East)

#	Northing	Easting	Northing	Easting	Sigma_a3	Sigma_b3	distance(ft)	Nc-NI	Ec-EI	xDIFF^2	yDIFF^2
140	1657138.177	201916.774	1657054.103	201929.474	0.000863	0.000923	85.027	84.074	-12.700	7068.355	161.278
142	1657418.569	202374.944	1657334.636	202387.816	0.001163	0.000824	84.914	83.933	-12.871	7044.771	165.672
144	1657405.944	202959.425	1657322.692	202975.534	0.000313	0.000596	84.796	83.252	-16.109	6930.831	259.491
160	1658449.065	208134.598	1658365.869	208146.192	0.000950	0.000726	84.000	83.196	-11.594	6921.656	134.426
161	1658611.096	208737.930	1658528.511	208751.854	0.000822	0.000806	83.751	82.585	-13.924	6820.289	193.876
162	1658769.990	208771.294	1658687.321	208784.416	0.000856	0.000573	83.704	82.669	-13.122	6834.177	172.184
163	1658802.822	209368.246	1658718.908	209380.971	0.000511	0.000408	84.873	83.914	-12.725	7041.500	161.936
165	1658831.914	209817.782	1658749.330	209831.624	0.000545	0.000425	83.736	82.584	-13.842	6820.087	191.588
167	1659061.581	210109.513	1658978.732	210124.339	0.000417	0.000394	84.165	82.849	-14.826	6863.950	219.807
169	1659212.160	210842.340	1659130.537	210857.570	0.000714	0.000588	83.032	81.623	-15.230	6662.338	231.953
171	1659210.645	211642.217	1659128.895	211657.844	0.000453	0.000481	83.230	81.750	-15.628	6683.016	244.219
177	1659681.140	213642.210	1659599.795	213655.912	0.000721	0.000681	82.491	81.345	-13.702	6616.995	187.749
178	1659585.845	214317.586	1659504.025	214330.623	0.001410	0.000788	82.852	81.820	-13.037	6694.472	169.966
179	1659732.160	214345.924	1659650.255	214358.738	0.000780	0.000573	82.901	81.905	-12.814	6708.428	164.191
180	1659803.845	214978.990	1659722.296	214991.152	0.001258	0.000891	82.451	81.549	-12.162	6650.199	147.918
181	1659947.921	215008.129	1659865.791	215020.074	0.000696	0.000589	82.994	82.130	-11.945	6745.302	142.677
182	1660026.767	215659.345	1659945.567	215673.167	0.000907	0.000454	82.369	81.200	-13.823	6593.507	191.069
183	1660163.881	215665.613	1660082.506	215679.533	0.000673	0.000422	82.557	81.375	-13.920	6621.891	193.770
184	1660107.239	216326.614	1660025.647	216341.245	0.000469	0.000515	82.893	81.592	-14.630	6657.215	214.049
186	1660456.252	217027.529	1660375.792	217040.146	0.000637	0.000473	81.443	80.460	-12.617	6473.825	159.185
188	1660644.605	217715.412	1660564.187	217729.850	0.000704	0.000719	81.704	80.418	-14.438	6467.103	208.456
189	1660489.146	217838.357	1660409.592	217852.452	0.000705	0.000591	80.793	79.554	-14.094	6328.830	198.648
190	1660511.872	218329.201	1660432.521	218344.264	0.000431	0.000461	80.768	79.351	-15.062	6296.522	226.879
233	1656806.731	199994.044	1656721.859	200008.974	0.000952	0.000675	86.175	84.872	-14.930	7203.253	222.891
251	1657692.793	204834.544	1657609.617	204851.567	0.001354	0.001191	84.900	83.176	-17.022	6918.226	289.756
262	1659237.037	212004.749	1659155.227	212021.177	0.000525	0.000503	83.443	81.810	-16.428	6692.901	269.889
								Avg_Nc-	Avg_Ec-		
								NI	EI		
					meanDIST		83.306			175359.640	5123.521
					maxDIST		86.175	82.115	-13.969	26.000	26.000
					minDIST		80.768	26.000	26.000	nRMS	eRMS
										82.126	14.038

STRIP B3 (West To East)

#	Northing	Easting	Northing	Easting	Sigma_a3	Sigma_b3	distance(ft)	Nc-NI	Ec-EI	xDIFF^2	yDIFF^2
137	1656627.696	200927.969	1656543.001	200941.552	0.001097	0.000714	85.778	84.695	-13.583	7173.319	184.503
138	1656870.779	201297.810	1656787.149	201311.887	0.000620	0.000622	84.807	83.630	-14.076	6994.009	198.137
150	1657388.081	204818.667	1657305.614	204832.355	0.000463	0.000431	83.595	82.467	-13.688	6800.826	187.352
156	1657780.449	206842.996	1657698.201	206855.515	0.000830	0.000612	83.195	82.248	-12.519	6764.730	156.717
157	1657954.471	207457.213	1657872.181	207470.176	0.001180	0.000542	83.304	82.290	-12.963	6771.570	168.051
158	1658117.305	207495.574	1658035.201	207508.796	0.000822	0.000661	83.162	82.104	-13.222	6741.066	174.827
159	1658279.805	208086.918	1658197.466	208099.709	0.000850	0.000646	83.326	82.339	-12.791	6779.680	163.619
166	1658684.342	210208.320	1658603.171	210224.688	0.000559	0.000852	82.805	81.171	-16.368	6588.727	267.921
168	1658714.346	210953.873	1658633.773	210968.388	0.000354	0.000411	81.870	80.573	-14.515	6492.043	210.692
170	1658739.419	211668.528	1658658.140	211683.239	0.000544	0.000480	82.600	81.279	-14.710	6606.296	216.394
172	1658936.437	212307.276	1658855.497	212321.764	0.000437	0.000320	82.227	80.940	-14.488	6551.319	209.913
173	1659111.245	212362.023	1659030.450	212375.615	0.000473	0.000347	81.930	80.795	-13.592	6527.784	184.753
174	1659144.455	212973.544	1659064.106	212986.597	0.000535	0.000464	81.402	80.349	-13.052	6455.990	170.367
175	1659304.426	213015.607	1659223.838	213028.483	0.000314	0.000258	81.610	80.588	-12.876	6494.458	165.786
176	1659229.457	213643.317	1659148.941	213655.914	0.000720	0.000651	81.496	80.516	-12.597	6482.906	158.675
178	1659585.845	214317.586	1659505.384	214328.622	0.000568	0.000433	81.215	80.461	-11.037	6474.021	121.811
191	1660106.246	218526.100	1660027.714	218540.578	0.000676	0.000419	79.856	78.532	-14.478	6167.324	209.601
192	1660258.473	218826.737	1660180.616	218840.094	0.000587	0.000656	78.994	77.857	-13.357	6061.719	178.412
240	1656553.373	201674.727	1656634.257	201644.008	0.000728	0.000451	86.521	-80.884	30.718	6542.191	943.622
242	1656826.049	202353.978	1656742.915	202368.754	0.000918	0.000908	84.437	83.134	-14.776	6911.255	218.319
244	1657146.020	202834.360	1657062.883	202848.706	0.001002	0.000761	84.366	83.137	-14.346	6911.820	205.796
246	1657034.452	203288.890	1656950.985	203303.080	0.001837	0.001056	84.664	83.467	-14.190	6966.708	201.354
253	1657688.295	205465.056	1657605.761	205479.344	0.000045	0.000042	83.761	82.534	-14.288	6811.800	204.141
254	1657699.373	205688.559	1657617.037	205702.512	0.000489	0.000371	83.510	82.336	-13.953	6779.188	194.685
267	1659858.646	216269.311	1659778.932	216282.362	0.000854	0.000684	80.776	79.714	-13.050	6354.393	170.308
269	1659731.064	216553.703	1659651.903	216568.015	0.000370	0.000374	80.444	79.161	-14.311	6266.406	204.811
							Avg_Nc-NI	Avg_Ec-EI			
							meanDIST			172471.545	5670.567
							maxDIST	75.209	-12.004	26.000	26.000
							minDIST	26.000	26.000	nRMS	eRMS
										81.446	14.768

STRIP B4 (West To East)

#	Northing	Easting	Northing	Easting	Sigma_a3	Sigma_b3	distance(ft)	Nc-NI	Ec-EI	xDIFF^2	yDIFF^2
148	1657128.402	204306.485	1657047.567	204319.396	0.000518	0.000435	81.860	80.835	-12.911	6534.369	166.696
149	1657124.773	204953.999	1657044.122	204967.313	0.000515	0.000523	81.743	80.651	-13.314	6504.607	177.266
152	1657427.201	205638.167	1657347.286	205652.104	0.000719	0.000452	81.121	79.915	-13.937	6386.394	194.237
153	1657306.696	206194.353	1657226.570	206208.677	0.000860	0.000705	81.396	80.126	-14.324	6420.142	205.185
154	1657459.828	206221.467	1657381.008	206235.769	0.000323	0.000553	80.107	78.820	-14.302	6212.591	204.539
155	1657610.299	206795.422	1657530.297	206809.220	0.000563	0.000419	81.183	80.002	-13.798	6400.278	190.384
191	1660106.246	218526.100	1660028.143	218538.904	0.000525	0.000379	79.145	78.103	-12.804	6100.007	163.946
195	1660091.852	219306.505	1660013.787	219319.581	0.000906	0.000686	79.153	78.065	-13.076	6094.213	170.992
240	1656553.373	201674.727	1656472.506	201690.678	0.000624	0.000385	82.426	80.867	-15.952	6539.530	254.454
								Avg_Nc-	Avg_Ec-		
							meanDIST	NI	EI	57192.130	1727.699
							maxDIST	79.709	-13.824	9.000	9.000
							minDIST	9.000	9.000	nRMS	eRMS
										79.716	13.855