APPLICATIONS OF LASER SCANNING AND IMAGING SYSTEMS

By

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A THESIS PRESENTED TO THE GRADUATE SCHOOL
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This thesis is dedicated to my wonderful parents, Robert and Phyllis Drake, to my loving girlfriend, Melissa Crosby, and to her family who has been my ‘family away from home,’ Oler, Sandra, and Stacy Crosby. It is with the love and support of my family and friends that I am able to reach my goals.

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An overview of the technology involved in Laser Scanning and Imaging (LSI) systems is given, including the history of survey equipment and techniques prior to the introduction of LSI systems. In particular, the ILRIS-3D by Optech, Inc., of Toronto, Canada, was researched and evaluated. Descriptions of internal and external components are listed as well as the purpose of each component of this system.

Research involved experimenting with various applications for LSI technology. Applications involved include scanning roadways and bridges for the Department of Transportation (DOT), scanning intersections for the DOT, scanning buildings and using scanned data for as-built surveys, construction project monitoring, traffic homicide investigations involving skid marks and other measurable evidence and emergency assessment of burned or collapsed buildings. Examples for each use are given and various techniques on data collection are discussed for the applications.

InnovMetric's Polyworks™ Software was used to analyze the output. The Polyworks™ software was researched as a tool for conducting survey related measurements with LSI data. Aligning data, editing data, and other data manipulation techniques are discussed. Using the software modules to merge other datasets from an airborne laser scanning system is discussed. The application for merging the data researched and aspects that affect the quality of the merged dataset are discussed.

Georeferencing scans is evaluated and discussed on the usefulness of georeferenced data. Measurements were taken to find the offset of a GPS antenna mount added to the top of the ILRIS-3D. The coordinate offsets can be applied for data analysis and georeferencing.

CHAPTER 1
INTRODUCTION TO 3D LASER SCANNING AND IMAGING

Measuring distances has always been a preliminary task of any engineering project and probably the most important. Distances can be measured by a variety of methods. Before the development of electronic distance measuring instruments surveyors used rods, chains and steel tapes. This was a time consuming effort for surveyors because of the terrain they had to traverse. For longer distances, surveyors used triangulation. In triangulation, a "baseline" was measured, and then angular measurements were used to establish a "chain" or "network" of triangles. Starting with the known length of the baseline and the measured interior angles the law of sines could be used to compute the lengths of the other sides in the triangular network. As the triangular network was extended errors tended to buildup, and another baseline would have to be measured. Triangulation was used mostly for geodetic control purposes and would be done from mountain top to mountain top or by means of temporary towers. The use of towers increased the distance in "line of site" observations, and reduced the atmospheric scintillation common at ground level.

In the 1950s, the first electronic distance measurement (EDM) instruments were introduced to aid in measuring longer distances with more accuracy and in a more timely fashion. An EDM instrument transmits electromagnetic waves (light or radio frequency) between two instruments to determine the distance between the two points. The geodimeter used amplitude modulated waves, transmitted to retro-reflectors at distant stations, requiring that the two occupied points be intervisible (Breed, Hosmer and Bone, 1962). The geodimeter was based on experiments begun in 1941, by Erick Bergstrand, to improve the determination of the speed of light (Ewing and Mitchell, 1970).

Bergstrand's approach to measuring the speed of light was similar in principle to the approach taken by Fizeau more than a century earlier, beginning in 1849. Fizeau used a light source to project a beam of light through cogs in a wheel onto a mirror. Visually, he adjusted the angular velocity of the wheel until the returning light was blocked by a cog of the wheel. Using the known distance from the light source to the cog wheel and the angular velocity of the wheel and the dimensions of the cogs, he could determine the speed of light. Bergstrand used this same principle in his experiments, but the cog wheel was replaced with an electro-optical device, known as a Kerr cell. A Kerr cell is a device by which light beams can be amplitude modulated. By applying a sinusoidal electrical signal to the Kerr cell, the light beam could be modulated at selected frequencies. The modulated light beam was projected to a mirror and reflected back to the instrument. A photomultiplier tube within the instrument received the returned light beam and generated a electrical signal with the same frequency and phase of the returning light signal. The distance was computed by comparing the phase of the return signal to that of the transmitted signal. The name geodimeter stood for *geo*detic *dis*tance *meter* (Ewing and Mitchell, 1970).

The first geodimeter was developed before the invention of the laser and used incandescent or mercury vapor light sources. The light beam was linearly polarized before passing through the Kerr cell. The maximum range of the geodimeter was limited by the brightness of the light source and the number of retro-reflectors placed at the far end of the lines, with typical distances being 5 to 60 kilometers (3 to 30 miles) depending on the model. A Model 2 Geodimeter weighed 225 pounds and took approximately an hour to set up and take a set of measurements. The Model 3 Geodimeter and Model 4 Geodimeter weighed considerably less and took about half the time to complete the same tasks as stated above.

The geodimeter, and EDM instruments in general, used a series of modulating frequencies to enable the distance to be unambiguously determined. By measuring the phase difference of the transmitted and returning signal, and knowing the frequency, the distance can be determined as shown in Figure 1-1. Equation 1.1 shows the relationship between frequency and wavelength. The frequencies emitted were often in intervals of 10, thus corresponding to a distance in each of the numerical places to be determined. For example, a frequency that measures the thousandths place will be followed by a frequency to measure the hundreds place, followed by a frequency for the tens place, and so on. Modern EDM's change the frequency automatically unlike the older models in which the operator had to manually change the frequency and record distances (Schmidt and Wong, 1985). With earlier EDM's as well as the geodimeter, longer distances were only measured at night due to the interference caused by the atmosphere and light sources.

$$\lambda = \frac{c}{v} \tag{1.1}$$

where λ = Wavelength

c = Speed of light in a vacuum (299,792, 458 m/s

v = Frequency, measured in Hertz

Of course, the observations had to be corrected for the effect of atmospheric refraction, using temperature, barometer pressure and humidity observations and an atmospheric model.

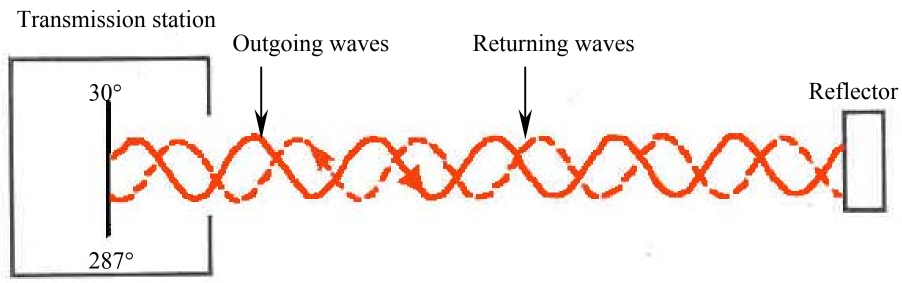

Figure 1-1. Phase difference measurement. Image derived from Schmidt and Wong, 1985.

With the development of small, reliable, affordable Q-switched solid state lasers most manufacturers of EDM instruments switched from the continuous wave (CW) modulation and phase measurement technique to short pulse time-of-flight (ToF) technique. In the ToF approach a short intensive signal is transmitted by the instrument. This pulse travels to the target and is then reflected back to the instrument. By measuring the round trip travel time of the pulse of light, i.e., the time it takes for a pulse to travel to the target and back to the instrument, the distance may be calculated using Equation 1.2. (Rüeger, 1996).

$$2d = c'\Delta t' = c'(t_R - t_E) \tag{1.2}$$

where d = distance between instrument and target

c' = speed of light in a vacuum corrected for atmospheric refraction

$\Delta t'$ = flight time of pulse

t_E = time of departure of pulse, timed by gate G_E

t_R = time of arrival of returning pulses, timed by gate G_R

Most of the earlier model EDM's were separate units from the theodolites that were used to measure angles. EDM's were mounted on a tripod to measure distances before or after the angles were measured. This was a time consuming and labor intensive task, but still easier and faster than taping. As time progressed, survey instrument manufacturers began to combine the theodolites and EDM's resulting in what is known as a total station (TS). With a TS, a user has the ability to determine the horizontal and vertical angles and distances, i.e. Vectors from the observer to distant points.

Total stations made the task of gathering measurements easier but each point had to be measured individually. An individual has to stand by the instrument, take notes and operate the instrument while a rodman holds a prism pole on the object being measured. This too is time consuming and labor intensive. With a rodman holding a prism pole at every point or feature needing to be measured, only a limited number of points can be collected. For example, if an intersection is being located, an instrument operator shoots the edge of curb, edge of asphalt, ends of paint stripes, power poles, cross walk areas and other features that are pertinent to that particular intersection. A drawing must still be sketched in the field book to aid the draftsman in 'connecting the dots' to re-create the intersection from data collected by the survey crew.

A recent advancement in distance measuring devices now replaces the rodman, and collects more data than a rodman and instrument operator combined in a shorter amount of time. This advancement is Laser Scanning and Imaging (LSI). LSI systems use the same principle as the total station in the sense that it measures vectors (distances and direction) from the instrument to points in the scene. LSI also uses the same time-of-flight principle as the total station, but the data recorded often includes intensity, or reflectance data from the object. Figure 1-1 shows a total station and a tripod mounted LSI.

With a tripod mounted laser scanner, thousands of data points can be collected per second – orders of magnitude higher than 200 to 300 data points collected by a typical survey crew using a total station in one day. This thesis investigates uses of tripod mounted LSI systems as well as the technology behind the scanners. Real world applications are evaluated. The primary advantage of a LSI system is the rate at which data is collected and quality of detail of the data that is collected over a short amount of time. Secondly, there is no need for retro-reflectors or a rodman. The data that is collected recreates the object or scene being scanned leaving no need for a sketch by the operator. Furthermore, a digital camera captures a real-time image of the scene for future reference. Another benefit to a tripod mounted LSI system is there is no need for a draftsman in the office, only someone to analyze and edit data collected by the scanner. Most LSI systems collect intensity data along with coordinate data in order to better differentiate objects in the scan.

There are a few differences in the surveying methods used with a laser scanning unit and a total station. The coordinate system changes from set-up to set-up with the laser scanner. For example, if a unit scans a wall, a set of coordinates is given to a specific feature on the wall. If the scanner is moved and the wall is scanned again, the same specific feature will have a different set of coordinates. This issue is resolved in the office by using software capable of reading and processing data from the scanner. When using a total station an arbitrary coordinate system is created at the beginning of the project and is carried throughout the project.

Figure 1-2. A total station (left) and a tripod mounted laser scanning and imaging unit (right).

Several companies manufacture laser scanners, however, only a few companies have a long range scanning and imaging product. The ranges of the scanners vary as well as the accuracies and data collection rate. However, all of the companies are producing products with survey related applications. Each scanner has it's own capabilities and limitations. Some use commercial software, such as InnovMetric's Polyworks™, and some use software written in-house by the manufacturer of the laser scanner. The scanning rates vary from instrument to instrument, ranging from 1000 points per second to 18,000 points per second. Some of the units that collect at a higher rate do not have the accuracy of some of the slower scanning units. Appendix A shows a comparison of a few scanners that are on the market.

As with any product that is going to be taken into the field, compact design, weight and user friendliness are important aspects of design. A bulky laser scanner is the last thing that an instrument operator wants to be mounting onto a tripod several times in the process of completing a survey. The weight of the scanner is a more important factor than one might think. In instances where the scanner is being used to scan objects that are at ground surface level, it is beneficial to have the scanner at an elevated position above the surface being scanned. Getting the scanner in a good position can be difficult if the scanner is heavy and hard to handle. User friendliness is also a good aspect to have with any piece of equipment. A system that is hard to operate only leads to possibilities of poor data collection or errors in system set up.

Data collected from a scanner should be formatted in a way that enables the user to do quick calculations and make accurate distance, area and volume measurements. Different software packages enable the user to complete most of the necessary tasks that are performed with the data. Occasionally, it is necessary to convert data to another format that is readable with another software package.

Optech Inc., manufacturer of the product used for research in this thesis, uses a software package written by InnovMetric Software called Polyworks™ Modeler and Inspector. Polyworks™ Modeler and Inspector consist of separate modules to aid in the data manipulation that is required to do data analysis and to conduct measurements with the data. Data can then be exported as primitives, cross-sections, IGES files or ASCII text files for use in other programs. More information about data manipulation and software will be discussed later (Optech, 2002).

Data used in this thesis were collected using a system manufactured by Optech Incorporated in Toronto, Canada. http://www.optech.on.ca/ Optech named this system the Intelligent Laser Ranging Imaging System (ILRIS-3D). This unit was chosen due to the availability of the unit through the University of Florida's GeoSensing Systems Engineering Research Group in the Civil and Coastal Engineering Department. http://www.alsm.ufl.edu

CHAPTER 2
THE TECHNOLOGY BEHIND 3D LASER SCANNING

The Optech ILRIS-3D System

The ILRIS-3D consists of several separate components (Figure 2-1). The scanning unit measures 315mm x 315mm x 200 mm, weighs 12 kilograms, (26.5 pounds), and is sealed to protect the electronics, optical and mechanical elements from water and dust. Other components include a power supply, a PCMCIA card (flash card, ATA Type II) for data storage, a Palm Pilot for external communication with the unit and a tripod to use as a mounting surface. Secondary items for data collection include a PC with a data parsing program and Polyworks software for data analysis.

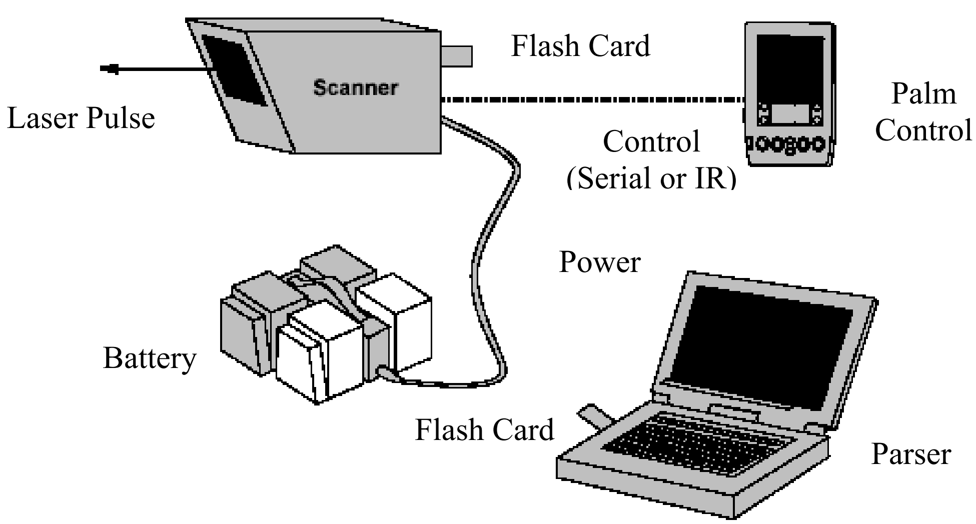

Figure 2-1. ILRIS-3D set-up. (Courtesy of Optech Inc.)

The Scanner

The scanner is where the data collection process takes place. This is where the laser, mirrors, the microprocessor and the digital camera are housed. Along with these items are other optical and electronic components including: Time Interval Meter (TIM), a Discriminator, Optical Bandpass Filter, Receiver, fiber optic cable (FOC), X-axis and Y-axis drivers for the mirrors and a Beam Expander. Figure 2-2 shows the basic concept of how these parts are connected in order for the ILRIS-3D to operate.

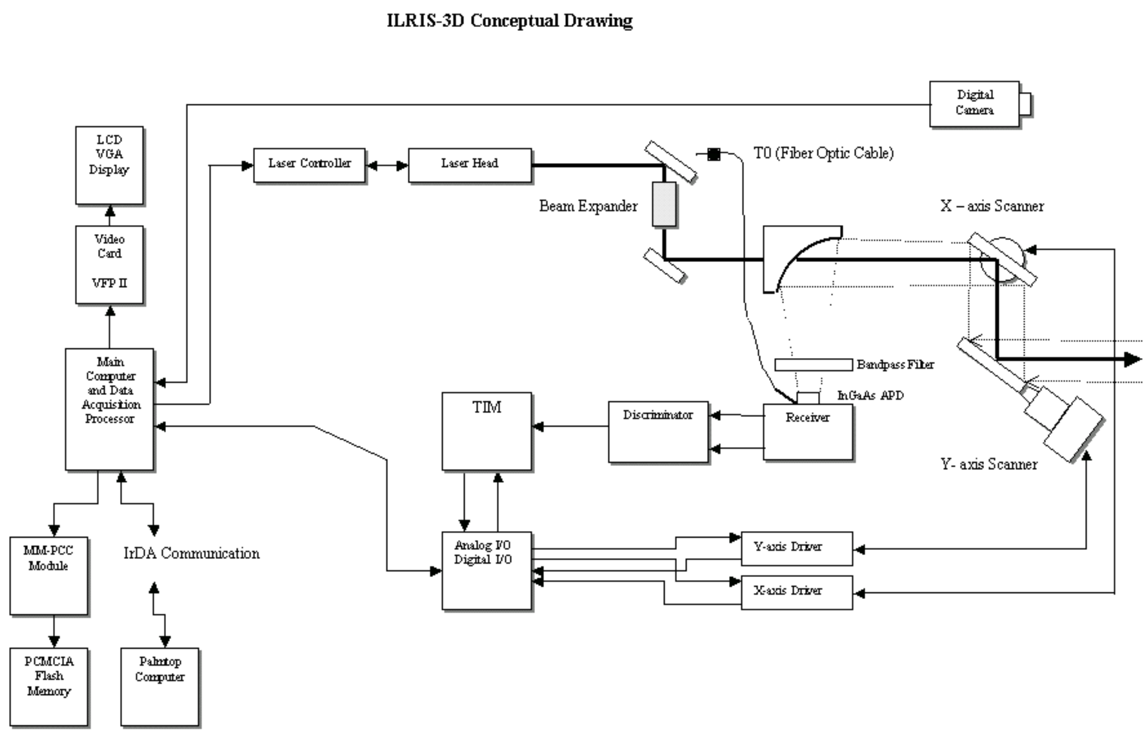

Figure 2-2. ILRIS-3D Conceptual Plan. (Courtesy of Optech Inc.)

The Laser

Optech incorporates a Class I pulsed laser in the ILRIS-3D. A Class I laser is eyesafe in all modes of operation (Optech, 2002). The wavelength of the laser light is 1547 nanometers. The ToF of the laser pulses are measured by a high precision counter, or TIM. The time of travel data for each pulse is then used by a microprocessor to calculate the distance to an object known as the range.

Following along in Figure 2-2, we can trace the path of the laser beam. Starting at the laser head, a small portion of the laser pulse passes through the FOC, directly to the avalanche photo diode (APD), then through the constant fraction discriminator (CFD) to the TIM to start the ToF measurement of the laser pulse. The primary beam travels through a beam expander that improves the beam collimation (Price and Uren, 1989). After the beam has passed through the expander, it continues on to two scanning mirrors, generally labeled the X-axis mirror and then to the Y-axis mirror in Figure 2-2. These mirrors direct the beam to the object being scanned. The returning beam comes back to the mirrors and passes through an optical bandpass filter and into a receiver. This filter allows only light in a narrow range of wavelengths, centered on 1547 nanometers, to pass, while rejecting others. After passing through the filter the light reaches the detection, an indium gallium arsenide (InGaAs) APD, where the photons are detected, yielding a pulse of electrons. The output of the APD is sent to the CFD, and the output of the CFD is used to trigger the TIM and the voltage is sent to an analog to digital (A to D) converter and the digital value is recorded as the “intensity” of the returning signal.

Since the range measurement is based on the time it takes for the pulse to be sent out and return, measuring the time is a very crucial task. The TIM is used to keep track of the time and it keeps track based on a specific point on the pulse. The leading edge of the pulse can sometimes be very misleading so the TIM measures time based on a point on the pulse set by the CFD. The CFD usually marks the pulses at a fraction of the amplitude i.e., the 25% or 50% point. The TIM starts the time when it senses that fraction of the amplitude of the pulse and stops the time at that fraction of the amplitude of the returning pulse.

The Mirrors

In order for the ILRIS-3D to create a survey, pulses must be distributed throughout the field of view. ILRIS-3D uses two single-axis beam steering mirrors to scan the laser pulses across the surface of the object being mapped.

Before explaining the operation of the scanning mirrors, it is necessary to define the axis system of the ILRIS-3D. The ILRIS-3D uses a coordinate system in which the X-axis is parallel to the front face of the ILRIS-3D, the Y-axis is the range or distance to an object perpendicular to the front face of the ILRIS-3D and the Z-axis is the vertical axis in reference to the ILRIS-3D being mounted normal on a tripod as shown in Figure 2-3.

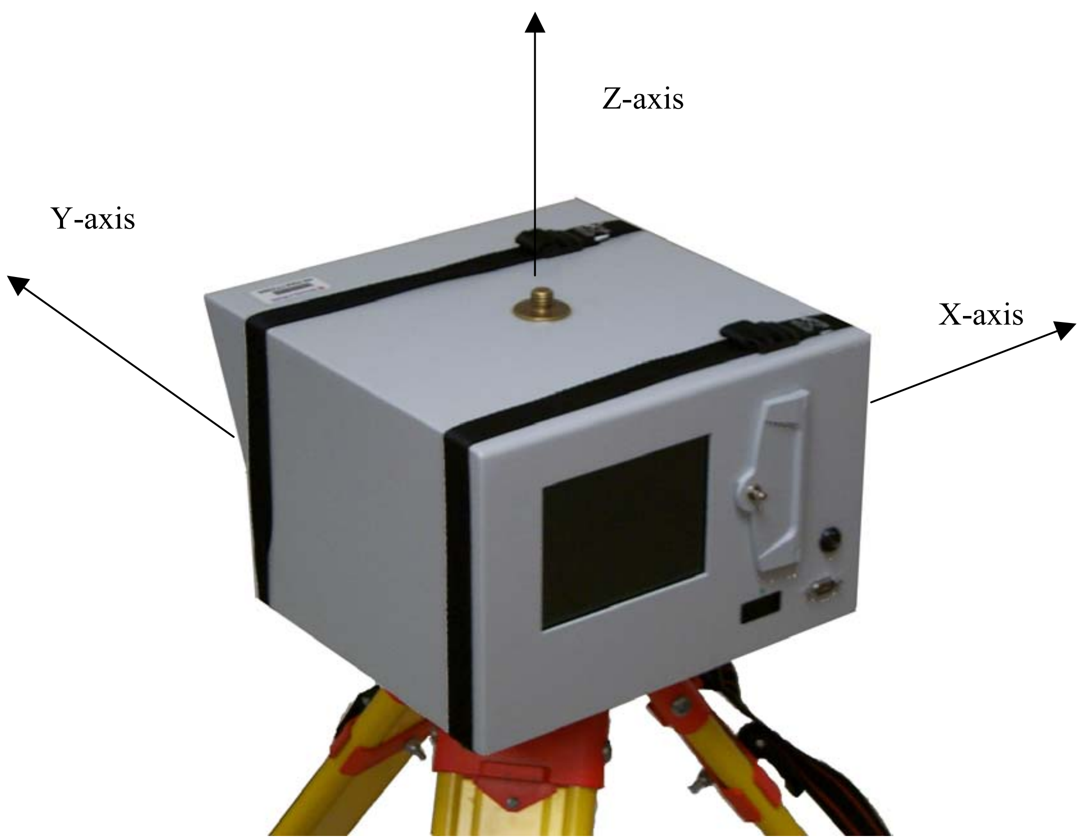

Figure 2-3. The axis system used by ILRIS-3D.

The laser is pulsed into the mirror that rotates on the Z-axis oscillating up to ± 20 degrees left and right of the Y-axis. This spreads the beams in a horizontal fashion onto the surface being scanned. At the same time, another mirror slowly rotates up on the X-axis scanning the user specified area from the bottom to the top. As the laser pulses are being sent out and returned, the angle of the mirrors are stored for each pulse of the laser and then used for calculation of X, Y and Z coordinates. The coordinate system is based on the mounting hole on the bottom of the base plate being at (0,0,0) representing X, Y and Z. The range, known as the distance to the object, is measured along the Y-axis; therefore, it is impossible to have negative Y values.

Digital Camera

The ILRIS-3D has a 480 X 480 color resolution digital camera. This camera serves a dual purpose. First, the camera is used as a viewing tool for selecting the scanning area. Secondly, at the time that the scanning area is selected a picture is taken via the digital camera and saved to file. The bitmap image can be used during the data processing stage to aid in determining the orientation of the scan.

Viewfinder

A 17 cm (640 x 480 pixel) flat screen viewfinder is located on the rear panel of the scanner and is shown as the rectangular black area in Figure 2-4. This viewfinder is used as a panel for communication with the operator. Text messages with status data are displayed along with an image being collected from the digital camera. The operator can watch the viewfinder while selecting the scan area to determine what is being selected for the scan. During the scan, data such as the total time of the scan, time left for completion of the scan, percentage of scan complete, file name and operation status are displayed on the viewfinder.

External Components

Power Supplies

The ILRIS-3D can be operated on either AC power or by batteries. Two batteries are supplied with the unit on initial purchase and additional batteries can be purchased if desired. The AC converter is also an option for purchase. At the present time, Optech, Inc. is researching the possibilities of a solar powered unit that would be used to operate the unit and charge batteries at the same time.

Figure 2-4. The rear panel of the ILRIS-3D showing the VGA monitor, flash card port, battery connection and the communication ports.

The batteries are two Digital HyTRON 100’s and are manufactured by Anton Bauer and are considered by Optech to be the most applicable battery for this application due to the runtime. The batteries are 100-WHr, 14.4-V rechargeable nickel metal hydride batteries and are linked in series to a battery holder capable of holding four mounted batteries as shown in Figure 2-5. The batteries are used in video cameras and are listed as having typical runtimes of two to four hours, depending on the watts of power being used. Optech suggests that a typical run time of 100 minutes can be obtained with two of these batteries in the ILRIS-3D application.

Figure 2-5. Two Digital HyTRON 100's mounted in the battery holder with connection cable.

Data Storage

ILRIS-3D uses a 128 MB, ATA Type II PCMCIA flash card as its primary data storage device. Although the ILRIS-3D comes with only one card, there are two slots for the flash cards to be inserted into the unit. The cards are also used as a secondary way of transferring data to the ILRIS-3D itself such as updates in operating software. Once data is collected from the ILRIS-3D and stored on the card, the card can be removed and inserted into a PCMCIA port on a laptop. From here, data can be transferred to the laptop hard drive or burned to a CD for secondary storage of raw data.

External Communication

Direct communication with the ILRIS-3D is accomplished with a hand held Personal Digital Assistant (PDA). A Palm Pilot IIIc is used to operate the ILRIS-3D and to set scanning parameters such as spot spacing, mean distance and the scanning extents. Data from the PDA controller to the ILRIS-3D can be accomplished via cable or Infrared (IR). A control program is installed on the PDA along with an operation demo. Altogether, the PDA makes for an operator friendly environment.

Mounts

In order to have a stable platform from which to survey, a tripod is necessary. The sealed unit has a 5/8” x 11 female receiver for easy mounting on a typical surveying instrument tripod. This unit can also be mounted on a tribrach with a 5/8” x 11 stud. Mounting the ILRIS-3D on a tribrach allows for fine tune pointing without adjusting the legs of the tripod. Since the ILRIS-3D does a scan and collects point data relative to the position of the scanner, there is no real need for the scanner to be level or over a point in a random survey. The ILRIS-3D is not equipped with leveling aids or devices nor does it contain an optical plummet. Special care should also be taken when mounting the unit to the tripod as the unit does not have handles by which to be lifted or stabilized.

Intensity Data

Along with collecting range data, the laser pulses also return an intensity value. The intensity is related to the reflectance of the object being scanned, the angle of incidence of the pulse on the object, and the distance of the object from the LSI. It is determined by the voltage out of the APD. The voltage is converted to a digital value by the analog/digital converter and recorded. The voltage is related to the return power of the pulse as expressed in Equation 2.1 (Baltsavias, 1999). The response of the APD is non-linear and the intensity values indicate only relative differences in the strength of signal. Intensity values obtained from the ILRIS-3D range from 0 to 255 and these values are not precisely calibrated. The values are recorded along with the x, y and z coordinates for each of the points scanned and used to determine the reflectance of any of the objects in the scan as each surface has its own reflective properties.

$$P_r = \frac{\rho}{\pi} \frac{M^2 A_r}{R^2} P_T \tag{2.1}$$

where P_r = Power of returning pulse

$^{\rho}/_{\pi}$ = Lambertian Bidirectional Reflectance Distribution Function

M = Atmospheric transmission

A_r = Receiver area

R = Range

P_T = Power of transmitted pulse

One of the hopeful benefits of the reflectance properties of objects being scanned is the benefit of classification. In order to make an LSI system more beneficial and user friendly, intensity information should be able to be used to classify objects in scans. The idea is that objects within scans have their individual reflectance properties and the user can utilize the intensity data to determine what the object is. For example, without using a digital image, the user can determine whether or not a surface is concrete, asphalt, or any other substance, just by looking at the intensity values.

Software

As stated earlier, Polyworks™ Modeler and Inspector by InnovMetric Software is the data manipulation tool selected by Optech to work with ILRIS-3D data. Polyworks™

can be operated on a computer with a minimum of Windows NT/2000, a 450 megahertz processor, 256 megabytes of RAM, 300 megabytes of free disk space, 300 megabytes of swap space and an OpenGL-compatible video card (Optech, 2002). Polyworks™ accepts several data types. Two of the types used most common when working with ILRIS-3D data are ASCII text files and PIF files. Once data are imported, merged, aligned and manipulated, it can be exported as a group if several scans are involved. Other file types can also be created including Drawing Exchange Format (DXF) files for Computer Aided Drafting (CAD) programs.

Data Collection – Start to Finish

Site Selection

Before beginning a survey with the ILRIS-3D, care must be taken to evaluate the site. Knowing the capabilities of the ILRIS-3D is important in determining instrument placement for optimized data quality during the scanning process. The minimum distance of an object to be scanned is four meters and the maximum distance is quoted as 350 meters but data has been collected from objects at 1500 meters (Sean Belshaw, Optech Inc. 2002). Any object closer than four meters is subject to invalid coordinate and intensity values. Along with determining instrument placement, data quality must also be considered. As the distance between the instrument and the object being scanned increases, so does the spot spacing that is set by the instrument. This spacing can be changed to a smaller or larger spacing by the user via the Palm Pilot. Care should be taken in selecting the angular resolution on step size as well. Also, data manipulation should be considered when choosing instrument placement. Scans that are going to be merged should have at least 25% overlap for accurate alignment and merging of scans.

Beginning the Survey

Once an instrument position has been decided upon, the ILRIS-3D can be mounted on the tripod or tribrach. Once the instrument is mounted, the batteries can be plugged into the ILRIS-3D to begin the boot process. There is not a power button on the ILRIS-3D; the supply of power will turn the ILRIS-3D on. While the instrument is booting, the flash card is inserted into the data storage port and the Palm communication device can be connected to the ILRIS-3D if necessary. Another option is to attach a global positioning system (GPS) antenna to the top of the ILRIS-3D for easy georeferencing of scenes. This option is being tested by researchers at the University of Florida and will be discussed later.

Once the ILRIS-3D has booted, all communication with the ILRIS-3D is done via the Palm communication device. Communication is accomplished via a serial cable or by pointing the Palm to the infrared receiver (IR) on the rear panel of the ILRIS-3D. After turning the Palm on and opening the ILRIS-3D Operator Software it is necessary to 'PING' the scanner. Pinging is an action to initialize communication between the Palm and the ILRIS-3D. After a 'ping' has been completed with no errors, it is safe to say that communications between the Palm and ILRIS-3D are okay; otherwise, the communication settings should be checked. Common errors include communication type, serial or IR.

After proper communication has been verified, 'TARGET' must be selected to initialize the process of setting up the parameters of the survey. Targeting the scanner will allow the image from the digital camera to be viewed on the rear panel VGA monitor of the ILRIS-3D. A closer look will reveal a 'window' within the bounds of the monitor. This window is used as a selection device for the scanning surface. The box can be moved left, right, up or down and can be compressed or expanded in height and width via commands from the Palm. This feature allows the user to scan a small or large area depending on the results desired.

Once the scan area is selected, a mean distance is measured by the ILRIS-3D. This is the average distance to a surface within the scanning area. Once the mean distance is determined, a spot spacing is suggested that can be edited by the user. The suggested spot spacing is the spacing of points at the mean distance. Objects closer to the ILRIS-3D will have points that are spaced closer than the suggested spot spacing and objects farther away will have a larger point spacing. The suggested spot spacing as well as the mean distance can be edited by the user to more adequately suit the survey purpose.

Collecting Data

A file name is given to the file before the scan begins and any notes that need to be recorded can be done on the Palm. These notes will be saved on the data card for future reference. The next step is to begin the scan by tapping the 'SCAN' icon on the Palm. While the scan is in progress, the percentage complete will be shown on the Palm while the percentage done, total time of scan, and time remaining in scan will be displayed on the VGA monitor of the ILRIS-3D.

Once the scan is complete, the ILRIS-3D stores all data to the data card and the card can be removed. Data are retrieved from the card by inserting the flash card into the PCMCIA slot of a laptop and transferring data. Data should be transferred to a job folder specific for that job. All data files written to the flash card by the ILRIS-3D are given an *.I3D extension. This serves as a metafile that contains all data from the scan including scanning parameter data, calibration data, and the bitmap image of the scene.

Parsing Data

Before data manipulation can begin, the data must be extracted from the *.I3D metafile. ILRIS-3D uses a program called Parser. Parser is designed to enable the user parse and re-parse data with different settings time and time again. Parser has several output formats, a range and intensity gate and data reduction to reduce the overall file size. Scan data can be output as XYZ files, PIF files, raw files or PTX files. PIF and XYZ files are the files used by InnovMetric's Polyworks™ software. The range and intensity gate enables the user to cut out unwanted intensities of a scan, i.e. highly reflective objects returning high intensities or darker objects returning lower intensities. The calibration data, scanning parameter data and the bitmap are files created for future reference.

CHAPTER 3
TYPICAL USES AND APPLICATIONS OF A LAND BASED SCANNER

Transportation Uses

Transportation is a large and important industry. People are always on the move from one place to another and the transportation industry is responsible for getting people to their final destination. There is always room for improvement in our different means of transportation. When improvements need to be made to an existing route, civil engineers are involved in the planning and design process. In order for engineers to do planning or design, they need precise measurements of the existing route and any structures associated with the route being renovated.

Currently, surveyors are contracted to go out to the site of improvement to gather data that will be used by engineers in determining the current conditions of the site. These data might include the centerline of the existing road, the topology of the existing road, the edge of paving, the existing curb along the road and power poles or other existing utilities that might need to be relocated. These data collection process involves a survey crew consisting of a rodman and an instrument along a possibly heavy traveled route. Not only is this a dangerous process of collecting data, but also it is very limited in the amount of data that can be collected.

Shots along the centerline might only be taken every 50 feet in a straight section and every 25 feet in a curve. Location of power poles will place the poles on the ground, but the direction of the lines connected to the poles must be noted in a field book for a survey technician to draw on the plat. Along with the centerline being taken every 50 feet, the edge of pavement is likely to be taken at 50-foot intervals as well. In intersections, turn lanes and stop bars can be tricky for a survey technician to interpret. Location data on turn signal boxes, turn arrows and painted lane stripes will be gathered as well as any water meters, gas valves or man holes that might be in the intersection. Along with using the data to locate structures around and within the intersection, surveyors and engineers can also use the data to produce a topographic map of the location. Topographic data of an intersection will aid the engineer in the design of the location in question.

For surveys in which bridges are involved, much more data is needed by the engineer in order to plan for additional bridges or additions to a current structure. Information needs to be gathered concerning all directions of traffic. Data is also needed for the top of the bridge as well as underneath the bridge. Structural location data of columns and beams might also be necessary. Gathering this data puts the surveyor in harms way as most of the data that needs to be gathered is in the flow of traffic.

Gathering data at intersections and bridges for use in engineering applications can be easily accomplished using a laser imaging and scanning device. Not only does scanning the site with a laser scanner create safer working conditions for the surveyors, it is very time efficient. Collecting data using a laser scanner eliminates the guesswork of the office personnel. Scanned scenes can be merged and georeferenced virtually recreating the site surveyed.

The data collected by a LSI system were also used in creating a detailed survey of a building. The outer surface of the building can be scanned as well as the inner surface to create a virtual 3 dimensional model of the structure. A project such as this was done by researchers at UF in a joint effort with the Federal Aviation Administration (FAA) to locate airport obstructions at the Gainesville Regional Airport. This data can be valuable to the government in the event damage were to ever occur to the building. Data collected before the damage occurred can be compared to data collected afterwards in an attempt to conduct a damage assessment of the site.

Bridges

Using a laser and imaging system to collect data on bridges dramatically enhances the visualization of the data collection site. In an effort to see how well a 3D laser scanning device works on surveying a bridge, researches at the University of Florida (UF) took the ILRIS-3D to a bridge in Gainesville, Florida. The bridge is located on the northwest side of Gainesville at the intersection of Interstate 75 and State Road 222 (NW 39th Avenue) as shown in Figure 3-1. The survey of the bridge took place in April of 2001. A total of 16 scans were taken of the site along with airborne data that were taken in an effort to explore the possibilities of merging airborne and land based scanner data. The merging of data will be discussed in a later chapter.

These 16 scans were taken over a period of two days. Out of those two days, the crews worked approximately 2 – 3 hours a day. Time spent in the office merging the data amounted to approximately 30 hours. These were one of the first data sets researchers at UF worked with, which means that the 30 hour time period included a learning curve for the software. After gaining experience with the software, the total time involved from start to finish was about 14 hours.

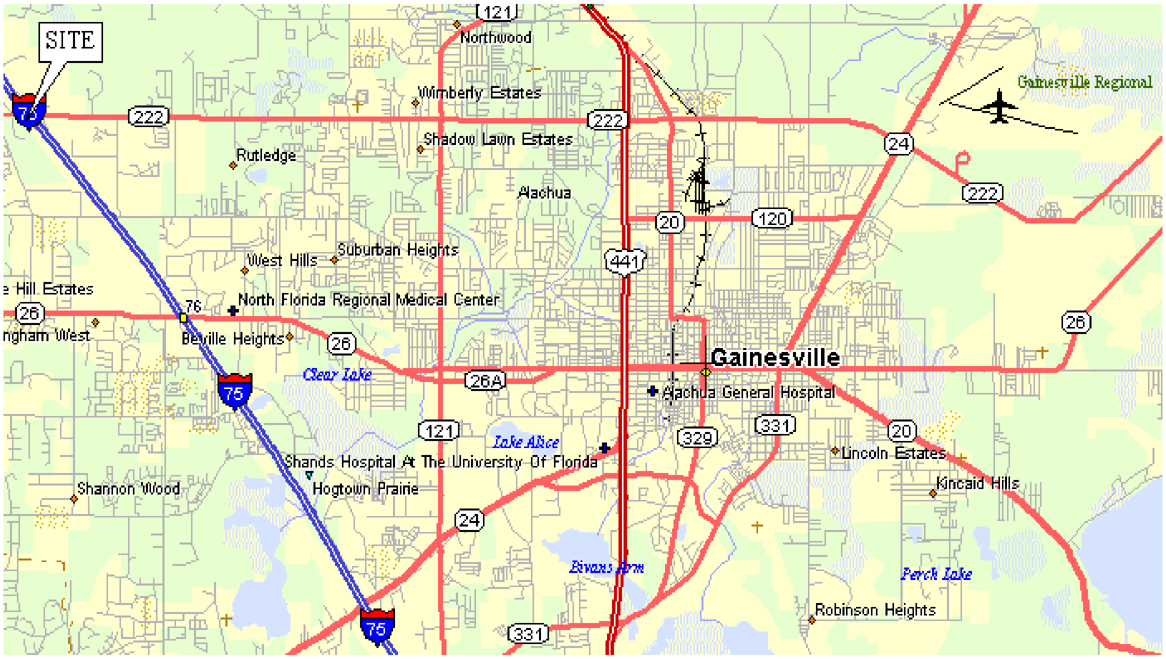

Figure 3-1. Location map of I-75 and SR 222 bridge survey in Gainesville, Florida.

Initial data collection began by setting up along the side of the interstate. Scans were taken of the bridge as would be viewed in a profile. Data collected included embankments on either side of the bridge, support columns on either side of the bridge as well as in the middle, and the basic framework of the structure itself. Four scans were taken of each side of the bridge, 4 of the northbound side and 4 of the southbound side. Additionally, scans were taken of the underside of the structure showing the beams and their placement on the columns.

No data were taken of the drivable surface of the bridge as all data were taken at I-75 ground level. Data were collected from the right-of-way (ROW) and no lane closures were necessary. Had the survey been done with a total station, lane closures would have been necessary in order for the survey crew to reach the areas covered by the ILRIS-3D. By surveying from the ROW, the possibility of injury to a member of the survey crew was minimized.

As stated previously, a total of 16 scans were taken of the bridge. After merging the scans, a complete view of the bridge can be viewed from any angle. This image is shown in Figure 3-2. Black areas in the scans represent no data collected. This is caused by either the range limits of the scanner or the pulse not penetrating through another obstacle (shadowing) to reach the black area. Although the survey was not taken from the angle depicted in the figure, Polyworks™ allows the user to rotate and move the scene into any position desired. A comparison of two bridge surveys can be made in Figures 3-2 and 3-3. Figure 3-2 is by an ILRIS-3D and Figure 3-3 done by traditional survey methods. These images show the level of detail obtained by the traditional survey methods vs. the detail obtained by a LSI system.

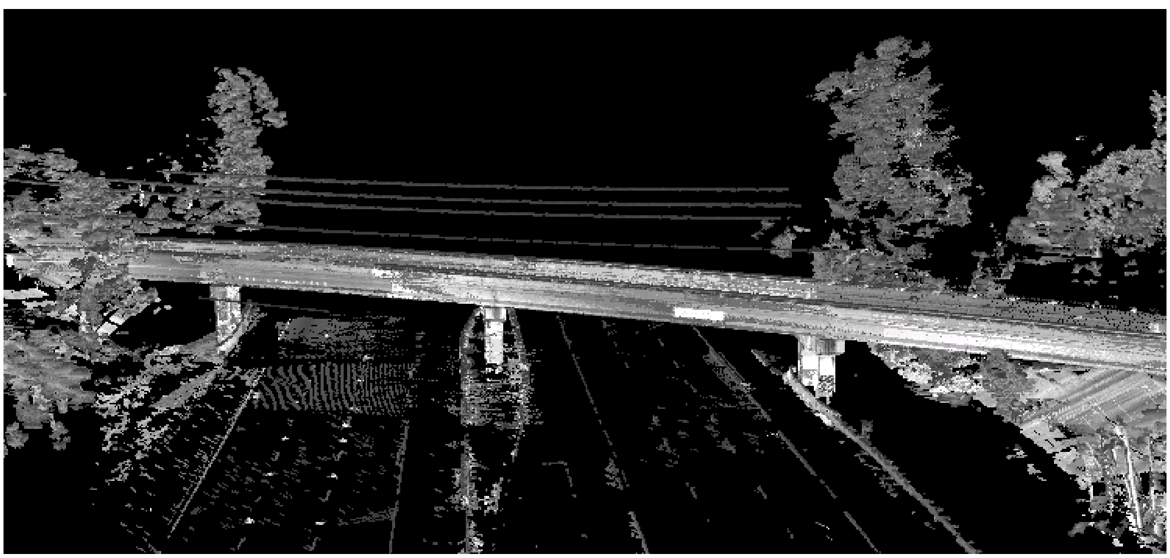

Figure 3-2. Looking northbound at the I-75/SR222 overpass.

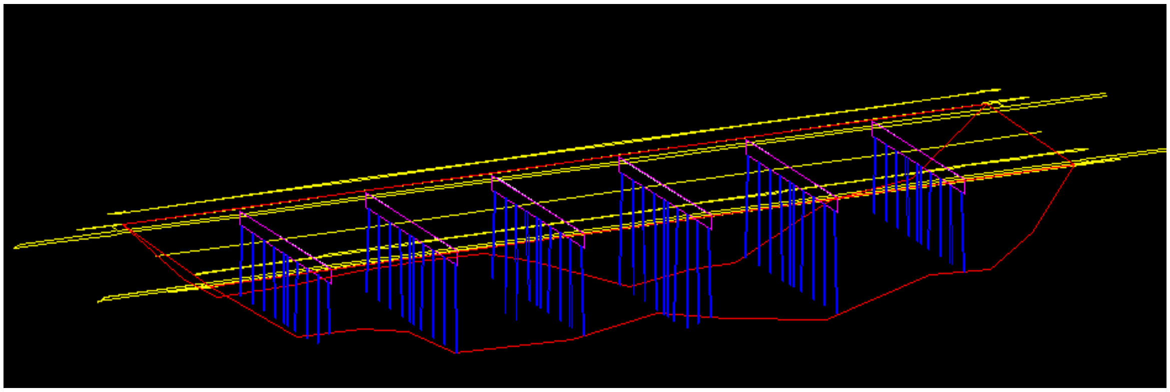

Figure 3-3. Oblique angle view of a bridge drawn in a CAD program. (Courtesy of Jason Woods, Hoffman & Co., Inc.)

Measurements can be taken from these data and a structural analysis performed to determine if there is any structural damage to the structure. Figures 3-5 and 3-6 show the embankment on the west side of the bridge as well as the structural detail that can be seen in an intense data set.

Data were collected on every surface of the bridge that can be seen from the interstate level. Collecting data on every surface allows the user to reproduce the bridge in the office. Figure 3-4 is a profile view of another bridge that was surveyed using traditional survey methods and drawn in a computer aided drafting (CAD) program. A data set with the ILRIS-3D can cause complications due to the large amount of data. A user can be overwhelmed by the amount of information. A simple CAD drawing of shots taken in the field will be sufficient in most applications but a view of the surrounding area definitely creates the environment for the designer. Sometimes, the engineer just wants the measurements needed to do his design, nothing more. Polyworks™ has a module that exports measurement data for this purpose. Measurements can be made by the user and exported into a text file or a drawing exchange format (DXF) for the engineer to use.

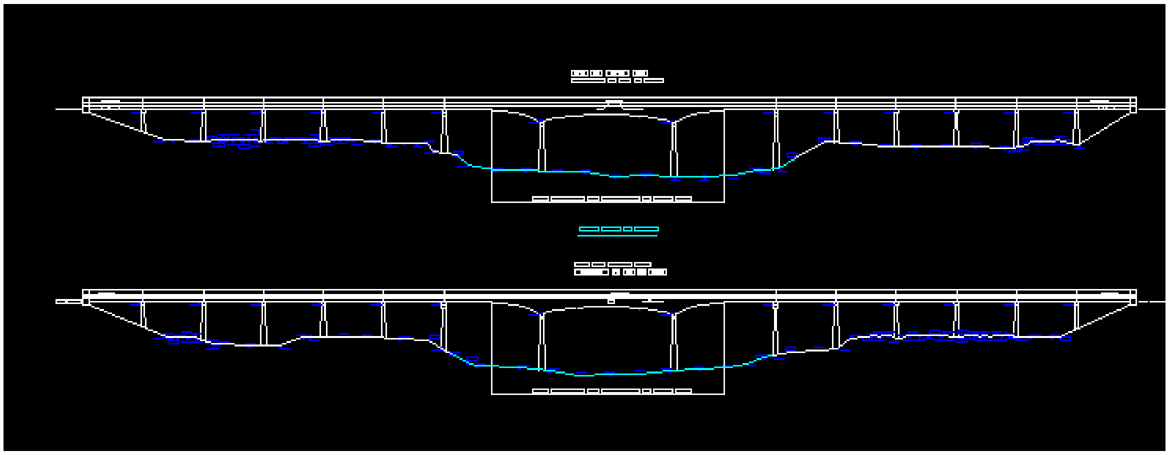

Figure 3-4. Bridge profile drawn in a CAD program. Note the difference in the level of detail. (Courtesy of Jason Woods, Hoffman & Co., Inc.)

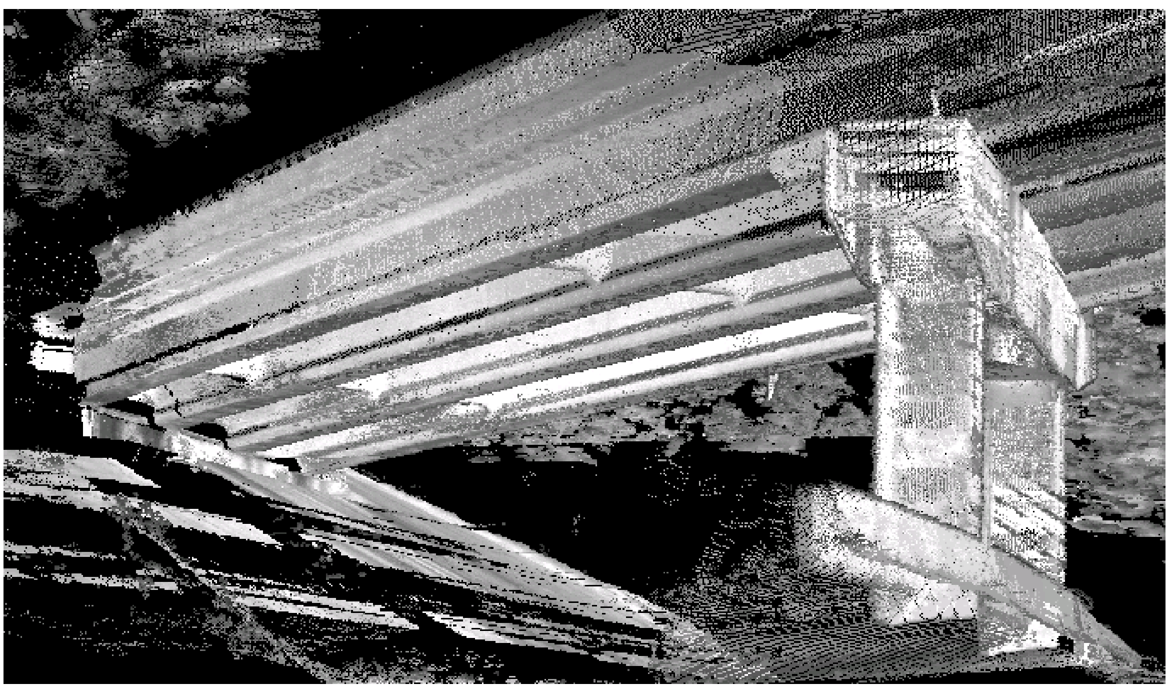

Figure 3-5. West side embankment of bridge.

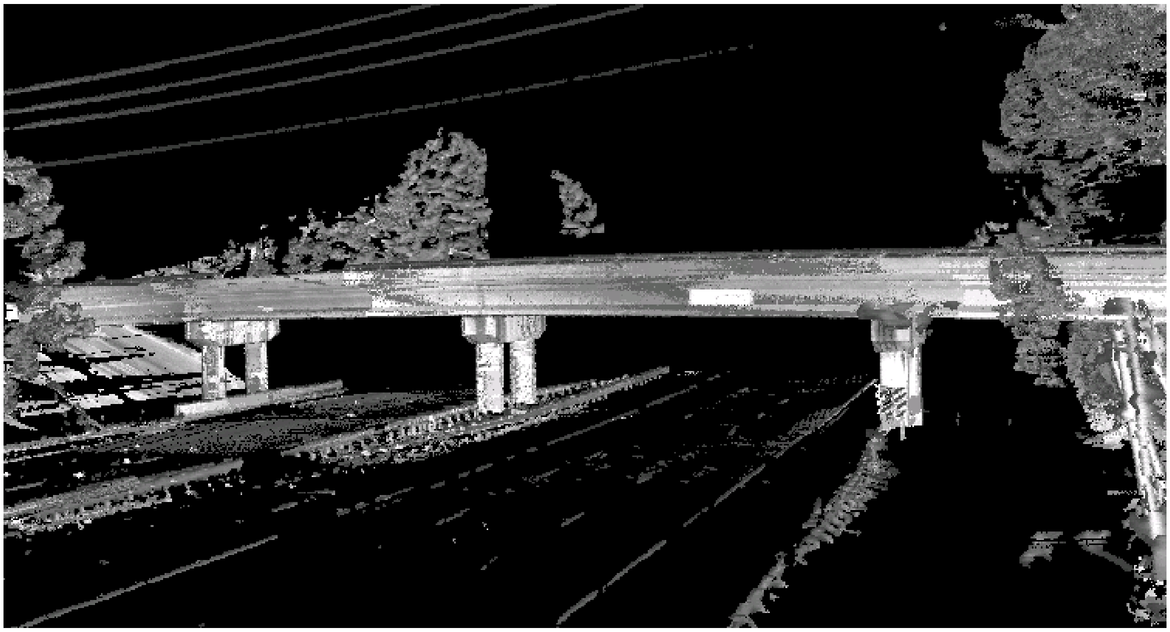

Figure 3-6. Southside of bridge, looking towards the northwest.

The range of the ILRIS-3D is approximately 350 meters. This is useful when performing surveys such as the bridge survey because of other features that can be noticed in the scan. Not only are the bridge and interstate in the scan, but surrounding features that might be needed by the engineer are also caught in the scene. Notice in Figures 3-2 and 3-6 the power lines crossing the interstate on the south side of the bridge. This information might be hard for a survey crew to collect because they would have to be able to see the power poles on either side of the interstate in order to create the power lines. After locating the power poles on either side of the interstate, straight-line distance between the poles will serve as the location of the power lines. However, in the data collected with the ILRIS-3D, the power lines can be seen in their exact location. Distances can be measured from the power lines to the bridge or clearance data can be measured from the power lines to the interstate as shown in Figure 3-9. In Figure 3-7, the above mentioned power lines along with a distant cell phone tower are visible. The cell phone tower might serve as an obstruction that might need to be located in the event that an expansion were to take place. All of these details are valuable to an engineer design on a project.

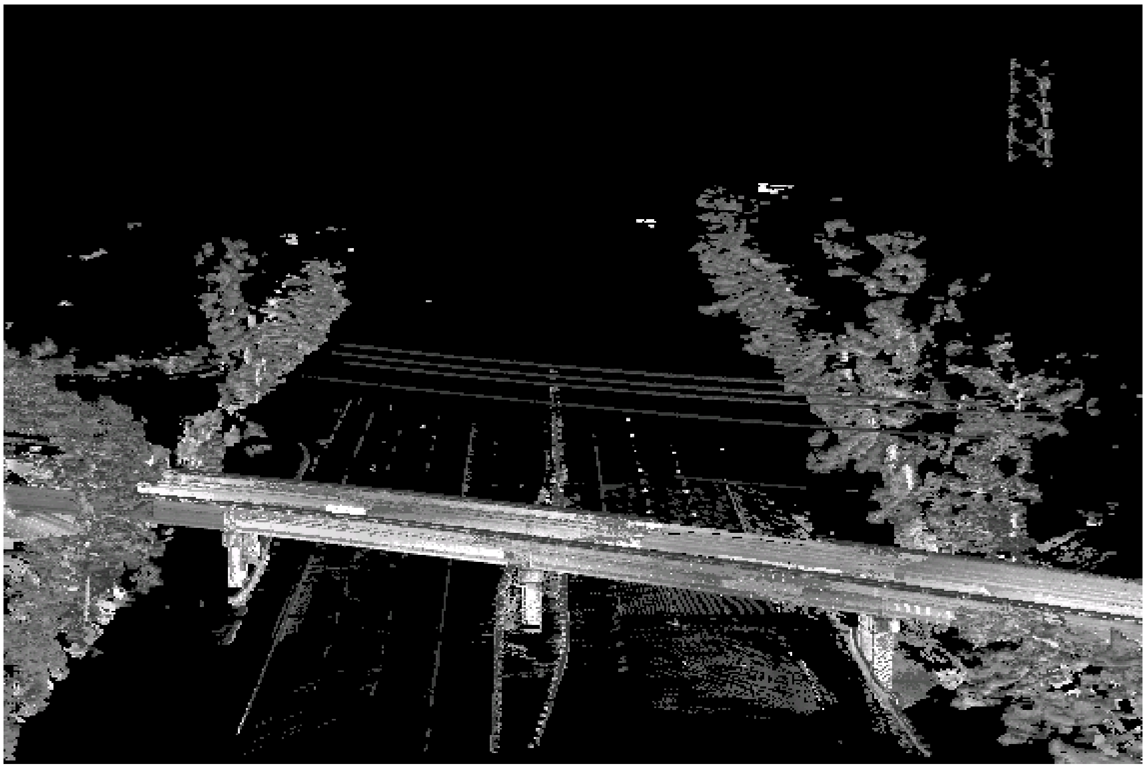

Figure 3-7. Power lines on the south side of the bridge along with a cell phone tower farther south.

Figure 3-8 is a plan view of the scanned area. The bridge is shown with north at the top of the image. The power lines are shown in relationship to the bridge along with the cell phone tower. The tower is triangular in shape and is located to the southwest of the intersection. The tree line in the ROW of I-75 is shown in the plan view. When merged with airborne dataset, the plan view will give the engineer a better feel for the site. One thing not shown in the LIS system data is the topographic features of the surrounding area. These are data that will become more evident with the aid of airborne data.

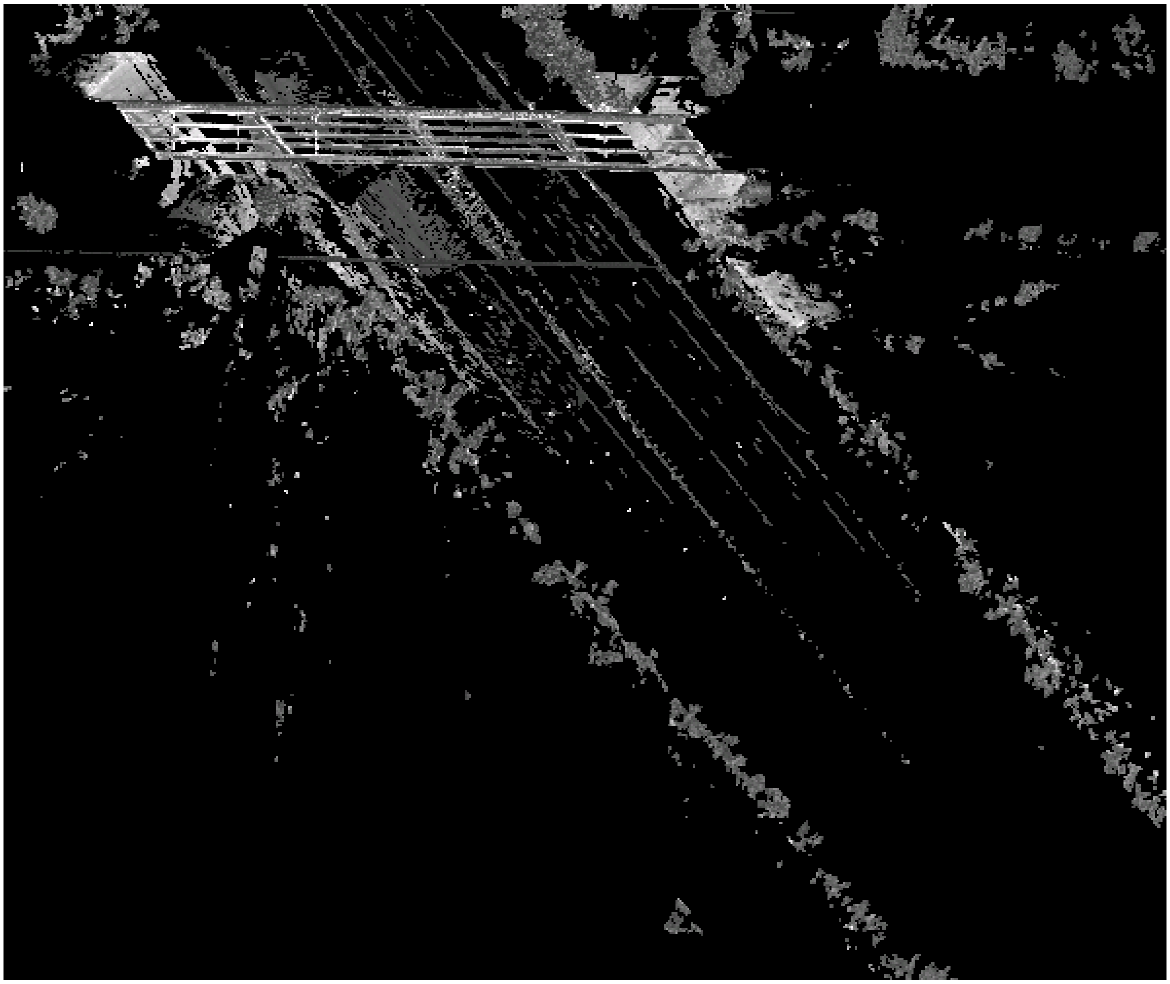

Figure 3-8. Plan view of the I-75/SR222 intersection.

Using LSI for surveying bridges can be very useful to the engineer. Not only can measurements be made, but location aspects are enhanced by the level of detail seen in the data. The survey procedure is time efficient and safe for the survey crew. The ideal set-up would consist of a stable vehicle in which the LSI system is hoisted into the air, secured in place, and operated from within the vehicle. This idea was tested by Mark Thomas & Company in the San Francisco Bay area. They used a Cyrax scanning system that they hoisted 35 feet into the air (Milo, 2000). Operation of the unit was conducted from inside a van equipped with a desk and a computer. With the use of this technology, they completed 8 miles of highway topography in a total of 229 scans. This venture took

31 days to complete and it was done with no lane closures and without working nights or weekends. The crew worked about six hours a day collecting data.

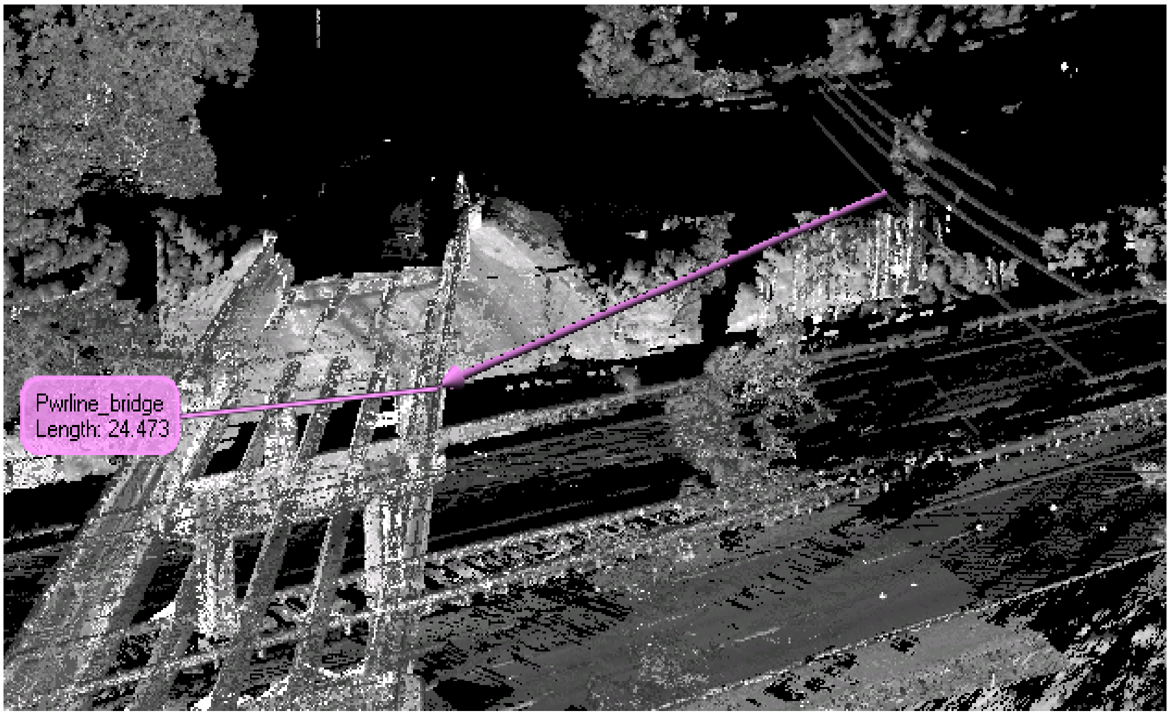

Figure 3-9. A measured distance from the closest power line to the bridge to the railing on the bridge.

Intersections

In March of 2002, an intersection on University of Florida campus was scanned in an attempt to see what type of detail could be recognizable in an LSI scan. The intersection is located southwest of Ben Hill Griffin Stadium at North South Drive and Stadium Road. Figure 3-10 is a detailed map of the area surrounding the site.

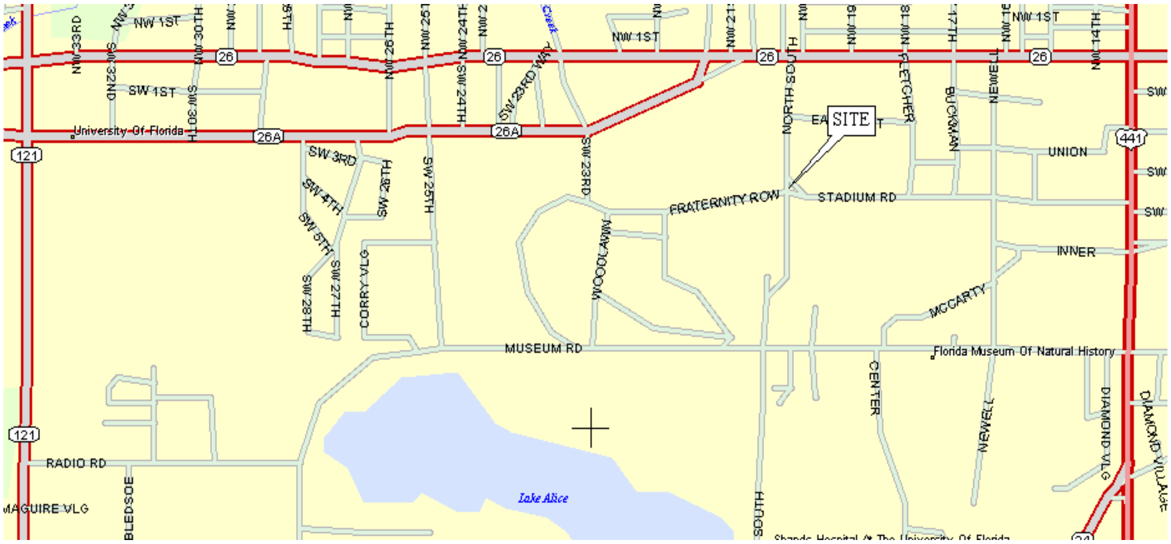

Figure 3-10. Detailed location map of intersection scan site and surrounding area.

In the scans of the intersection, it was noticed that moving vehicles caused unwanted data (clutter) within the scan. The vehicles did not ruin the scan but they did cause more editing of data. Other things that cause unwanted data in scans include people, birds, or other moving features that are dynamic in the scan area. Such items can be selected in the data and deleted from the scan.

Traffic through the intersection is heavy during the day so researchers decided to conduct the scans at night. The scans were taken on March 28, 2002, beginning at 11:00 PM. Taking the 4 scans required approximately 45 minutes. Data analysis proved taking scans in off-peak times to be cleaner in the sense of having less unwanted data in the scan. The scans were taken from the second level pedestrian ramp on the southwest side of the stadium. The idea behind collecting data at this intersection was to see how detailed pavement data would be for this type of scan. An elevated view of the intersection was desired to view the intersection at a more perpendicular angle than if at ground level. Figure 3-11 shows the scanned image as seen from the second level of the stadium.

Figure 3-11. A scan view as seen from above the intersection at the ILRIS-3D set-up point.

Four scans were taken from the stadium occupation point and one scan was taken from the ground. The occupation point on the ground was on North South Drive, north of the intersection. In Figure 3-11, the ground occupation point located on the right side of the image on the near side of the road. In this particular set-up, the scanner was aimed south to collect data south of the intersection. After merging the data set with the previous 4 scans, it was evident that the ground level scan was not as useful as the data taken from the stadium due to the low set-up of the scanner. It was determined that high set-ups produced better datasets.

As mentioned previously, black areas are areas with no point data. In Figure 3-11, black areas can be seen starting at the bottom of the near utility poles and extending out towards the intersection. This ‘blank’ area is a ‘shadow’ of the pole. The ILRIS-3D could not collect data in this region from the occupation point in the stadium. This is the reasoning behind going to another location to survey the same site. These blank areas can be eliminated by filling them in with data from other scans. However, the second occupation point was not elevated, as was the first, causing the data to contain more clutter than was desired.

The intersection data set had an average spot spacing of 25mm. Data from this intersection are very detailed as seen in Figure 3-12. Instead of having a rodman in the middle of the road collecting data on the location of turn arrows, paint markings and the location of curb, the ILRIS-3D collects these data while keeping everyone out of harms way.

While the ILRIS-3D collects topographical data and location data of objects in the intersection, it also collects location data of anything within the user defined scan box. In Figures 3-11 and 3-12, trees can be seen hanging over the roadway. In a case where improvements were going to be done to this intersection, tree location data can be useful to the engineer. Drip lines and clearance information about the trees can be gathered by analyzing the scan data. In Figure 3-13, the scan has been rotated to view the data from ground level. Tree clearance is seen as well as traffic signals attached to the lines spanning across the intersection.

Figure 3-12. Looking west over the intersection, one can see the visible paint markings in the intersection as well as curb lines and the location of utility poles.

Figure 3-13. A view from ground level shows the clearance between the road and the trees surrounding the intersection.

As stated earlier, the ILRIS-3D records intensity data along with coordinate data as it scans. These intensity data are evident in the scan of the intersection as well as the bridge. Note the painted stripes for the turn arrows and stop bars on the asphalt. Also, note the difference in color between the asphalt and the concrete sidewalk. This is due to the different reflectance values contained in each of the materials. Paint on the asphalt is white and yellow, and shows up brighter than the dark asphalt. In Figure 3-11, parts of the east side of the intersection, shown at the bottom left hand corner of the image are darker than others. A dark area approximately 2 to 3 feet in width crosses the road and another dark area of the same thickness can be seen running along the curb. This is new asphalt that was poured to patch a part of the asphalt that had to be replaced.

Airport Obstructions

In April of 2001, UF worked with the FAA on a project to locate and map airport obstructions at Gainesville Regional Airport in Gainesville, Florida, as shown in Figure 3-14. This task was done with Airborne Laser Swath Mapping (ALSM) and parts of the project were supplemented with ground based data. The ILRIS-3D was used in locating the terminal building at the airport. The ILRIS-3D data was collected in hopes of merging with airborne data.

Data collected on the terminal building give more detail to the building itself than the airborne data. These data can be used as preliminary data for a damage assessment case. These data represent the building as it is in good condition, and can be used to compare against data collected after any damage occurred. These data are a valuable asset to government agencies in which scans have been taken of government buildings that are in good condition, not only for damage assessment, but for inventory purposes or a Geographic Information System (GIS) as well.

Data were collected by moving around the building at the airport. Each scan had 10% to 20% overlap from the previous scan. This allows common points to be picked out of the data for merging. A total of 16 scans were taken around the building. These scans had an average spot spacing of 30mm. The scanning process took 7 hours with about 20 hours for merging the scenes. With only 10 – 20% overlap, and in some scans less than that, merging became a difficult process. Optech recommends that there be a minimum of 25% overlap to provide positive identification of matching features.

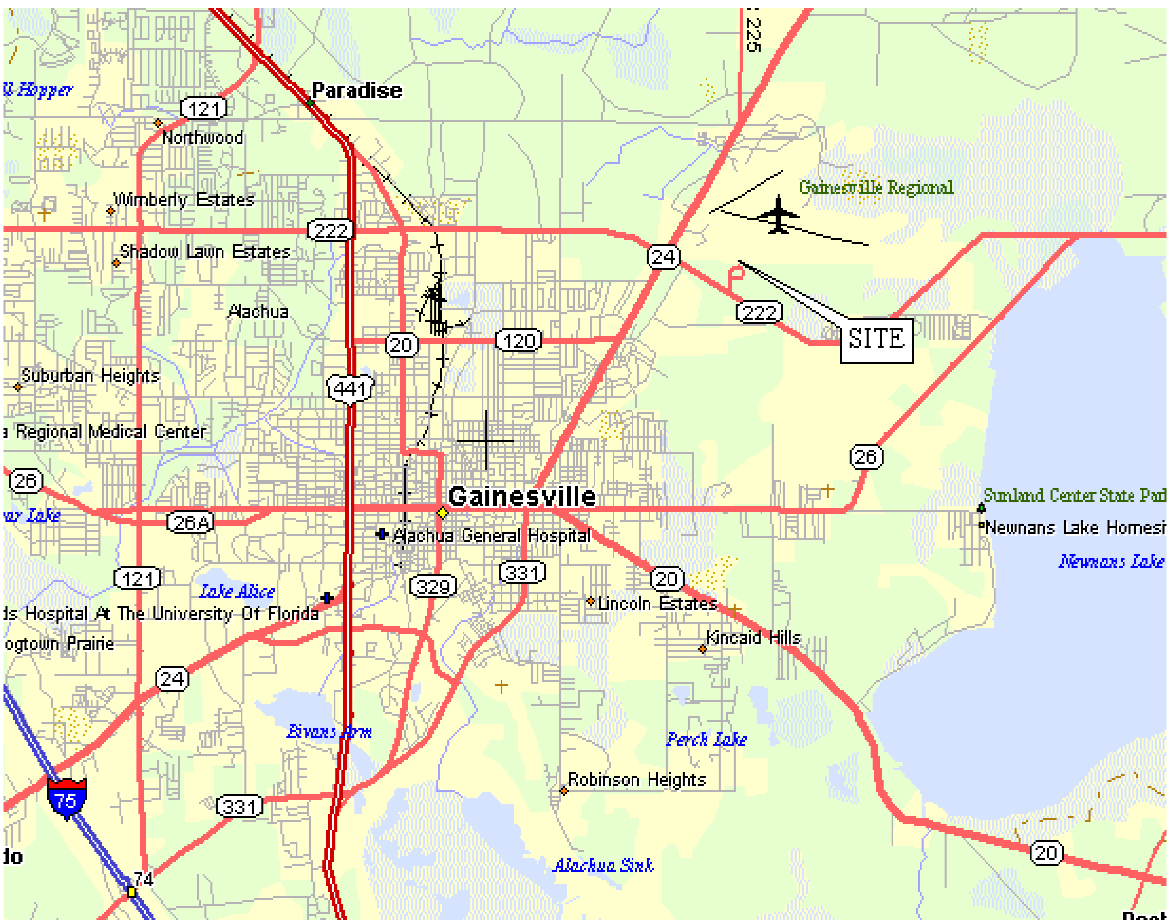

Figure 3-14. Location map of Gainesville Regional Airport and surrounding area.

Figure 3-15 shows the entire airport scan merged together. The surface of the building was coarse in texture aiding in the merging process. Buildings with easily definable features are easier on the office personnel to analyze data and merge scenes. Other things that aid in the merging process are items that are attached to the building or are in the foreground of the scan. These items are antennas that building have attached to the roof or light poles and street signs in the foreground. These items are easily identified because of their uniqueness.

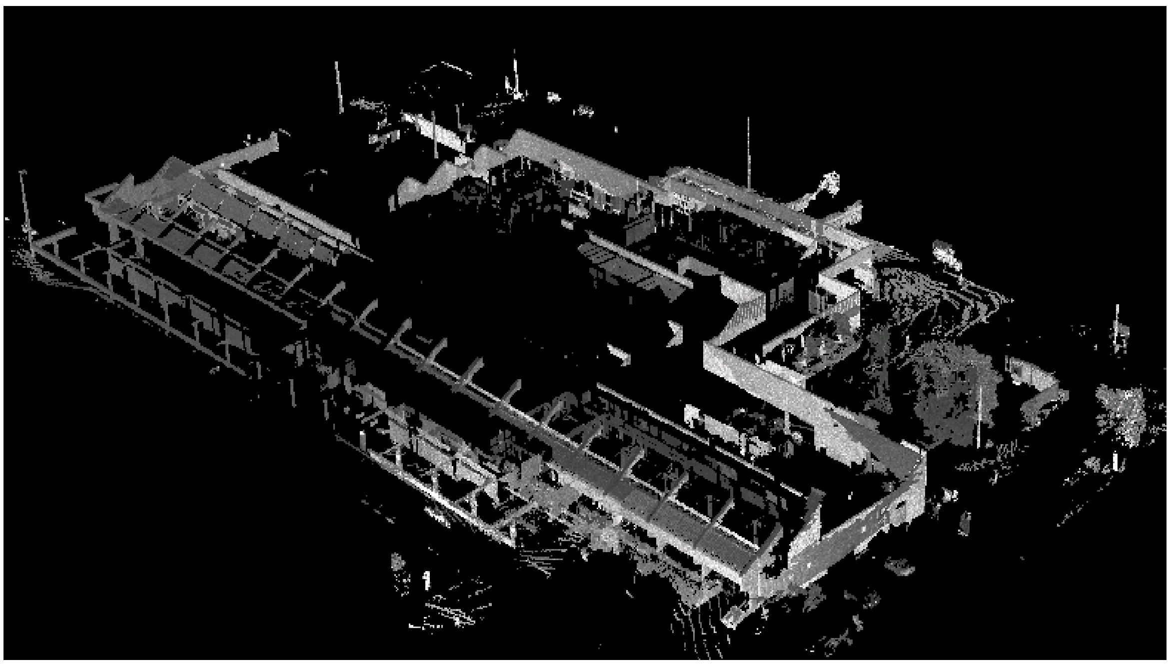

Figure 3-15. Entire scan of Gainesville Regional Airport terminal building.

Having items such as light poles and sign posts in the scan does not only aid in the data aligning process, but it also serves as a means for location of these items. When conducting a survey of a building site, the location of items such as trees, light poles, power poles, fire hydrants, and sign posts are necessary. These items can be seen in Figures 3-15 thru 3-17. Some of these items need to be located for the fact of knowing that they are there, and some are located for the purpose of knowing their location in relationship to the building and within the site. Figure 3-16 shows a view from ground level, looking at the front of the terminal building. In the foreground, a sign post and a fire hydrant can be picked out of the scene. These distance from these items to the building can be measured because they have coordinate values. Theoretically, this data can be used in a GIS database in which a fire department uses the database for pre-arrival planning. Another useful item that could be used in a GIS database is the plan view of a building. Firefighters can view the building from above, and possibly determine the best location to connect fire hoses prior to arrival at the scene saving them time and possibly saving civilian lives.

As mentioned before, intensity data is stored for each pulse that is returned to the ILRIS-3D. The importance and usefulness of this intensity data can be seen in Figure 3-16. Notice the sign in the scene. Without intensity data, the sign would be unreadable. From the image, it is clear that the top sign is ‘pedestrian crossing’ sign, a ‘no U turn’ sign in the middle, and a speed limit sign on the bottom. The intensity data also makes the fire hydrant stand out in the image.

For engineers, data collected with a LSI system can aide in the development process due to the large amount of data that is collected. Figure 3-17 is a view of the terminal from the ramp side. The ramp is where planes are parked for passenger loading and unloading. If additions were to be added on this side of the terminal, an engineer would need the location of utilities as well as other obstructions.

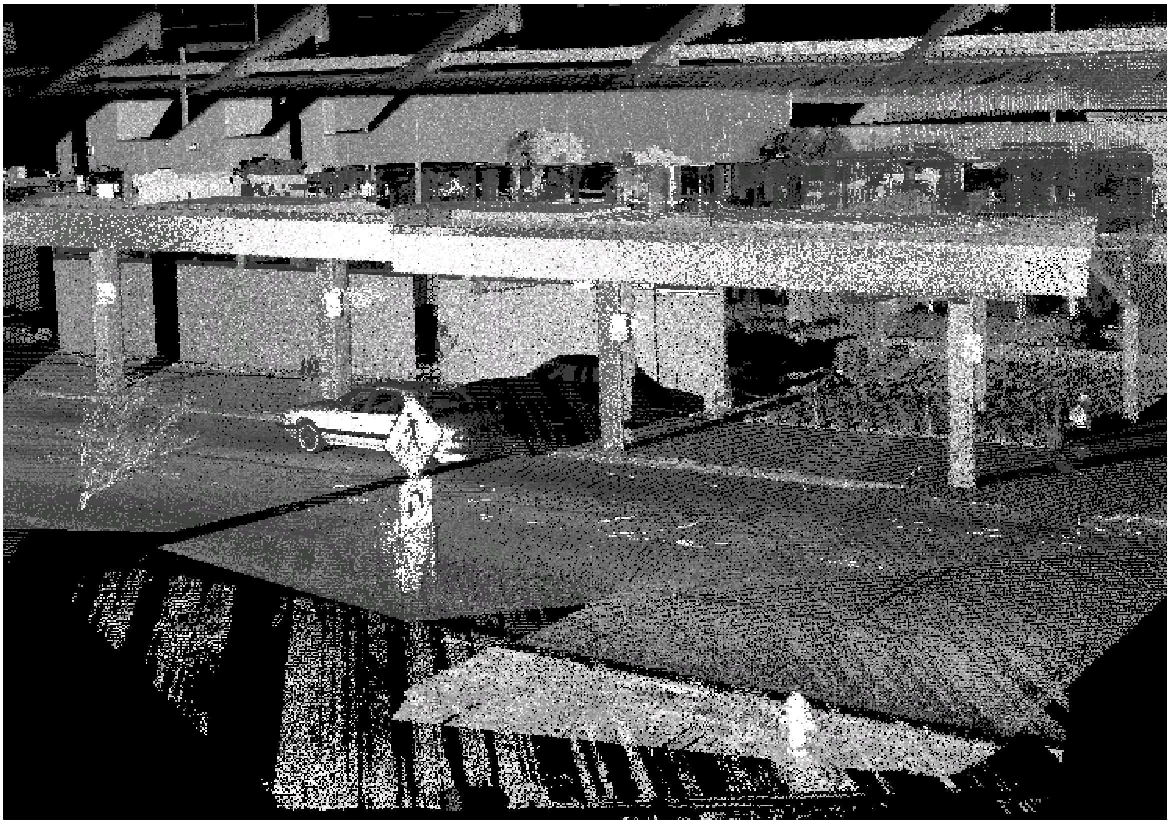

Figure 3-16. Front of Gainesville Regional Airport terminal building. A car, sign post and fire hydrant can be seen in the foreground.

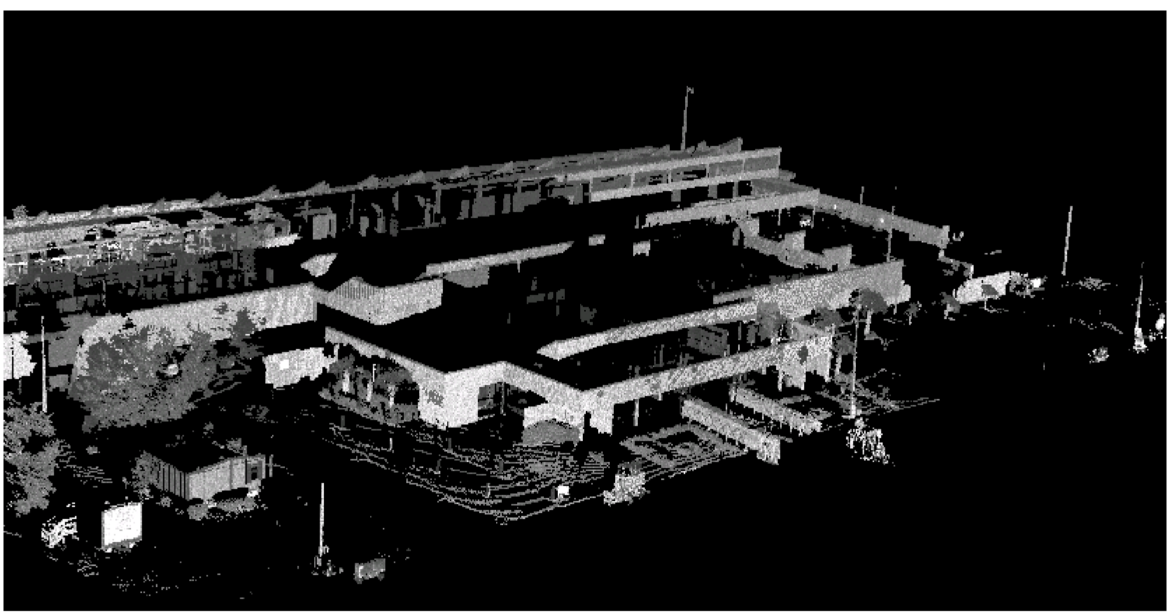

Figure 3-17. View of terminal from the ramp side.

Accident Investigations

As seen in the previous applications, intensity data can prove to be very useful. The intensity data changes according to the surface of the object the pulse returns from. Items which correspond to the change in intensity are the color, texture and brightness. In the previous section about intersections, the difference in intensities between the old asphalt and the new asphalt can clearly be seen. This detection of color could suggest that a detection can be seen between asphalt and tire skid marks. Data concerning skid marks can be useful in accident investigations. Figure 3-18 is a scan done in a parking lot showing skid marks made by a vehicle doing ‘doughnut’ maneuvers.

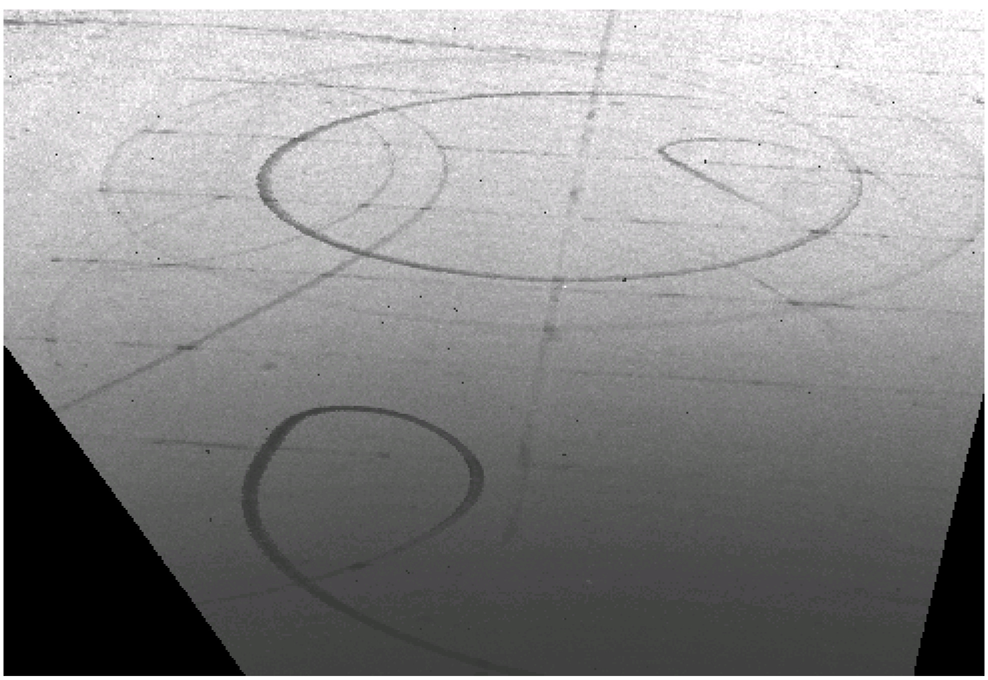

Figure 3-18. Skid marks in a parking lot. Painted parking stripes can also be seen in the image.

In most cases of automobile accidents where there are no fatalities the police write a ticket to the party at fault. However, when there is a fatality involved, an accident investigation team surveys the area to determine which vehicle did what and the approximate speed of the vehicles involved. This more intense investigation is needed because of the possibility of lawsuits following the accident.

After an accident in which a fatality is involved, police officials or other contracted individuals collect data at the scene. This data includes any evidence as to what happened and who is at fault for what happened. Skid marks from tires and final placement of vehicles along with the damage done to the vehicle play an important role in the investigation process.

Figure 3-19 is a digital image of a scan area taken by the onboard camera and figure 3-20 is the scan itself. The scan was taken on Newberry Road and NW 127th Street in Gainesville, Florida. The site is located in front of West End Golf Club. The scan consists of a set of skid marks created from a dual rear wheel vehicle or trailer. The scan wasn't taken due to any fatalities on the scene but instead, to show the ability of an LSI to be used in accident investigations.

As seen in the above scanned image, painted traffic lines are easily distinguishable. The intensity of the skid marks are also quite distinguishable as seen in the above figure and in Figure 3-21. Not only can the scan be used for skid mark analysis and measuring, but topography of the asphalt and the conditions of surrounding features can also be analyzed. This can be useful in an investigation in which someone pulls out in front of an oncoming car and claiming that their view was hindered by an obstruction such as a shrub or sign. All of these data can be collected with a few strategically placed scans. A vehicle used specifically for scanning, with jacks for stability, an extending boom for getting the scanner above traffic and computers with software onboard would be ideal for this type of data collection. A vehicle of this nature can be seen in figure 3-22.

Figure 3-19. Digital image of skid marks at the beginning of the turning lane on Newberry Road in Gainesville, Florida.

Figure 3-20. Scanned data of skid marks on Newberry Road and NW 127th Street in Gainesville, Florida.

Figure 3-21. Image of data from scan taken on Newberry Road showing change in intensity values.

Figure 3-22. A LSI unit mounted on top of a 'mobile office'. (Based on images from POBonline.)

It usually requires that a couple of officers to survey the scene of the accident. Currently, total stations and data collectors are used to store data about the location of skid marks and the cars involved. Before total stations were used, officers would survey the scene using traditional survey methods involving measuring tapes and transits. This was time consuming and required that the roads be closed down for extensive amounts of time while the officers completed the work. The total station was introduced as a time saving tool and were soon implemented into the accident investigation program.

Now that LSI systems are available, more data can be collected in a short amount of time. Data can be processed at the office allowing the road to be opened for free traffic flow. Instead of officers collecting data for hours, data can be collected in as little as 2 or 3 scans, each scan lasting about 10 minutes. The quality of the data is much better than data collected by officers using total stations because the LSI doesn't miss important data. As long as all data needed are within the scanning extents box, data will be collected.

Here in Florida, the Florida Highway Patrol (FHP) is in charge of collecting data dealing with accident investigations. In speaking with various individuals with the FHP, many of them have heard of scanning devices being used in homicide investigations but not in accident investigations. One of the reasons that more research hasn't been done in the area of introducing the LSI systems to accident investigations is the costs involved in acquiring a system and training an operator and data processor. The data shown above will be sent to the FHP in hopes that more interest will be sparked for the usability of this technology in accident investigations.

As-built Survey for Construction Monitoring

As with most construction projects, time is a major factor in whether or not a company makes money. If a projects finishes on time or ahead of schedule, the contractor in charge of construction has the opportunity to make money, or more money if they finish ahead of time. During a construction project in which building construction is involved, surveyors visit the scene periodically to verify placement of certain features. If errors are detected in the placement or alignment of features on the building, the surveyor alerts the contractor, who then sees to correction of such errors. Therefore, the sooner these errors are caught, the sooner they can be corrected before construction progresses.

In the fall of 2000, DEI Professional Services, LLC used an LSI system to monitor a building construction project. The reason for choosing the LSI system to monitor the site was safety involved and the ability to create an as-built survey of the site in survey plat form. A total station and traditional survey methods were used to create the survey control around the project and to complete the task of construction layout and a Cyrax 2500 was used to monitor construction.(Rubio, 2002).

DEI also saw the safety involved in a LSI citing that the Cyrax 2500 reduced the risk of a fall by eliminating a rodman that would be needed while conducting an as-built of the elevator core. DEI also claims that using the Cyrax 2500 gave them valuable geometry data. Analysis of this data helped reduce the risk of construction delays due to form mis-fitting or alignment. Only one quality assurance issue arose during the progress of the elevator core; analysis revealed that the core forms were beginning to run thin around the 11th floor. The contractor was alerted to the problem and the issue was resolved (Rubio, 2002).

Not only can an LSI system be used for quality assurance, they can also be used in progress analysis or for collecting data to provide the client with a week-by-week progress report. A scan can be taken of the building weekly from the same spot and the data can be merged. Data can then be colored according to the scan. New data will be evident over the previous weeks data thus showing the progress made since the last scan. These data can also be useful to the project superintendent for monitoring progress.

Emergency Damage Assessment of Buildings and Other Structures

After the terrorist attacks of September 11, 2001, researchers from UF were contacted to conduct an airborne survey of the World Trade Center area which included most of Lower Manhattan. Along with collecting airborne data, researchers thought that it would be beneficial to collect data using the ILRIS-3D of the buildings that were damaged. However, UF did not have an ILRIS-3D at the time so Optech was approached with the idea. Optech seized the opportunity to aide UF in the efforts of disaster relief.

Optech sent two ILRIS-3D units to be used in recovery efforts. One was sent to the WTC site and the other was sent to the Pentagon. The ILRIS-3D was going to be used to measure volumes and typical distance measurements at the WTC. At the Pentagon, it was used for measurement analysis of current building features. The ILRIS-3D proved to be a valuable asset at both sites.

The New York City Department of Design and Construction (DDC) was interested in volumes that could be calculated using the data collected. Another concern of the DDC was the distance between the debris and the surrounding buildings. Data collected with the ILRIS-3D gave information that could be used in these calculations. Figure 3-23 shows the Marriott building and some destruction around the building. Figure 3-24 is an image taken by camera of the same building. The height of the debris was also a major concern of the DDC. ILRIS-3D operators worked their way around the site to collect data from the best angles possible. At one point, the ILRIS-3D was carried to the roof of Liberty Plaza, 54 floors above the ground, only to be told that the roof was not a safe place to be. The ILRIS-3D was then set up on the 32nd floor where it collected data from the site below (Kern,2001).

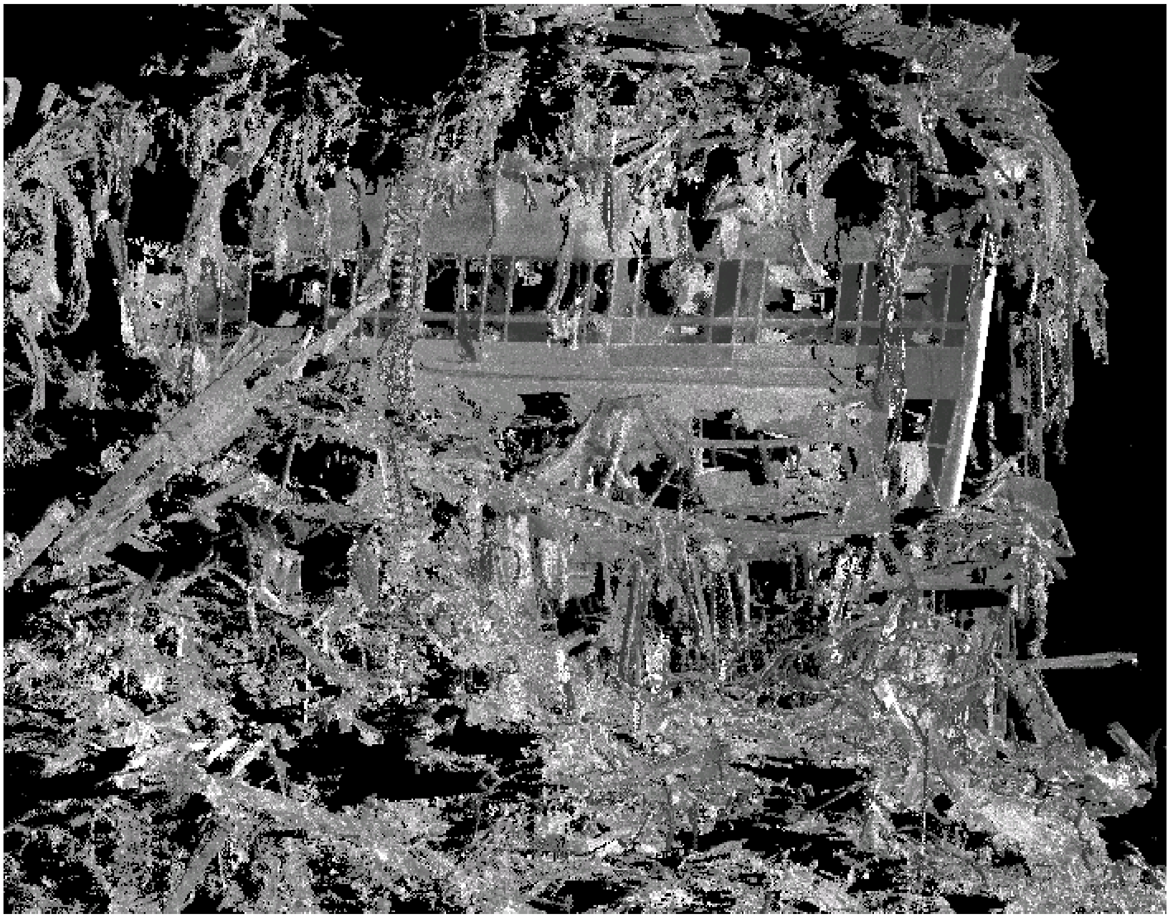

Figure 3-23. Destruction done to the Marriott Building in the WTC area.

The data collected at the WTC were processed and analyzed on location. The capability of data to be downloaded into a laptop and analyzed was a major asset to the DDC when answers to meticulous questions were needed. At one point, the DDC wanted to know about the angle and orientation of steel debris protruding from the American Express Building. Within minutes, data were analyzed and a determination was made as to the best way to remove the debris from the building without having to relocate the crane. The scan of this area is shown in Figure 3-25.

Figure 3-24. Digital image of the destruction caused to the Marriott Building due to the WTC attacks.

At the Pentagon, the ILRIS-3D had a different objective. Instead of doing damage assessment as it did at the WTC, the ILRIS-3D was used in a building reconstruction setting. People in charge of the reconstruction of the Pentagon wanted the re-built portions to look as close to the existing portions as possible. Since the blueprints for the limestone façades that surround the five sides of the pentagon don’t exist, the ILRIS-3D was used to scan the existing façades so that measurements could be taken for a replacement. Using the ILRIS-3D saved Masonry Arts Company the work of having to use scaffolding to manually measure each façade for a replacement to be cut. The goal was to have the rebuilt portion of the Pentagon look exactly like the existing portion.

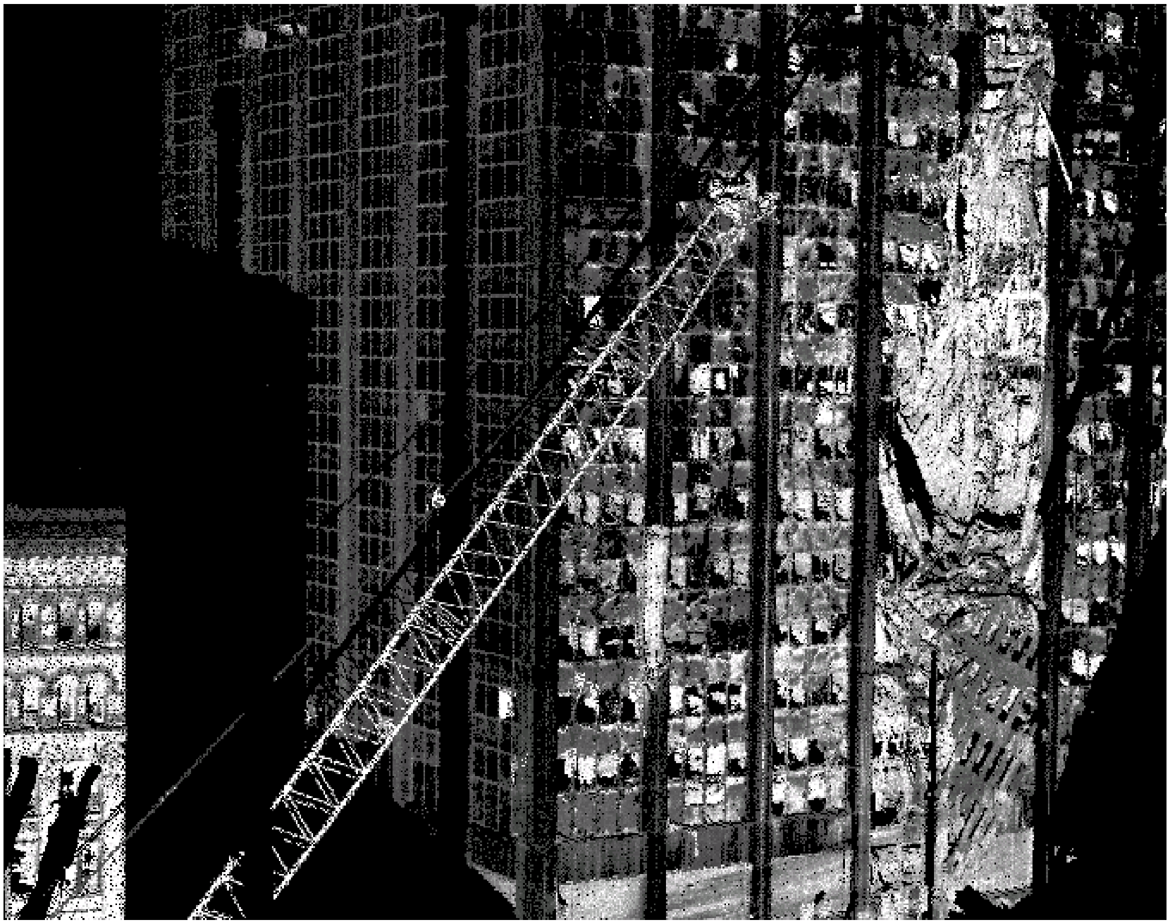

Figure 3-25. Image of the crane near the debris protruding from a building.

The Pentagon data can also be used for destructive analysis purposes. Figure 3-26 is a view of the scan taken from the front of the damage area. These data can be viewed at different angles to get a preliminary idea of the damage done to the Pentagon without endangering lives of investigators. However, this scan was taken after the investigators and engineers had entered the building and taken appropriate measures to make this part of the building safe for workers. In Figure 3-27, support can be seen built up around the load bearing columns that were feared to be unsafe.

Figure 3-26. View from outside the Pentagon.

Figure 3-27. Same data as Figure 3-26 viewed at a different angle. Note the support built up around the columns to help support the structure.

Most of the same objects and details seen in Figure 3-27 can be seen more clearly in Figure 3-28. In most cases, an accompanying digital image is an asset in comparing details between scans primarily because of the color in the digital image. Most of the same features seen in Figure 3-28 image can be seen in the ILRIS-3D scan in Figures 3-26 and 3-27.

Figure 3-28. A digital image of the Pentagon after most of the clean-up had taken place.

CHAPTER 4
GEOREFERENCING DATA FROM AN LSI SYSTEM

The ILRIS-3D does not include provisions to relate it to an external reference. It has no leveling feet, no level vial, and no visual telescopes to point it at a reference azimuth. Therefore, all points in the scene are given coordinates that are based on the arbitrary location and orientation of the ILRIS-3D. Usually, in surveying, when arbitrary coordinates are used on a project the coordinates are set so that all points within the project will remain positive. The ILRIS-3D coordinate system remains positive only in the range, the X-axis and Z-axis can generate negative values.

In many cases, it is desirable to have either State Plane Coordinates (SPC) or geographic coordinates. Polyworks™ IMInspect allows the user to manipulate data gathered by the ILRIS-3D so that the project can be translated into a specified coordinate system. This coordinate system can be one that the user generates based on project coordinates or coordinates based on some standard datum such as a geocentric or state plane system. In order to change the coordinate system, identifiable objects must be able to be chosen with good certainty. The accuracy of the georeferencing is limited by the point spacing within the coverage selected by the operator.

Implementing a GPS Antenna to Aide in Georeferencing

After receiving the ILRIS-3D in April of 2002, researchers at UF added a mounting screw to the top of the unit. The screw is roughly centered on the top of the unit and is used for mounting a GPS antenna to the ILRIS-3D. By mounting a GPS antenna to the top of the ILRIS-3D, coordinates can be gathered on the position of the unit. Since this was added onto the unit after receipt of the ILRIS-3D from Optech, no offsets were given for the distance from the antenna to the coordinate origin.

The mounting screw has a 5/8" standard survey thread. The mount does not go into the top of the ILRIS-3D sealed unit, it is mounted on top with epoxy as shown in Figure 4-1. This piece is mounted directly over the mounting hole that is located on the underside of the ILRIS-3D. Measurements from the bottom rear corners of the scanner were taken and duplicated on the top rear corners. When the ILRIS-3D is mounted and leveled, the placement of the GPS antenna is directly over the mounting screw on the tripod, the same as if the GPS were mounted to the tripod.

After leveling the ILRIS-3D on the tripod, a GPS antenna can be mounted to the unit via the mounting screw. GPS data can be collected while the ILRIS-3D collects data. After collecting data with the ILRIS-3D unit and the GPS receiver, there is still a need to collect geographic data on points in the field. These points will be used to aid in georeferencing the scan along with the data collected with the GPS on top of the ILRIS-3D which will give the location of the scanner.

Finding the Offset of the GPS Antenna

Before proceeding to determine the offset of the GPS antenna in reference to the coordinate origin, it was mandatory to determine the location of the coordinate origin. Albert Iavarone of Optech, Inc. informed researchers at UF that the coordinate origin of the ILRIS-3D is the opening of the mount hole on the base plate of the unit. To find the offset of the GPS antenna from this point, simple offset measurements are measured from the center of the hole out to the sides of the scanner. After the offsets to the sides of the scanner are known, then measurements are be made from the sides of the unit to the center of the GPS mounting screw. Vertical offset information was obtained by measuring from the base plate to the top of the ILRIS-3D unit, and then from the top of the ILRIS-3D to a known offset point on the GPS antenna.

Figure 4-1. Mounting screw on top of ILRIS-3D unit. The black straps are handles that were also added to the unit.

Results from these measurements yield that the primary difference in the offset is in the vertical axis. Measuring from the base plate, the reference point on the antenna is 0.323 meters above the coordinate origin. Measuring from the center of the mount hole to the center of the mounting screw on top of the unit, there is no offset in the Y direction. The offset in the X direction is –0.003 meters. The negative distance denotes that mounting screw on top of the ILRIS-3D is to the left of the mount hole on the bottom.

These offset measurements can be used to determine the position of the scanner in reference to a scan only if the scan is georeferenced. In a large project in which multiple scans are merged and georeferenced, the positional data of the scanner can be imported into the project using the coordinates obtained from using the GPS antenna and offset data. Scanner azimuth can also be determined in a single scan if one point in the scan has been labeled with GPS coordinates by using trigonometry.

Georeferencing Scenes without the GPS Antenna

Merging and georeferencing scans from the ILRIS-3D is similar to the relative and absolute orientation problems in photogrammetry. A relative orientation is the process by which the angular attitude and displacement between photographs is determined by an affine transformation. In this case, it would be the displacement and angular attitude between scans. An absolute orientation is the process by which the three-dimensional coordinate transformation is determined. It also is an affine transformation (Wolf and Dewitt, 2000).

A relative orientation consists of holding the ω, ϕ, k rotation angles and the X, Y, and Z values of the first photo. Then, by choosing common points (pass points) between two photos, the ω, ϕ, k rotation angles, the translations in the X, Y, and Z (Tx, Ty, and Tz) and the scale of the second photo are adjusted so that the two photos are 'joined' by the pass points, thus creating a pair of photos that exist in the same coordinate system.

When merging scans, points are chosen and used as pass points. The chosen points must be common points between the two scans. Holding the coordinate values of one scan is a process is known as 'locking' the scan in Polyworks™. Once the scan is locked, the next scan can be merged via the approximate values for the chosen pass points in the 'unlocked' scan.

An absolute orientation is the process of taking the 'pair' of photos that were merged in the relative orientation and assigning specific coordinates to selected points on the photo. Again, an affine transformation is performed in which changes will be made to the ω, ϕ, k rotation angles and the Tx, Ty, and Tz translations.

The absolute orientation process begins when the scans have been merged and are ready to be oriented into a geodetic coordinate system. Polyworks™ required that a minimum of three points be chosen for the coordinate transformation process. From a photogrammetry standpoint, only two horizontal and three vertical points are necessary, although more points provide redundancy in measurements. Once the geodetic coordinates have been computed and applied to the chosen points, the transformation parameters can be applied to all remaining points in the scan, thus bringing the entire scan or set of scans into the desired coordinate system.

When an area is scanned without the GPS antenna mounted on the ILRIS-3D, the only coordinate data that can be obtained are data collected on objects in the scan. Typically, this is done after viewing the data in the Polyworks™ modules so that points can be chosen on which to collect data. GPS coordinates are then obtained for those particular points or coordinates for specific points can be obtained from a local coordinate system.

After the scans have been merged, the aligned group of images is opened in Polyworks™ IMInspect. The points on which coordinate data was collected using GPS or other methods are chosen by creating a point at that location within the scan. Polyworks™ then creates a point at the nearest available data point in the area of interest and labels it with a point number and the existing coordinate data. The coordinate data listed is based on the coordinate system of the ILRIS-3D. This process produces points within the scan which are used to merge with the georeferenced data points.

After selecting points within the scene to use for merging, points are then created using the geodetic or local coordinate system as an origin. This provides a point with geodetic coordinates which can be matched to the corresponding data point that matches its location. After both sets of points, selected and created, have been imported into IMInspect, the alignment command is used to choose the points similar characteristics allowing the georeferencing process to proceed. The points chosen are merged with the geodetic points thus changing the coordinates of all data points in the scan to coincide with the geodetic or local coordinate system.

Georeferenced data can be important when airborne and land based data are merged. Georeferenced data makes the merging process of airborne and land based data easier and improves the accuracy of the merged dataset. More detailed instructions of georeferencing LSI data can be found in the ILRIS-3D Operation Manual by Optech, Inc.

Calibration Data Log

After a scan is completed, the ILRIS-3D writes a file that contains information about the scan. This file contains such information as a file name, time of scan, file size, points scan, spot spacing, mean distance and any notes that the operator might add at the time of the scan. This is a useful file and is necessary when importing data into Polyworks™ IMAlign. This data can also be used for future reference when information about a data collect is in question. Figure 4-5 is an image of a typical data log file created by the ILRIS-3D.

```
Decode Software Version:  Head: Mar.20, 2002

                 Image Information:
===========================================================
Name of 3d image file:          C:\Devin\Thesis\King Plow\kingplow1.i3d
Size of input file:             26037KB
Date of 3d image file:          08/02/02
Time of 3d image file:          07:19:00
System Software Version:        ILRIS-3D 2.2.1
System Serial Number:           SN010126
System Palm ID:
Input total shots:              2596562
Input number of scan lines:     1201
Input points per scan line:     2162
Output total shots:             2486070
Output number of scan lines:    1201
Output points per scan line:    2070
Range:                          25.00 m
Spot Spacing:                   7 mm
Range Correction:               750.00 cm
Intensity Correction:           0.00
Range Offset:                   0.14 cm
Pulse Mode:                     First Pulse

Calibration Frequency:          100 lines
                 Operator Log:
===========================================================


                 Parsing Settings:
===========================================================
Input File Name:                C:\Devin\Thesis\King Plow\kingplow1.i3d
Output File Name:               C:\Devin\Thesis\King Plow\kingplow1.pf
Output File Type:               pf
Range Gate:                     0 to 150 meters
Intensity Gate:                 0 to 255
Reduction Factor:               1
Shot Data is Trimmed:           Yes
Intensity is output:            Yes
Keep Saturated Readings:        Yes
Keep Dropout Readings:          Yes
Input File is of Old Style:     No
Shot Number is Reordered:       Yes
BMP file is generated:          Yes
```

Figure 4-5. Log file created by the ILRIS-3D containing scanning parameter data

Accuracy Test Results

Accuracy of scan data can be checked when primitives are fit to the objects being scanned. For this accuracy assessment, a flat surface was scanned and a 'plane' primitive was fit to the surface. Figure 4-6 shows a portion of the wall as it was scanned. The resolution of the scan is about 1.5mm. Figure 4-7 is an image of the same portion of the wall, but the wall has been rotated 90° so that the reader can see how much scatter is involved in the range measurement.

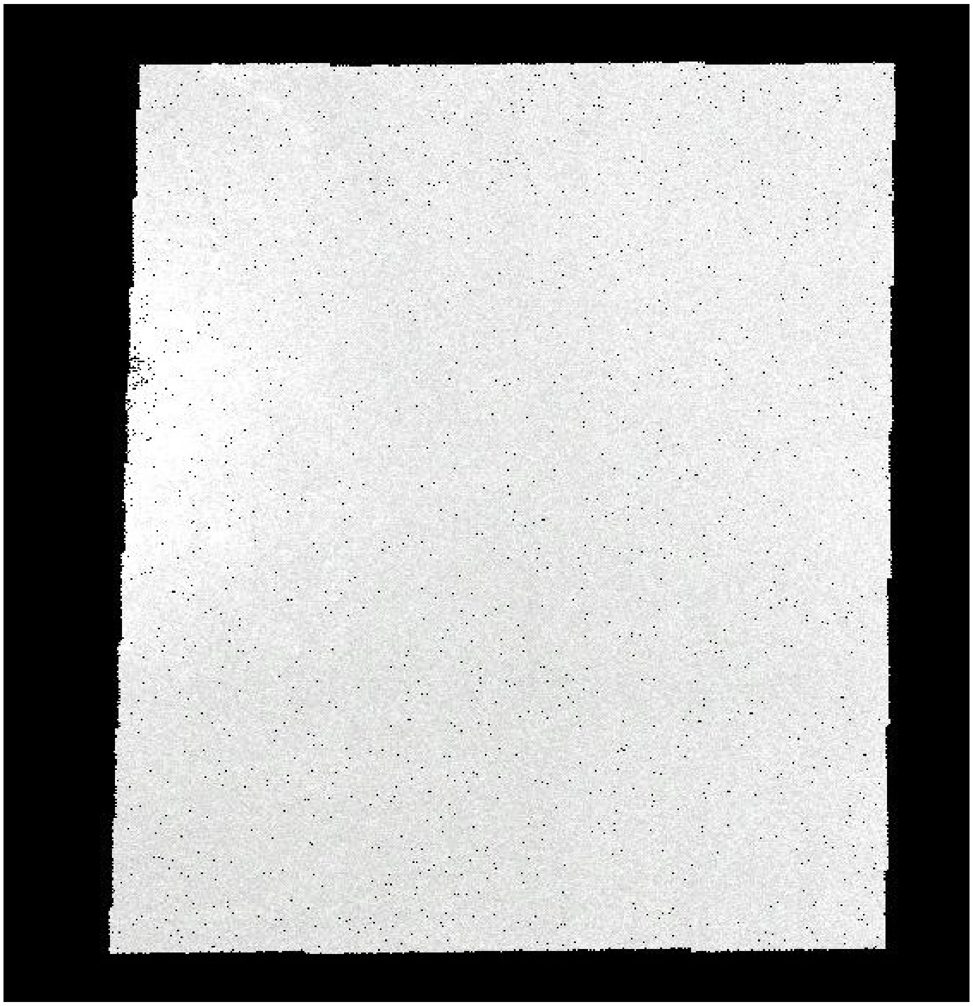

Figure 4-6. Wall surface viewed straight on in IMInspect.

To fit a primitive to this surface, the surface must be selected. After selecting the data to fit the primitive to, IMInspect does a best fit analysis to fit a plane to the surface using the average range over the entire selection. Figure 4-8 shows the plane fit to the data. Note that the plane is blue and it looks as if it hides behind the data points. This is the affect that averaging the points has on the plane. Figure 4-9 is an error map of the plane as it fits the data points. Figure 4-10 is a view of the same error map as viewed from the rear of the wall. Note the shading of the error map on the right side of the images as they compare to the color of the data points.

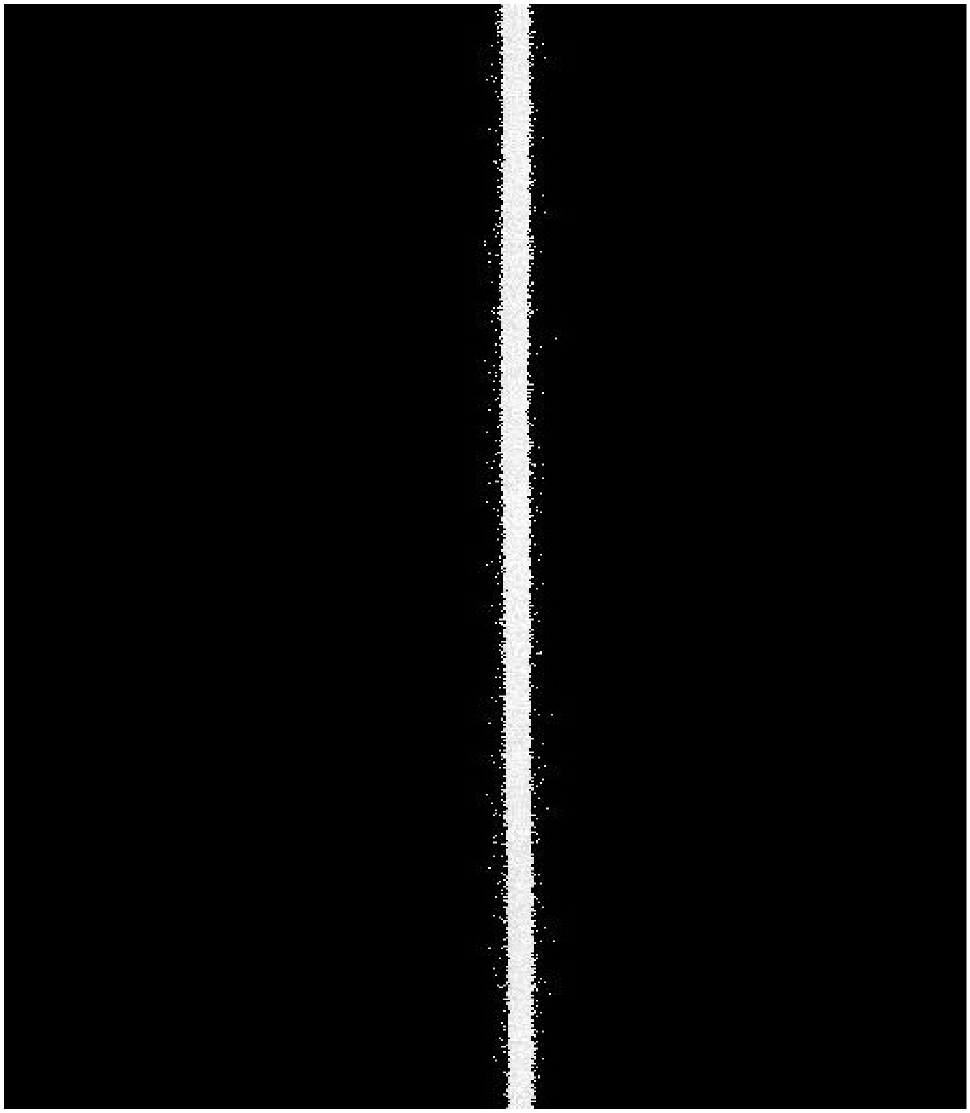

Figure 4-7. The wall in Figure 4-6 viewed from the side (approximately 1cm wide).

Figure 4-11 is a report of accuracy information from the error maps that are seen above. This report can be exported as an ASCII file, a HTML file, an Excel spreadsheet or as a Word file, which is seen here. This report summarizes the data as they pertain to the plane primitive that was fit to the selected data points. A note should be made that this data is only from one scan. Further accuracy data will be analyzed as more scans are added to the dataset.

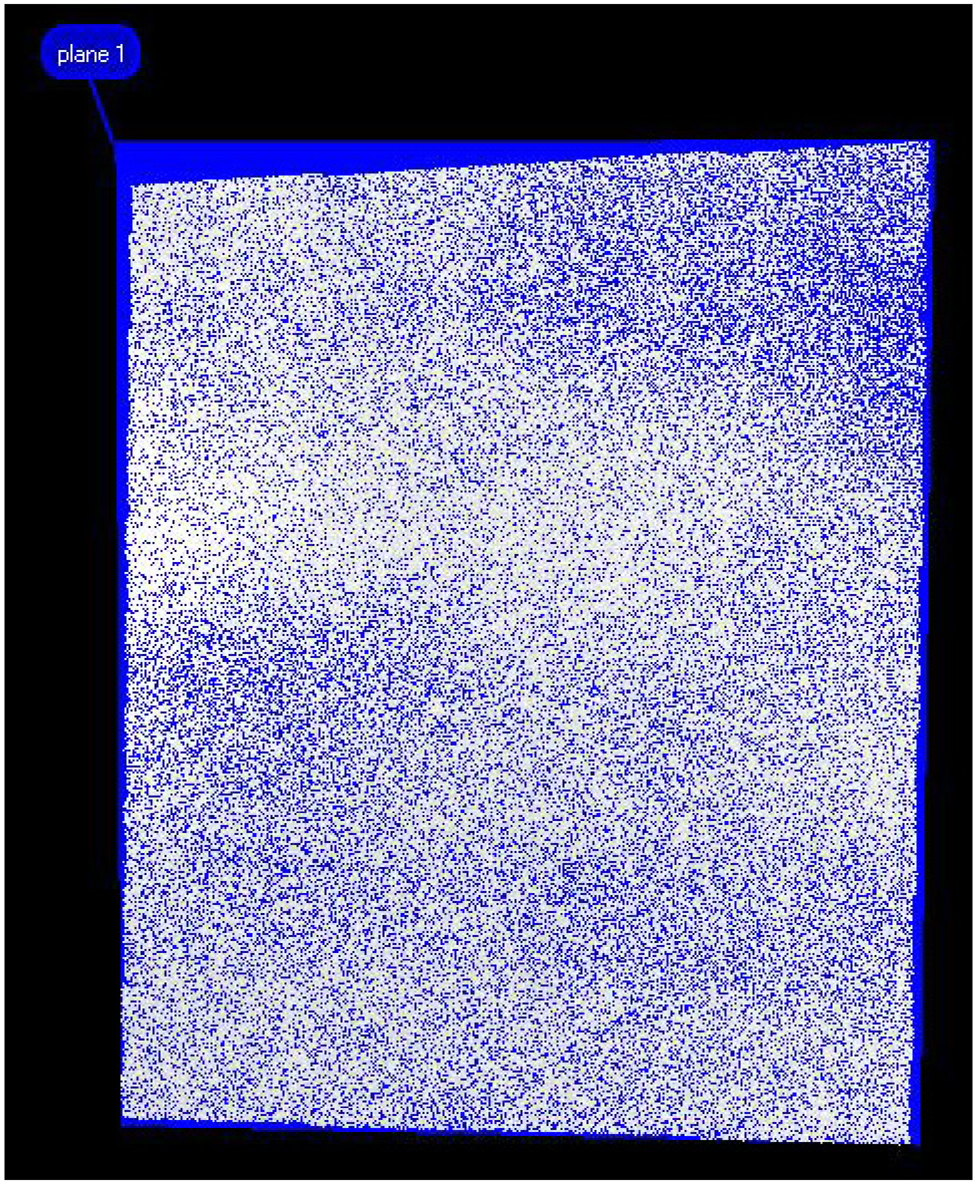

Figure 4-8. The plane fit to the wall data set.

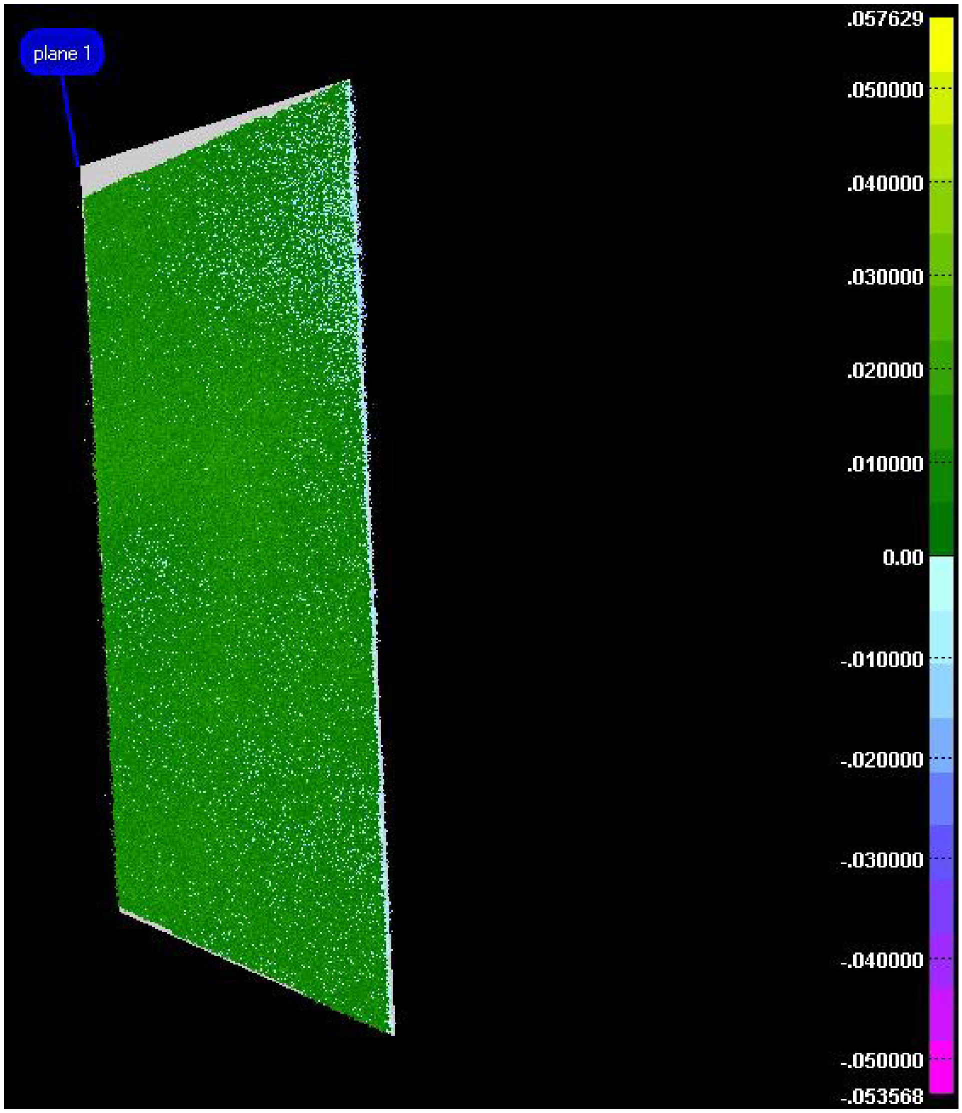

Figure 4-9. Error map of data points compared to plane primitive as seen on front surface of wall.

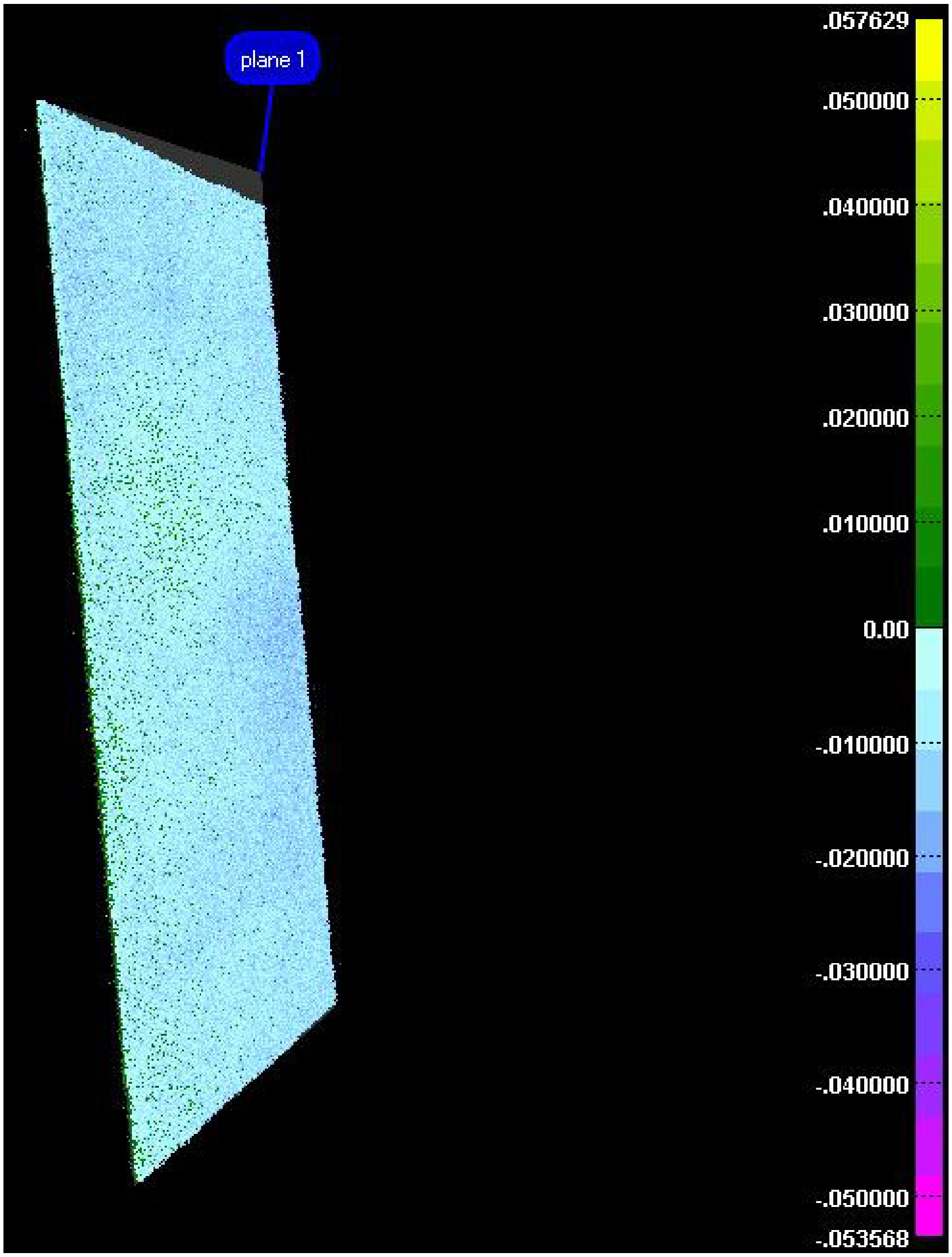

Figure 4-10. Error map of data points to plane primitive as seen from rear surface of wall.

	Data to Plane		
Cmp Object(s)	5thfloorwall.pf		
Cmp Dist	4.000000		
HiTol +	2.000000		
LoTol +	1.000000		
LoTol -	-1.000000		
HiTol -	-2.000000		
Err Dir	Shortest Distance		
Prim Name	plane 1		
Prim Type	Plane		
A,B,C,D	A=0.201581, B=-0.979456, C=-0.005476, D=6.160533		
Origin	-1.241849	6.033974	0.033733
Nl	0.201581	-0.979456	-0.005476
X Angle	78.370545		
Y Angle	168.366195		
Z Angle	90.313735		
#Points	453544		
Mean	0.000042		
StdDev	0.007072		
MaxErr +	0.057629		
MaxErr -	-0.053568		
Max Error	0.057629		
Min Error	-0.053568		
Pts within +/-(1 * StdDev)	298885 (65.899891%)		
Pts within +/-(2 * StdDev)	438149 (96.605622%)		
Pts within +/-(3 * StdDev)	452866 (99.850511%)		
Pts within +/-(4 * StdDev)	453358 (99.958990%)		
Pts within +/-(5 * StdDev)	453469 (99.983464%)		
Pts within +/-(6 * StdDev)	453519 (99.994488%)		
#Pts Out of HiTol	0 (0.000000%)		
#Pts Out of LoTol	0 (0.000000%)		

Figure 4-11. Accuracy report on the fit of the plane primitive to the selected data of only one scan.

Similar accuracies can be seen when two scans are merged. The wall discussed above was scanned twice, once from slightly off center and again from more straight on. These two scans were then merged together using IMAlign. The regular course of action for merging scans was taken with a rough alignment first followed by a fine alignment process. After the scans were merged, the merged data was saved and imported into IMInspect. After importing the data, the portion of the wall that was to be used for fitting the plane primitive to was selected and everything else was deleted. After the wall had been isolated, the same procedure was followed as in the accuracy assessment above on an individual scan. Figure 4-12 is the data report for fitting the data to the plane. Images of the wall and plane are not shown due to the similarity of the above images.

Report Type	Data to Plane		
Cmp Object(s)	wall_merge		
Cmp Dist	4.000000		
HiTol +	2.000000		
LoTol +	1.000000		
LoTol -	-1.000000		
HiTol -	-2.000000		
Err Dir	Shortest Distance		
Prim Name	plane 1		
Prim Type	Plane		
A,B,C,D	A=0.201536, B=-0.979460, C=-0.006394, D=6.160014		
Origin	-1.241467	6.033488	0.039386
Nl	0.201536	-0.979460	-0.006394
X Angle	78.373186		
Y Angle	168.367255		
Z Angle	90.366341		
#Points	1037870		
Mean	0.000078		
StdDev	0.006422		
MaxErr +	0.063766		
MaxErr -	-1.776521		
Max Error	0.063766		
Min Error	-1.776521		
Pts within +/-(1 * StdDev)	730119 (70.347828%)		
Pts within +/-(2 * StdDev)	1002257 (96.568645%)		
Pts within +/-(3 * StdDev)	1035180 (99.740815%)		
Pts within +/-(4 * StdDev)	1037071 (99.923015%)		
Pts within +/-(5 * StdDev)	1037473 (99.961749%)		
Pts within +/-(6 * StdDev)	1037707 (99.984295%)		
#Pts Out of HiTol	0 (0.000000%)		
#Pts Out of LoTol	1 (0.000096%)		

Figure 4-12. Accuracy report on the fit of the plane primitive to the selected data of the merged scans.

CHAPTER 5
MERGING AIRBORNE LASER DATA AND GROUND LSI DATA

Merging two datasets consisting of over one million points a piece requires a large amount of storage space and RAM. The benefits of using airborne laser data to create a topographical map of a given area along with other surveying methods are both systems collect large amounts of data in a short amount of time.

Airborne laser data are collected in the same fashion that the ground based LSI system collects data. The only difference is the airborne system uses an airplane as the surveying platform instead of a tripod. Data gathered from the airborne system are used to create a topographic map of the earth below. GPS is used in the process of collecting the airborne data which are georeferenced at the time of processing.

LSI data are collected but not georeferenced. Georeferencing is a process that takes place after the data are collected and aligned, only if GPS data were collected at the site or if points in the scan have known coordinates. Merging the airborne data to the LSI data is possible if both datasets can be positioned and oriented in the same coordinate system and if both datasets can be output into the same format; X, Y, Z, Intensity. Since researchers at UF have both types of systems, an effort was made to determine how the two data sets could be used in conjunction with each other, and how well the merging process would work.

Before merging the two datasets, three things must be considered. One is the resolution (point spacing) of point data for each dataset. The second consideration is how accurate is the georeferencing for either dataset. Another consideration is the method of georeferencing applied to the datasets. One dataset's coordinates will be held such as the airborne dataset while the LSI dataset remains free to be merged with definable objects or the LSI data set will be georeferenced using GPS data from identifiable coordinates in the scene and then import the airborne set into the same system.

The resolution of the airborne dataset is a major contributing factor in determining how well the datasets will merge. Most airborne datasets have a resolution of 1 meter to a half of a meter. Data resolution of a LSI system is typically a less than two centimeters. This difference in data can cause problems when the user is attempting to merge two datasets and the airborne dataset resolution is not less than one half of a meter. When the data resolution of the airborne set is at meter resolution, the data between the actual points is interpreted using the Kriging or Nearest Neighbor gridding algorithms. Low point resolution in airborne data can make the process of aligning data difficult because the points and elevations created by the gridding process cannot be chosen for alignment purposes.

Gainesville Regional Airport

Only original point data are imported into Polyworks™ in ASCII format. The shaded relief data that is seen in software packages such as Golden Software's SURFER® is not imported because of the inability to use the generated point data. Instead of choosing points to align LSI data to airborne data, surfaces or vague features must be chosen in hopes that the surrounding features will aid in the alignment process. When merging data, Polyworks™ aligning process searches for common characteristics in data to merge to. For example, sharp corners and common power poles give the software features on which to align common data. Figure 5-1 is a shaded relief image of airborne data collected over Gainesville Regional Airport. Figure 5-2 shows the same dataset displayed in Polyworks™. Notice the differences in the dataset and the way the data are displayed. The shaded relief image has been gridded using the Nearest Neighbor algorithm. This gridding process fills in areas between points.

Figure 5-1. Shaded relief image of Gainesville Regional Airport terminal area.

Another method of merging data as stated above is the process of georeferencing both datasets individually as best as possible. If both datasets are georeferenced prior to merging, then the merging process will be done iteratively by Polyworks™ IMAlign module. Polyworks™ IMAlign will align the dataset because X, Y, and Z files are being imported from the airborne data and the ILRIS-3D data. As long as these X, Y, and Z files are in the same coordinate system, Polyworks™ will import the datasets over one another. The accuracy of the georeferencing done to both datasets will determine the outcome of the merging process.

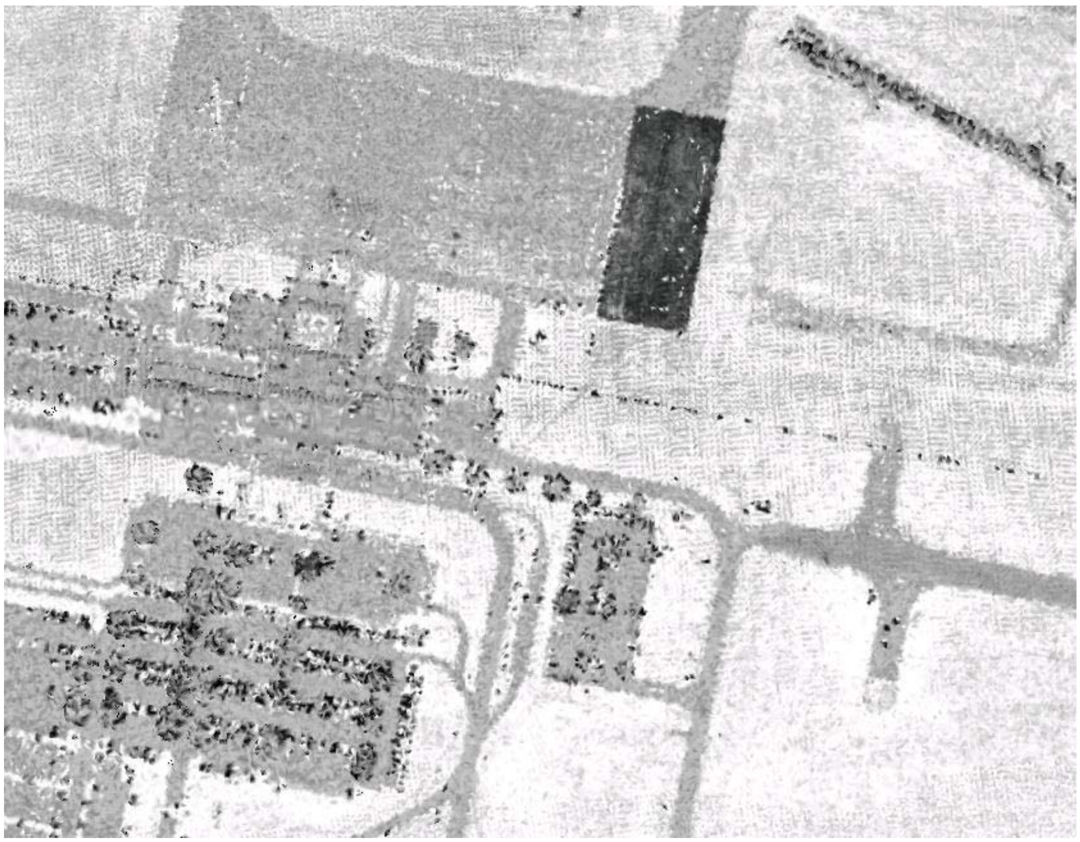

Figure 5-2. Points and Intensity image of Gainesville Regional Airport terminal area.

As seen in Figure 5-2, aligning the data could become a complicated task. Note the data to be merged are taken from two different perspectives. Airborne data were taken from above using an airplane as a survey platform and ILRIS-3D data were taken from the ground mounted to a tripod. The airborne data will only give features as seen from the air such as roofs of buildings, tops of trees, and ground surfaces. ILRIS-3D data taken from a tripod will show features such as walls of buildings, sides of trees and some ground features. Figure 5-3 is an image of the ILRIS-3D data of the terminal building that was used in the merging of airborne data and LSI data. This dataset consists of 16 scans with a point resolution between 1 cm and 2 cm.

In instances where common data between the two sets are rare, the quality of the merged datasets is going to be questionable at best. Data points on the ground or a slanted roof are the best chance one has other than georeferencing the data separately as described above. For the datasets merged in this thesis, common data points were chosen between the two datasets for the merge.

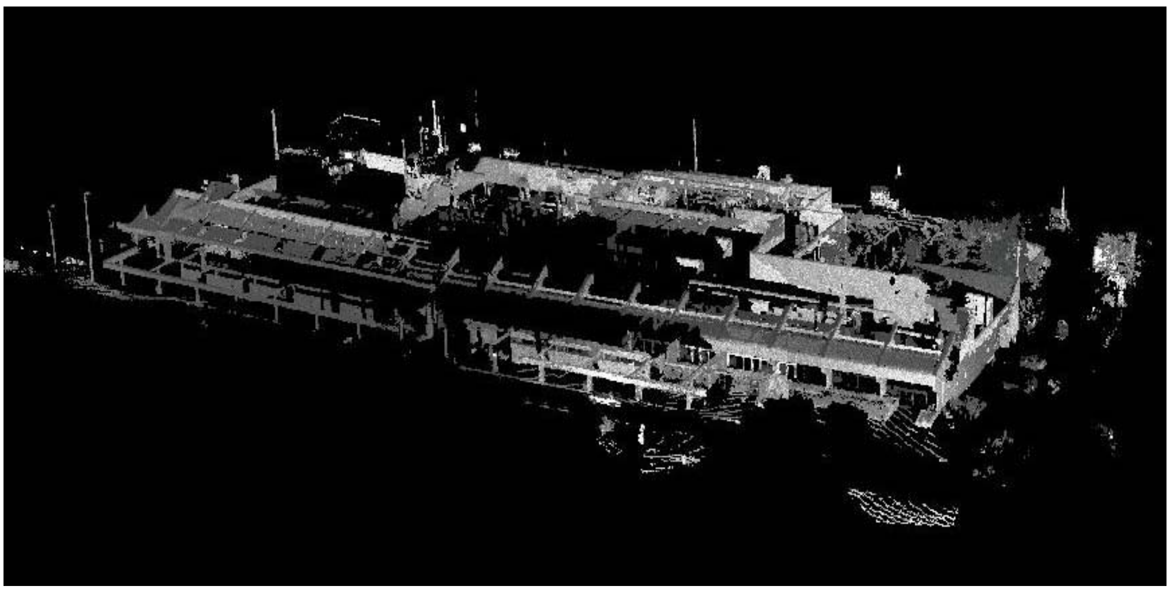

Figure 5-3. ILRIS-3D data of Gainesville Regional Airport terminal building.

Before merging datasets, common areas with data points were found in both sets of data. The points were primarily corners of the building, the ground surrounding the corners, and parts of the slanted roof on the front of the terminal building. The iterative process of merging the datasets can be time intensive because the resolution of the data varies between the two sets. Airborne data were taken with an Optech ALTM 1210 system, a 10kHz system manufactured by Optech, Inc. The point spacing on the ground for this dataset was about 1 meter. The large point spacing from the airborne data will not define the edges of the building as well as the ILRIS-3D data will, thus causing difficulties in the iterative process of merging. Figure 5-4 shows how the airborne data point resolution appears at close range. Notice that the individual features are harder to distinguish in the zoomed image as opposed to the ILRIS-3D data in the image in Figure 5-3. The shape of the terminal can still be seen, but details are hard to define.

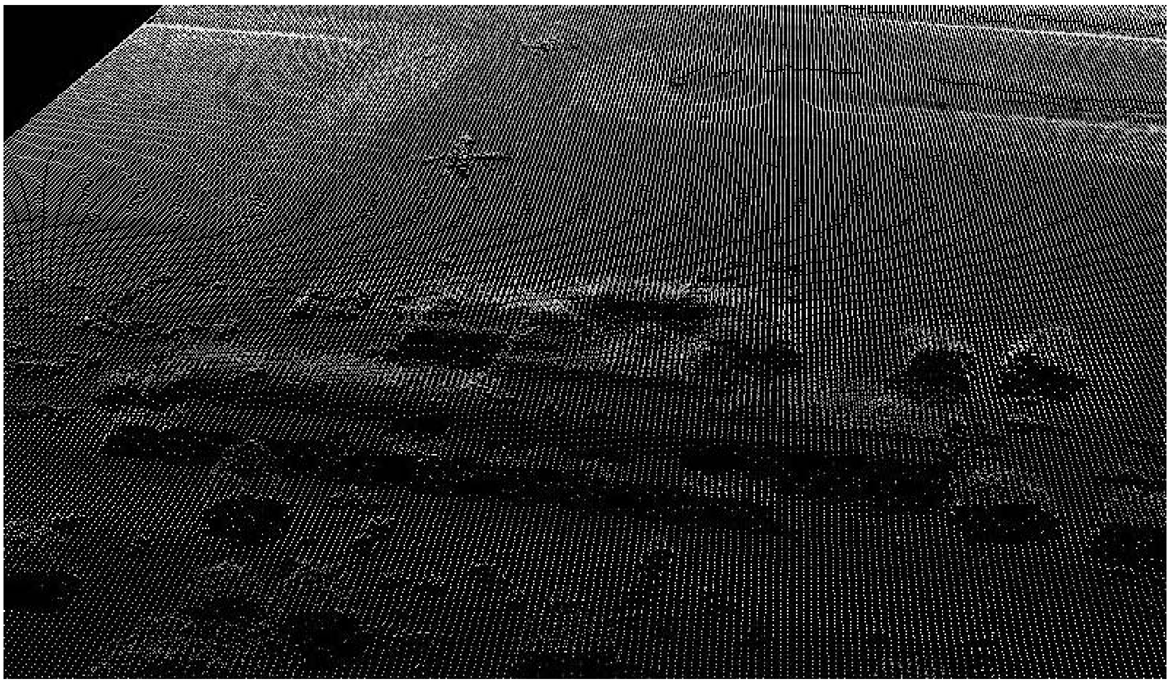

Figure 5-4. Close range view of the airborne data showing individual data points.

In the process of merging the two datasets, as stated earlier, corners were chosen because of the rapid change in elevation near the edge. Researchers decided the corners would be the easiest way to find common areas and aid in the iterative merging process. With the corners and the amount of detail surrounding them, the process is still questionable since data with a resolution of 1 meter are being merged with data of 1 cm resolution. The search radius for the iterative process was raised to meet the minimum resolution of the airborne dataset. This takes longer because Polyworks™ still searches through all of the data points in the LSI dataset that lie within the empty areas of the airborne dataset.

Before the merging process begins, a base coordinate system must be determined. For the example of the Gainesville Regional Airport, the airborne dataset will serve as the base because it is in the Florida North SPC system. While the airborne dataset serves as the base, it must be locked within its coordinate system after being imported into the dataset and must remain locked throughout the merging process. Although the exterior terminal scans were locked previously as a group, they must be unlocked to be merged with the airborne set so that both datasets will be on the same coordinate system. After the data are roughly aligned, the data can then be processed through the iterative process. Figure 5-6 is an image of the final product of merging airborne data and LSI data.

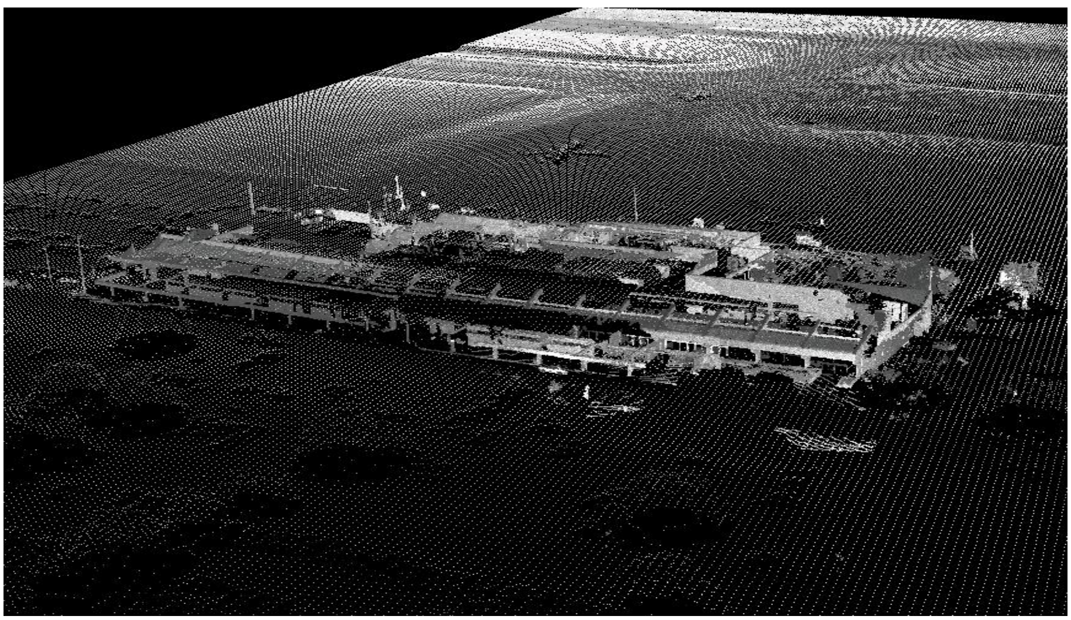

Figure 5-6. Airborne dataset and LSI dataset after merging process.

Upon completion of picking the approximate common points, the iteration process fine aligned the images so the datasets appeared to overlap in all areas. Fine tune merging was necessary in some areas. Fine tune merging is the process of reducing the search radius to an area that is concurrent with the accuracy that is desired, then repeating the iterative process of merging data. Fine tune merging was done by locking data that appeared to be accurately merged and unlocking data that were not. The unlocked data were then manually aligned with the LSI dataset and the airborne dataset. After visually aligning the unlocked scans the data were sent through the iteration process using the locked datasets as the base model. Repeating the alignment process allowed Polyworks™ to better align irregular scans to the base model producing a presentable end product.

I-75 and State Road 222

This process of merging airborne data and LSI data was also attempted with another project. The LSI data that were collected at I-75 and SR 222 also have an accompanying airborne dataset. These data were collected at the same time in an effort to determine the usefulness of such data in various applications. As stated in Chapter 3, 16 scans were taken of the bridge and the immediate surrounding area using the ILRIS-3D. The site was flown along both directions of travel, north-south and east-west. The image in Figure 5-7 shows the shaded relief image of the airborne dataset.

These data were also collected with the ALTM 1210 system by Optech. The dataset does not look as complete or smooth as the airport dataset because only one pass was used for each direction. The airport dataset included all data within given boundaries. By using only one strip of data from each direction, the effect of the overlap is lost therefore leaving more room for gaps in the data. If the dataset had flight lines on either side of the centerline, the gaps would have been reduced, therefore providing a smooth dataset. The shaded relief data were gridded using the Nearest Neighbor algorithm in SURFER®. Notice how the bridge in Figure 5-7 has jagged edges. This is caused by the point spacing of the flight. The 1 meter resolution of the dataset will not always allow the exact edge of an object to be in the dataset. Overlapping flight lines brings the resolution down providing a better idea of corners and edges in the dataset.

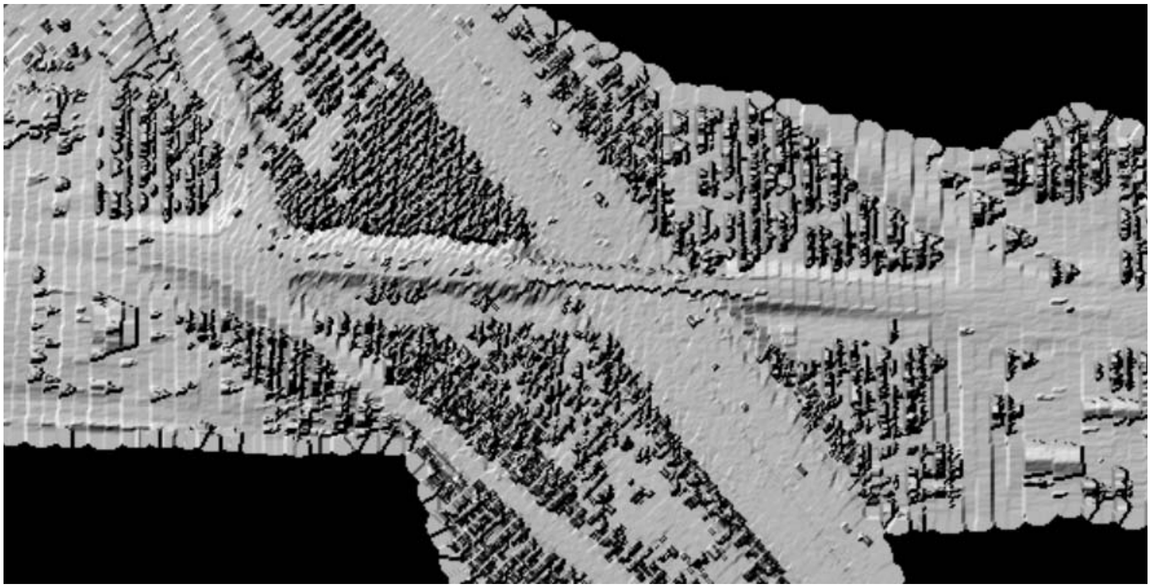

Figure 5-7. Shaded relief image of I-75 and SR 222 intersection.

As stated previously, only one strip of data for each direction was used in this example. When viewing these data in Polyworks™, the jagged edges become very evident as seen in Figure 5-8 and 5-9. Figure 5-9 is a close up of the data points giving a better idea of the point resolution. The jagged edges can alter the merging process because of the irregularities in data along the edge of the bridge. Since the LSI data were taken at ground level from I-75, data from the drivable surface of the bridge were not collected. Data from any horizontal surface on the bridge are from underneath the bridge and will not match up with airborne data from the drivable surface. Data of the bridge from the airborne dataset were not used for merging.

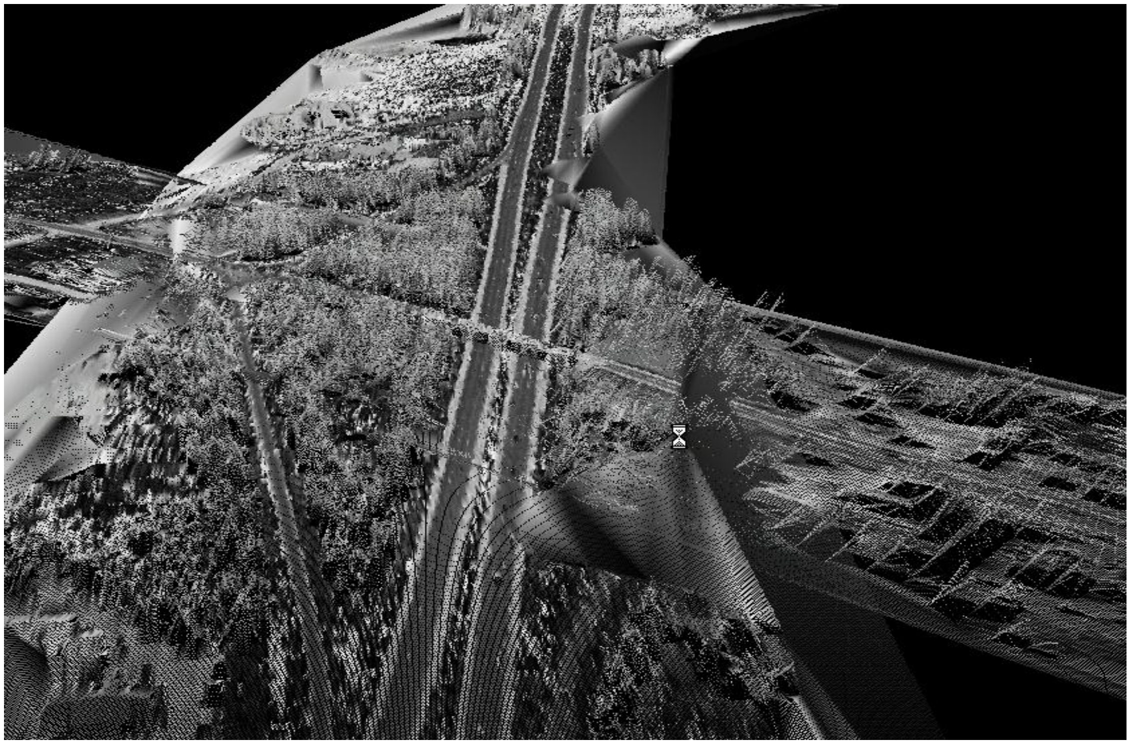

Figure 5-8. Airborne data of I-75 and SR222 as seen in Polyworks™.

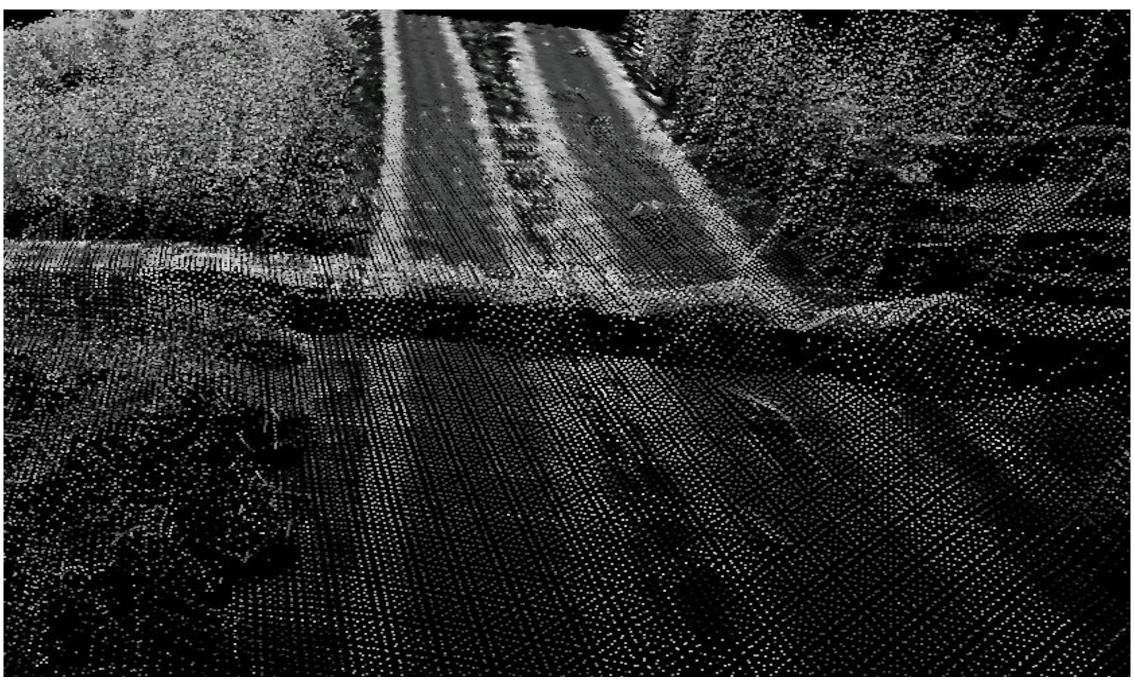

Figure 5-9. Close-up view of point data in Polyworks™.

The LSI data of the bridge consist of the bridge and surrounding areas. It is important to determine what areas are common in both datasets and not to delete the data that surround the bridge from the airborne set. If these data are deleted, there will be no data to use for merging. Figure 5-10 shows the LSI data of the bridge with the surrounding areas. For purposes of merging, the bridge embankment will be used along with the paving and median on I-75.

Before merging the data, other data manipulation had to be completed. The airborne dataset consisted of data from the tops of trees. The LSI dataset collected data from the side view of these trees. In an effort to ignore the complications, only features that were positively the same in both datasets were used. With the bridge data and tree top data from the airborne set ignored in Polyworks™, and the tree data from the LSI set ignored in Polyworks™, the merging process began.

The same procedure as discussed before was used in the I-75/SR222 dataset. The base coordinate system was the airborne dataset. After that dataset was imported, it was locked into its coordinate system and remained locked throughout the merging process. The LSI dataset was unlocked and merged as a group to the airborne set. The process of finding common areas of data began and a rough alignment was put through the iterative fine alignment process. Determining the accuracy of the alignment requires the points to be identified in the scene and coordinate data collected on those points in the field. Without conducting a 'ground truth' for the merged dataset, the assumed accuracy can not be any better than the point resolution of the airborne dataset. Figure 5-10 is a view of the final alignment of I-75 and SR 222.

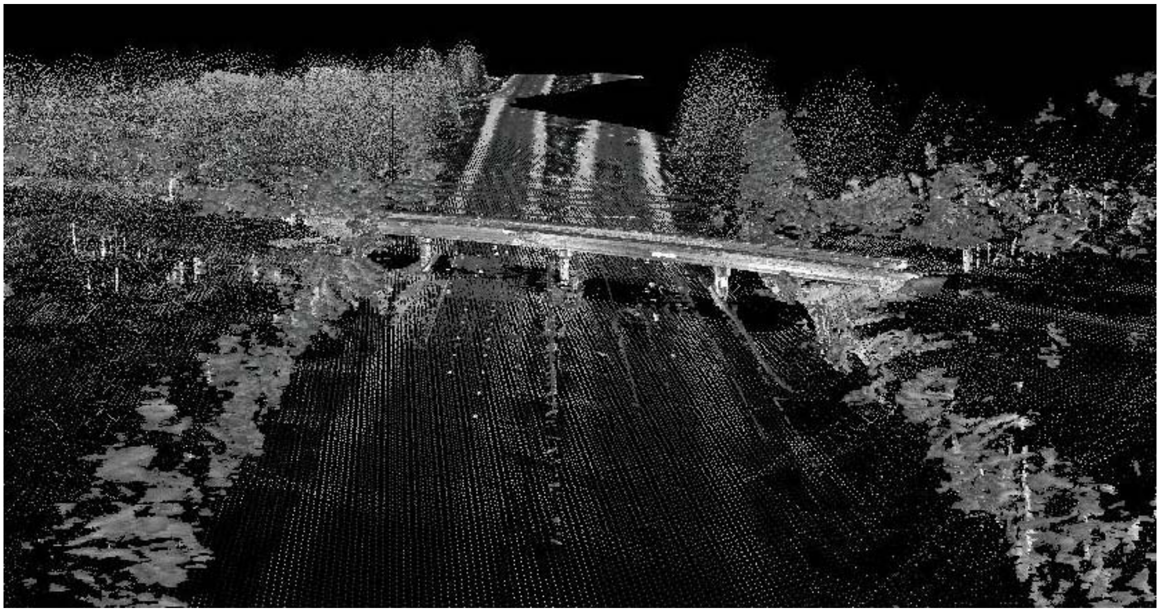

Figure 5-10. Combined dataset of I-75 and SR 222 in Gainesville, Florida.

As shown in the images throughout this chapter, large amounts of data can be displayed and analyzed simultaneously when airborne data and LSI data are merged. In an ideal situation, the airborne data will have a better point resolution than 1 meter. Collecting data with a more advanced system such as the ALTM 1233 generates more point data per second. However, the same flight parameters that were used with the ALTM 1210 system would need to be used to have a better point resolution. An advanced system such as the ALTM 1233 only allows the operator to change the flying altitude and speed of flight while still maintaining the point resolution obtained with the ALTM 1210. Keeping the same parameters and using the more advanced system will put three times as many points on the ground, roughly improving the resolution by a factor of three.

CHAPTER 6
DATA ANALYSIS

Data analysis provides valuable information on collected data. Collecting 2000 data points per second with the ability to determine coordinate data, distance information and create solid geometry provides a backbone for the LSI system. Polyworks™ IMInspect is used to analyze data allowing the user more flexibility to work with data as opposed to working with data on only points collected by using conventional surveying methods.

Resolution

One difficulty of data analysis is the point resolution of the collected data. When using traditional survey methods, a set of coordinates is obtained at the desired location. With LSI data, coordinate data on any specific point is only collected if that point happens to coincide with one of the points in the laser scan pattern. In order to check for available points, data must be checked before leaving the scene. Collected data cannot be viewed until after a scan is complete and data have been downloaded and parsed. If a desired point does not show up in the scan, another scan is taken after adjusting the scanning parameters. This concept also applies when merging data also. It is good practice to check scans before leaving the site to ensure enough overlap exists in order to merge scans.

Another important aspect is to ensure that the points of interest are in the scan, and that there is adequate point resolution around those points in the scan. When point data is not available for a specific point, the data analysis cannot be performed accurately in regards to the location of that point. Inadequate point data for an object is a result of large point spacings or an adequate point spacing at an average or short distance. Close point spacing at short distances will not guarantee close point spacing at a distance greater than the mean distance of the scan.

Figure 6-1 is an overall view of the intersection scan that was completed at UF. Shown in the image along with point data is the GPS coordinate data used in an effort to georeference the scene. Figure 6-2 is a zoomed image of the top of Figure 6-1. In comparing the two images, it is apparent how the spot spacing becomes an issue with georeferencing. If a point lies within an area between scan lines an accurate picking of a georeferenced point cannot be made. In Figure 6-2, the point with coordinates obtained from GPS lies within a gap in the point cloud because of the distance from the scanner. The corresponding scanned data point that must be chosen is at least 4 cm away, thus introducing errors into the georeferencing process.

GPS data were collected at the tip of the white painted line. This stripe, highly visible in the scan, was considered adequate for point geometry within the scan. Using GPS data, a point was created within the IMInspect project. During the data analysis, matching the GPS coordinates to a point picked within the scan resulted in inaccurate point data due to the point spacing in the area of the scan.

The curved lines in Figure 6-2 represent the horizontal scanning pattern of the LSI system. An area of the scan, farthest from the scanner as depicted in Figure 6-1, causes the point spacing to be greater than the point spacing at the mean distance in the scan. The disadvantage of the not having the point spacing at a lower interval is that the point that needs to be chosen for georeferencing is not seen in the scan. Again, as stated earlier, the spot spacing that is given during the scanning parameters set-up menu is only at the mean distance. Objects closer to the scanner will have a point spacing less than that given for the mean distance, and greater for objects farther away.

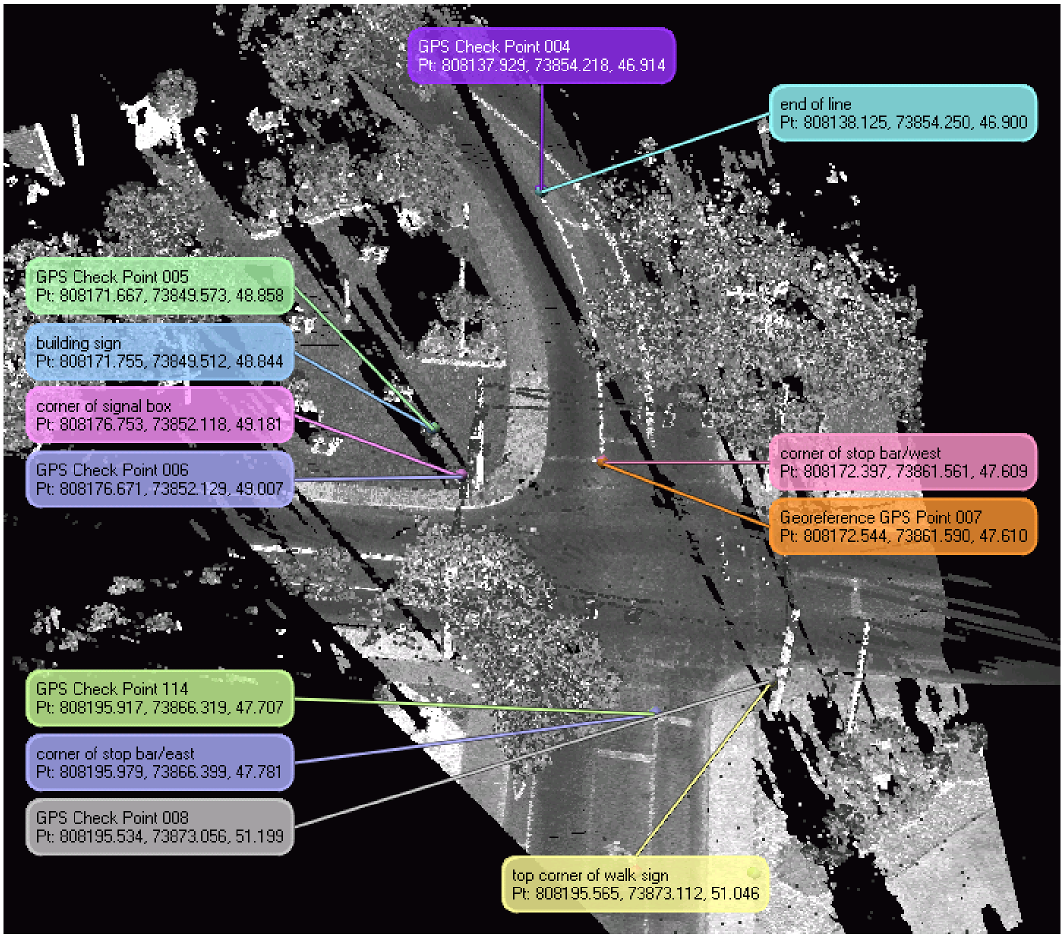

Figure 6-1. Georeferenced intersection on University of Florida campus.

Figure 6-2. Close-up view of the difference in GPS coordinates and points selected from LSI system point data.

Making Measurements with Point Data

Chapter 1 introduced that making distance measurements is the preliminary task of any engineering project. Chapter 3 showed how measurements could be used to determine the distance from the bridge to the power lines. Examples of measurements and other useful tools will be discussed in this section as well as how the measured data can be used.

Polyworks™ IMInspect is used to measure and analyze data. IMInspect also allows the user to create primitives, which are shapes and objects that can be created based on point data. An example of this is the creation of a sphere. If a globe was scanned from one side, only half of a sphere would appear in actual 3 dimensional point data. If these point data are selected and used in creating a sphere, IMInspect takes that point data and uses it to determine the radius of the globe or sphere and recreates the side of the globe that has no point data. Tools such as this can be useful when dimensional data are desired on objects.

Figure 6-3 shows a scan of a service drive near a building. A column is in the scan which is used to support the second floor of the building. This is only one scan so only one side of the column is visible, yet the radius of the column is desired. There are two ways to find the radius. One is to pick two points on opposite sides of the column, measure the distance between them and divide by two. The other is to select the point data representing the column and create a cylinder from the selected data as shown in Figure 6-4. This feature can be used to determine the dimensions of cylindrical power poles and pipes. Manufacturing plant surveys is a major application in which this tool is currently being used. Not only is the route of a pipe being located, but also its dimensional properties.

Along with the ability to create cylinders, Polyworks™ IMInspect also allows the user to create primitives such as flat planes, circles, cones and spheres. From these created primitives, the user can acquire point data on the radius, center point, and length.

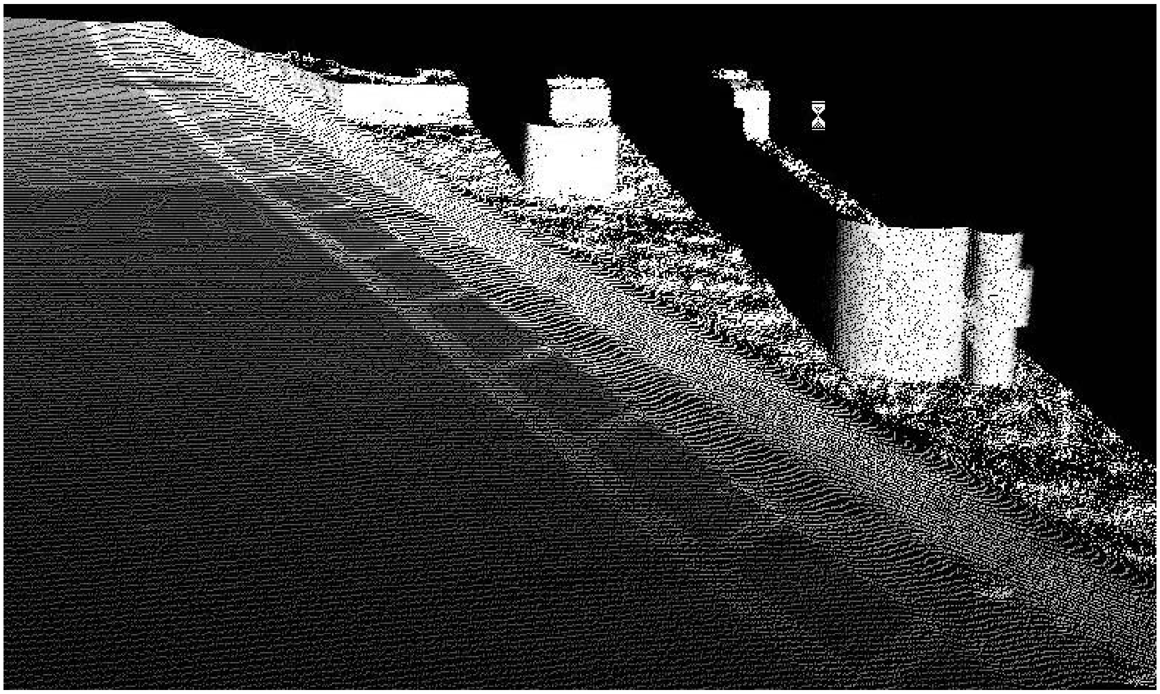

Figure 6-3. Scan of a service drive near a building being supported by cylindrical columns.

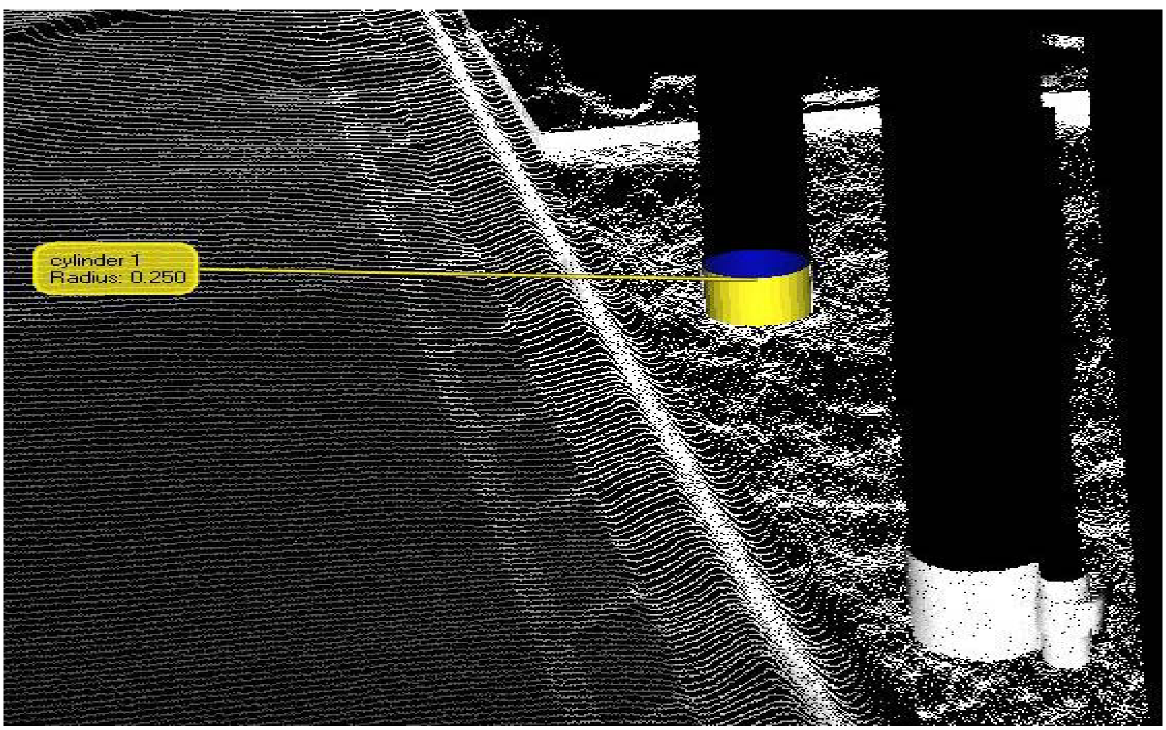

Figure 6-4. Cylindrical primitive created by Polyworks™ IMInspect using scanned point data.

Another useful tool in Polyworks™ IMInspect is the point and vector tools. The point tool allows the user to create points or pick points in the scan. This is the tool that allows the user to conduct distance measurements between objects. Scanned points can be chosen and vectors can be measured between chosen points. Being able to measure objects in a 3 dimensional aspect is something that is hard to visualize with data collected with traditional survey methods. Measuring LSI data in 3 dimensions is the characteristic that gives this method of surveying an ability to give the data a feel of reality. Seeing data in 3 dimensions actually puts into perspective the lines that a 2 dimensional survey only leaves to the imagination, or interpretation. Figure 6-5 and 6-6 are some images of simple measurements done with the Polyworks™ IMInspect module. Figure 6-7 is an image of how measurements can be made in accident investigations.

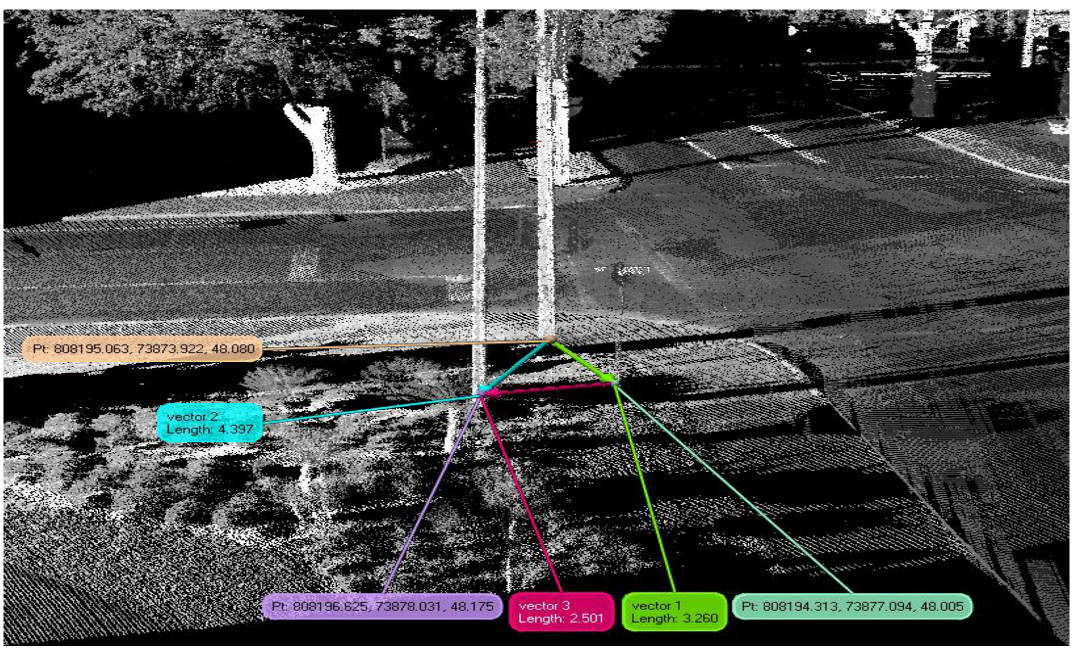

Figure 6-5. Simple measurements between poles at an intersection. Measurements done with Polyworks™ IMInspect. Note that coordinate data is also displayed.

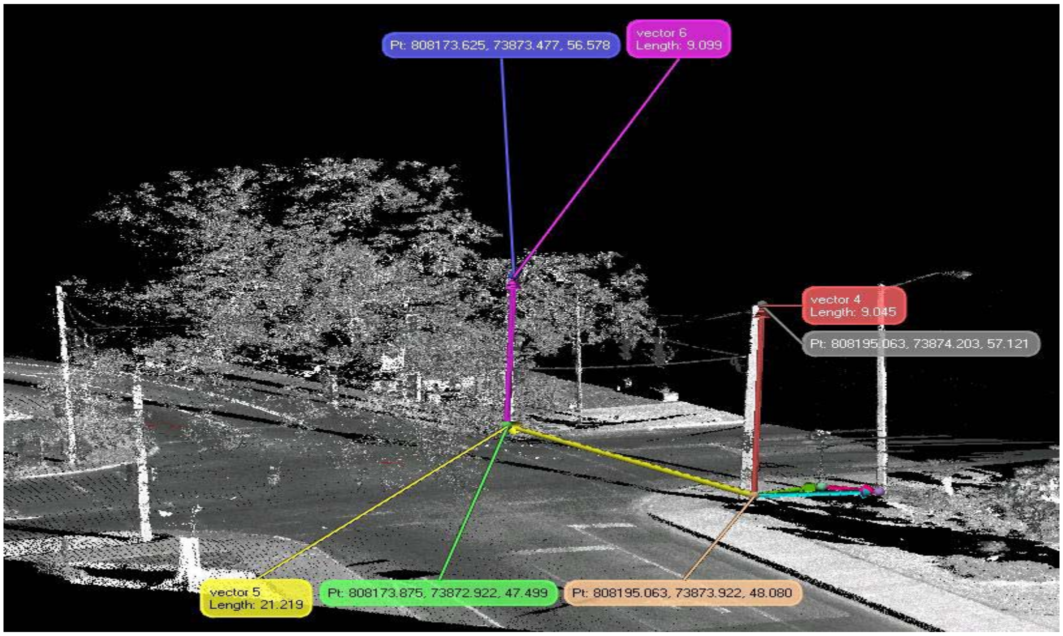

Figure 6-6. Typical measurements that can be done with an LSI's 3D dataset.

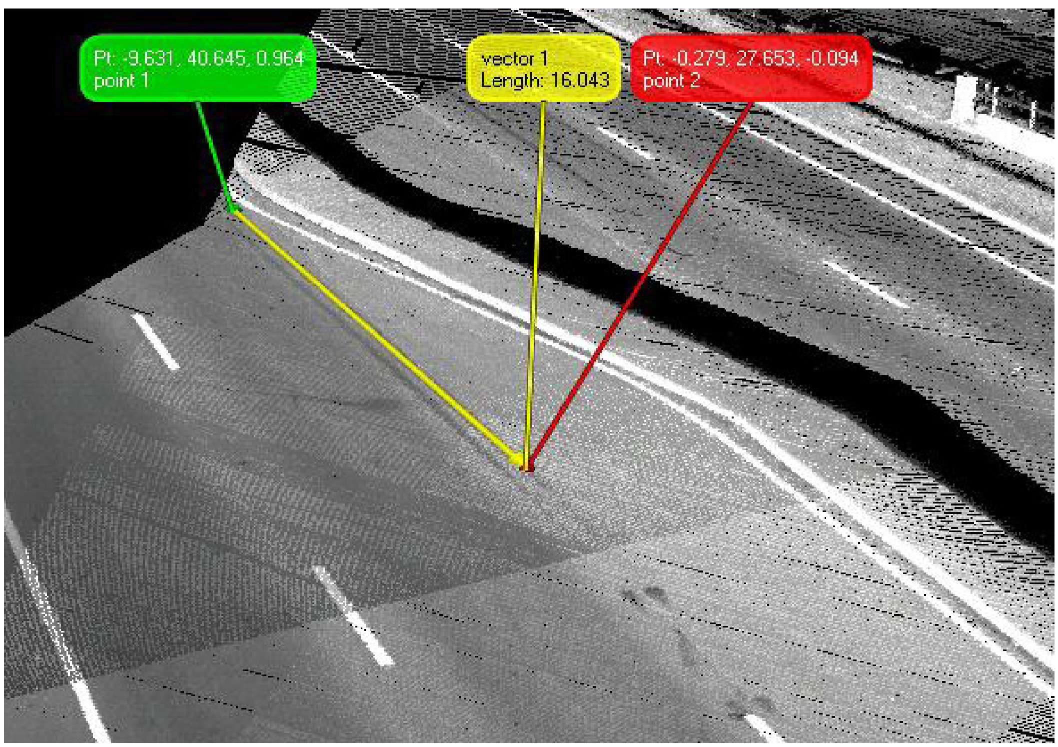

Figure 6-7. A measurement made on a skid make from LSI data.

Using Intensity Data for Object Classification

As stated earlier, the ability to use the intensity data to classify objects in a scan would make an LSI system more valuable to the user. IMInspect has a tool which allows the user to pick individual points and view the intensity data for that point. Using other tools within IMInspect, the user can select an intensity range centered around the individual point intensity that is desired and have the program select all points within that range.

An attempt to classify skid marks in the parking lot scan was made but the effort was unsuccessful. Since intensity data are dependant on the angle of incidence and the distance to the object, it is hard to assign a certain intensity to a particular object within the scan. Using the IMInspect module, a point can be selected within the skid mark and coordinate data as well as luminance (intensity) data can be viewed. In theory, one could use the intensity of the point within the skid mark to locate all skid marks within the scan. However, due to different angles of incidence and reflectance properties of other objects in the scan, it is possible that other points that are not 'skid mark' points can have the same intensity.

Figures 6-8 thru 6-10 show the process of selecting points that are to be used in classifying a set of skid marks. In this process, a dark point within the skid mark was selected as well as a light point (Figure 6-8). These two points were used to set the inclusive intensity values in the point selection application (Figure 6-9). And finally, IMInspect changes the color of all points within the set intensity range to red (Figure 6-10), showing that the intensity values can not be used for classification purposes. This is because the intensity values are based on the range, angle of incidence, and reflectance of the surface being scanned. Another contributing factor could be the narrow wavelength that is used in LSI systems as opposed to the airborne systems.

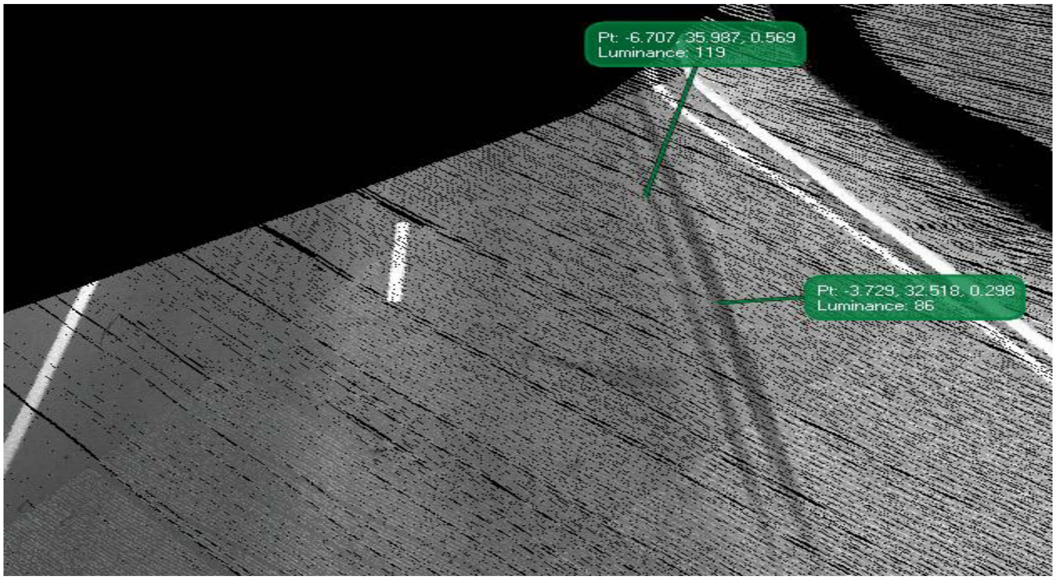

Figure 6-8. Coordinate data and luminance (intensity) data for points selected within the skid mark.

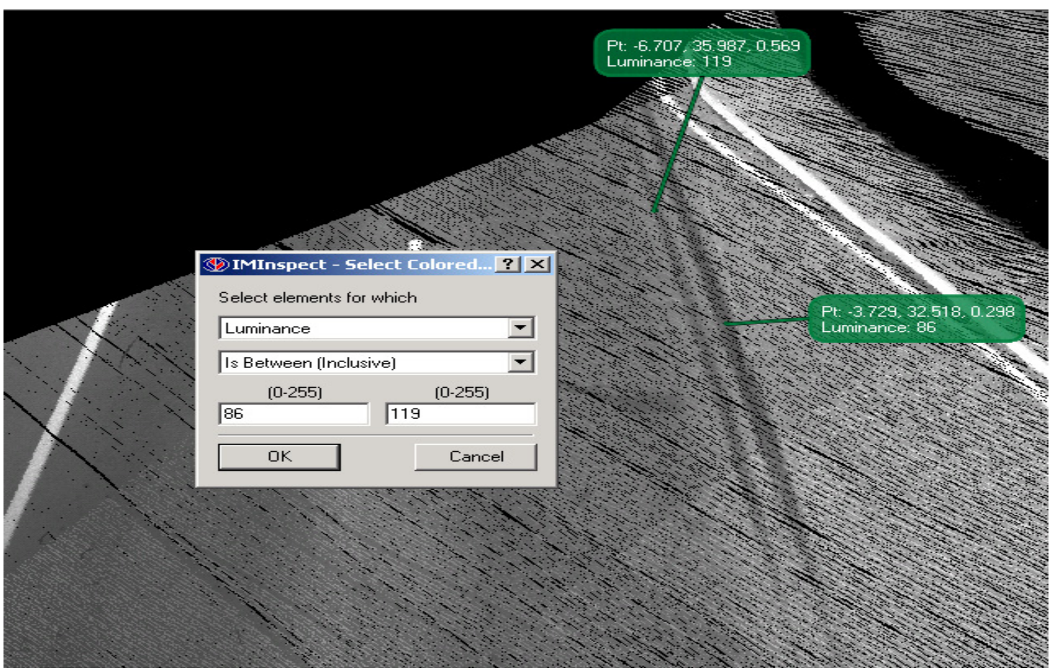

Figure 6-9. Selection of intensity range values for data classification.

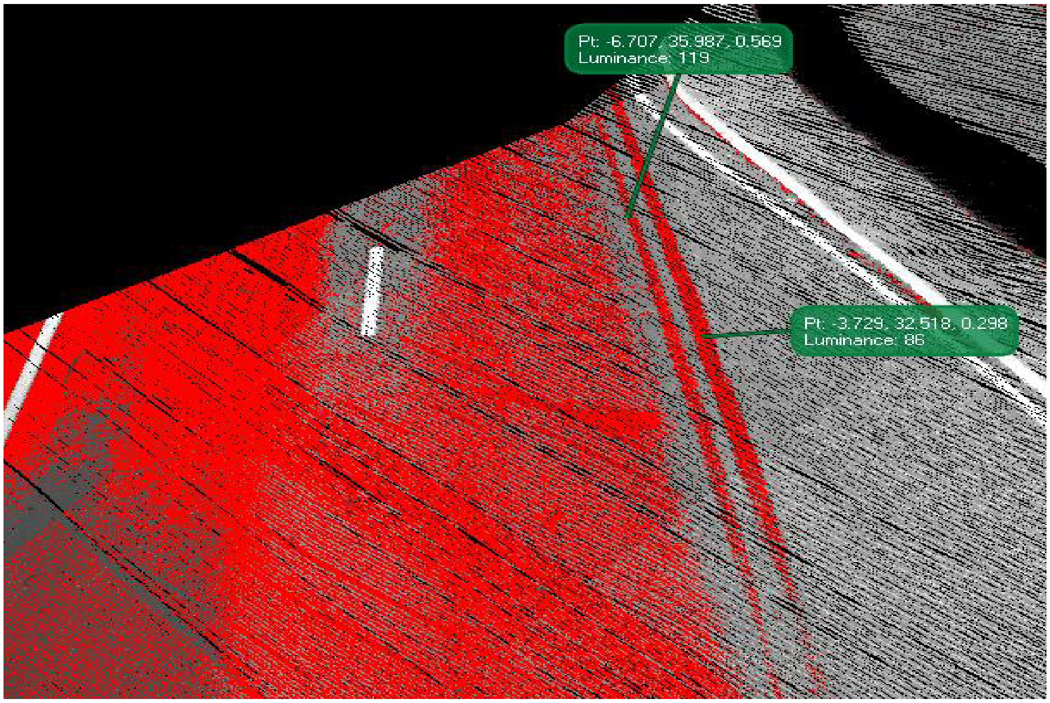

Figure 6-10. All points that were selected with the set range values

CHAPTER 7
SUMMARY

Conclusions

This thesis focused on the technology and applications of LSI systems. The systems greatly enhance the quality of survey data with the rapid rate of data collection. The rate of data collection that the systems employ allow more data to be collected than in a traditional survey. The final survey creates a three dimensional image of the data putting the dimensions of the scene into perspective.

The research conducted only scraped the surface of the unique uses of the ILRIS-3D. As more people become acquainted with this method of surveying, more uses will emerge. Furthermore surveys will be conducted thus making laser scanning a popular surveying method among surveyors and engineers.

Based on data collected for this thesis, it was observed that using a LSI system proves beneficial for survey applications in which locating features can be dangerous for surveyors. Using the LSI system to locate features along roadways can be advantageous to surveyors and civilians alike. Without the requirement of closing lanes to collect data, users of the LSI technology put themselves in a safer position to collect data without impeding the flow of traffic.

This technology is not yet at a point to conduct typical lot surveys but the possibility is present. Reflectors, such as those used by other systems for alignment purposes, would be necessary to locate property corners accurately. Implementing reflectors into scans would allow the user to accurately locate identifiable objects and aid in merging scans to one another. Cyrax uses such reflectors for merging data because the in-house software used by the system requires them. The software used by Optech only requires at least 3 common points to be visible in each scan for merging.

Recommendations

While researching LSI systems by means of the ILRIS-3D, several techniques and lessons were learned. Recommendations will be made to pass along some of that information in this section. These techniques and lessons may pertain to other LSI systems, but are unique to the ILRIS-3D.

Overlapping scans is a definite measure to be taken. Without the proper amount of overlap, merging scans is almost impossible because of the searching techniques used by Polyworks™. It is useful to have a laptop on site as scans are taking place in order for data to be downloaded after each scan. With a laptop the user is able to check data for the proper amount of overlap by means of merging previous scans while the scanner is scanning. If gaps are noticed in the data, the area of the gaps can be re-scanned in an attempt to complete the dataset.

When scans are being conducted of the ground or roadway, it is advantageous for the unit to be elevated as it will enhance the quality of the data. Several scans depicted in this thesis were taken from the bed of a pick-up truck. The height of the laser mounted on a tripod in the back of a pick-up truck was approximately 9-10 feet above ground level. Objects with a surface perpendicular to the X-Z plane of the ILRIS-3D give better returns than objects with a surface parallel to the X-Y plane.

Although it was mentioned earlier that the ILRIS-3D can be mounted to a tribrach, it is not recommended. Using the system when it was mounted on a tribrach introduced the possibility of an unstable platform. The tribrach allowed the ILRIS-3D to swivel from side to side during the scan when the ILRIS-3D was in a tilted position. Cardboard was used between the tribrach and the ILRIS-3D as a wedge in an effort to stop the movement.

Researchers at UF added straps to the ILRIS-3D to aid in handling the unit. The ILRIS-3D used for research in this thesis did not have handles thus making it difficult and unstable to handle. Handling the system is very difficult without handles because of the care needed in protecting the front glass of the scanner along with the expense of the system.

Viewing the VGA screen on the back panel of the ILRIS-3D is difficult in sunlight. Having a view hood or a shading device would be useful for viewing the screen. Other viewing options are being researched by Optech, Inc. to resolve this issue.

APPENDIX
LASER SCANNING AND IMAGING SYSTEMS SPECIFICATIONS SHEET

Tripod Mounted Commercial Laser Scanners - Specification Comparison	Optech	Cyra	Riegl	Mensi
Model	ILRIS-3D	Cyrax 2500	Z210	GS100
Retail Price	US$150K	US$140K	US$80K	US$125K
Technology	2-axis beam steering scanner	2-axis beam steering scanner	Axial step, rotating mirror rangefinder	Single axis scanner on rotating platform
Eye-safety	Class 1, FDA / IEC - All ranges all conditions	Class II, FDA / IEC	Class 1 or Class 3B depending on configuration and scanning conditions	Class II Laser,(EN 60825:1994)*, International Standard
Laser Type	1550 nm pulsed	532 nm pulsed	904 nm pulsed	532nm pulsed
Spot Size @ 50 m	21 mm	6 mm	200 mm	3mm
Data Rate	2000 points/s	1000 points/s	9300 points/s	1000 points/s
Range (4% / 20% target)	350m to 4% target - see table for others	50 m / 100 m	150 m to > 10% target	
Range Resolution	1 mm	1 mm	Not quoted	
Target Registration Accuracy (±)	2-6mm	2-6 mm	Not quoted	Not quoted
Modeled Surface Precision	3-5 mm	2-4 mm	Not quoted	Not quoted
Scanner FOV - Horizontal	±20° Programmable	±20° Programmable	80° Fixed	360° Programmable
- Vertical	±20° Programmable	±20° Programmable	340° Variable	60° Programmable
Spot spacing 50 m / 100 m (low res and high res)	8 mm / 16 mm - low; 1.3 mm / 2.7 mm high res	0.5 mm / 1 mm	20 cm / 40 cm	
Angular Resolution (low res / high res) - Horizontal	0.0098° / 0.0001° (170 / 26.5 μrad)	0.00057° (10 μrad) in registration mode	0.24° (4.2 mrad)	0.0018° (6.6 arc second)
Angular Accuracy - Horizontal	0.0024° (43 μrad)	unknown	0.036° (630 μrad)	
- Vertical	0.0024° (43 μrad)	unknown	0.018° (315 μrad)	
Video Targeting	480X480 Color Resolution	400X400 Color Resolution	None	768X768 Color Resolution
Display	Integral - with targeting and remote	Computer Monitor	Computer Monitor	Real-Time Video Transmission
Control	Hand-held Remote (Palm Pilot)	Notebook Computer	Notebook Computer	PDA available soon
Power Input	18-36 VDC - Battery or AC Adapter	24 VDC - Battery or AC Adapter	11 to 18 VDC, PC not incl.	24V nominal, 110/240V - 50/60Hz, AC or DC
Battery / Battery Life	28.8 V NiMH 200 / 400 WHr battery combinations / provides > 5 h scan time.	Sealed Lead Acid / 4 hrs. @ 20°C	Sealed Lead Acid / Not quoted	
Power Consumption	75 W	125 W	45 W	3 hour and a 2.4 hour battery
Operating Temp	0° to 40° C	0° to 40° C	-10° to 50° C	0° to 40° C
Storage Temp	-20° to 65° C	-25° to 65° C	-20° to 60° C	-20° to 50° C
Environment	Nema 4X water and Dust proof - suitable for operation in direct sunlight rain & snow	Dry weather	Dry weather	IP 63 rating: Heavy rain, IP 40 rating: Light to moderate rain
Product Approvals	CE Marked	None quoted	None quoted	
Size (L x W x H) - Scanner	315 x 315 x 200 mm	472 x 337 x 430 mm	210 (dia) x 435 mm	380 x 420 x 280 mm
Size (L x W x H) - Auxiliary Equip.	None	312 x 280 x 238 mm	Not quoted	Not quoted
Weight - Scanner	12 kg	28 kg Scanner and power supply	13 kg	17.5kg scanner and power box
Accessories	Carry case Batteries and charger Palm PDA PC Flash Card Cables and Cords	Carry case Battery and charger Tripod and mount Cables and power cords Special targets		Power box Transportation box Connection Cables

Table courtesy of Optech, Inc., Toronto, Canada.

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BIOGRAPHICAL SKETCH

Devin Robert Drake was born March 25, 1977, in Atlanta, Georgia, to Robert L. and Phyllis B. Drake. He graduated from Landmark Christian School in May 1995 and started his college career at Southern Polytechnic State University in Marietta, Georgia. He graduated with a bachelor degree in surveying and mapping in December of 1999, and continued his education graduating with a bachelor degree in civil engineering technology in December 2000. Although Devin was introduced to surveying at Southern Tech, he furthered his surveying knowledge by working with Integrated Science and Engineering for two and a half years before leaving to work for Hoffman & Company, Inc., in Smyrna, Georgia. After receiving his civil engineering degree from SPSU, Devin was influenced by Matt Wilson, a University of Florida alumnus, to pursue a Master of Science degree at the University of Florida. After graduating from UF, Devin plans on a career in surveying with an interest in airborne and land based surveying applications. The next goal in his professional career is to become a licensed Professional Land Surveyor in the state of Georgia.