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New and Emerging Inspection Technologies for Vegetation Management

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ABSTRACT

Recent regulatory changes and budgetary pressures have prompted utilities to seek a more in-depth understanding of the terrain along their transmission line corridor rights-of-way (ROW) and the vegetation on that terrain. Vegetation inspections play an important role in acquiring this information and in avoiding costly vegetation-related outages. While the methods by which the inspections are conducted vary from utility to utility, some form of periodic inspection of transmission ROW is required to manage encroaching vegetation.

Traditional methods of transmission line vegetation inspection have generally relied on human observation and data recording, whether performed from the ground or by airborne methods. Regulatory changes and budgetary pressures have prompted utilities to seek improved information of the terrain and vegetation along their transmission line corridor ROW. New approaches to vegetation inspection take advantage of sophisticated recording equipment, global positioning system (GPS) technology, and software.

This report provides information on state-of-the-art inspection technologies and services (new and emerging) available for utility use.

Keywords
Transmission line inspection
Vegetation inspection

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1
INTRODUCTION

The blackout of August 14, 2003, left more than 50 million people in the north east USA and Canada without power. The blackout led the Federal Energy Regulatory Commission's (FERC) North American Electric Reliability Corporation (NERC) to develop Standard FAC-003, a "Transmission Vegetation Management Program," which was adopted in 2005 (1). The program is designed to improve the reliability of the electric transmission system, which requires utilities to validate their vegetation management practices.

Traditional methods of transmission line vegetation inspection have generally relied on human observation and data recording, whether performed from the ground or using airborne methods. Regulatory changes and budgetary pressures have prompted utilities to seek improved information of the terrain and vegetation along their transmission line corridor rights-of-way (ROW). New approaches to vegetation inspection take advantage of sophisticated recording equipment, global positioning system (GPS) technology and software.

The objective of this report is to provide information on state-of-the-art inspection technologies and services available to electrical utilities. In this investigation information was gathered from technology and service providers via phone and email. Several technologies and methods to approach data management were identified and documented. Please note EPRI does not specifically endorse vendors.

The report provides the findings and includes the basis for future technology development.

The outline and approach for this document are as follows:

- Literature search and review
- Technology identification and description
- Gap assessment, including future research identification

2
LITERATURE REVIEW

Available literature suggests utilities around the world are investing in new vegetation inspection technologies to reduce costs and outages, and meet increasing power reliability demands. This is due in part to the extensive blackout of August 14, 2003 in the northeastern United States.

Research into terrain analysis techniques demonstrates that in recent years there has been a marked increase in the development of advanced ground inspection technologies and software that yields high resolution ground detail. These advances are being incorporated into high accuracy terrain and topographical analysis systems.

The literature search highlighted the following inspection approaches and technologies:

- Hyperspectral imagery systems/devices
- Satellite imagery
- Mobile LiDAR systems
- Aerial photography/imagery
- Aerial/Airborne LiDAR inspection systems
- Robotic systems
- Vegetation growth algorithms
- Handheld laser inspection devices
- High Spatial Resolution LiDAR
- Work management systems
- Integrated approaches using GPS, GIS, LiDAR, algorithms, work management systems, field assessments and verification of results
- Camera imagery

A matrix of the technologies with applications is given in Table 2-1. This matrix summarizes various technologies that are addressed in the report and maps them to categories of sensing applications.

A detailed list of references is provided in Appendix A, B, and C. Appendix A provides utility related articles, Appendix B a1ist of general articles and Appendix C vendor information.

Table 2-1
Summary Mapping of Sensor Technology to a Transmission Line Vegetation Inspection Application

	High Resolution Airborne LiDAR System	**Mobile LiDAR System**	**Unmanned Robotic Crawler**	**Integrated Handheld Laser System Technologies**	**Laser Range-finders**	**Hyper-spectral Imaging**	**Satellite Image Sensing**
Application	Chapter 3.1	Chapter 3.2	Chapter 3.3	Chapter 3.4	Chapter 3.5	Chapter 3.6	Chapter 3.7
Clearance							
Vegetation	x	x	x	x	x	x	x
Avian	x	x	x	x			
Encroachment	x	x	x	x	x	x	x
Line Sag	x	x	x	x	x		

3
INSPECTION TECHNOLOGIES

Light Detection and Ranging (LiDAR)

A LiDAR instrument transmits light to a target where a portion of the light is reflected back to the instrument. The time for the light to travel to the target and back to the instrument is used to determine the distance to the object or target. The simplest LiDAR instruments are single point distance rangefinders. Their accuracy varies depending on the environment, elevation, and speed at which the inspection is done.

In more complex LiDAR systems an optical scanner is used to direct the laser beam in a fan or raster pattern and the distance is measured over a line or area. Line scanning systems are often used on airplanes or helicopters to measure the profile of a strip under the flight path. New systems are combined with GPS/Inertial Navigation Technology (INT) to ensure stability and uniform measurements. During flight a scanning laser rangefinder measures the distance to the ground thousands of times per second as it scans below the aircraft.

These systems have a variable field of view, up to a maximum of 75 degrees, to match the ground footprint of a conventional camera system and can operate up to 25,000 feet/7,622 meters above the ground. Some systems, like RIEGL, are equipped with an integrated high-performance 80-megapixel camera, with an optional second integrated camera, making it suitable for an aerial survey of ultra-wide areas and complex urban environments (2). An example of the integrated sensor is shown in Figure 3-1.

This sensor allows for up to 800,000 measurements per second, with an effective rate of about 532,000 measurements per second on the ground. It can scan 116 square miles/300 square kilometers per hour at a range of 6560 feet/2000 meters flying at a speed of 110 knots/203 km per hour. An example of the RIEGL LMS-Q680i mounted on a helicopter is shown in Figure 3-2 and an example of a power line point cloud in Figure 3-3. This system is used by GeoDigital.

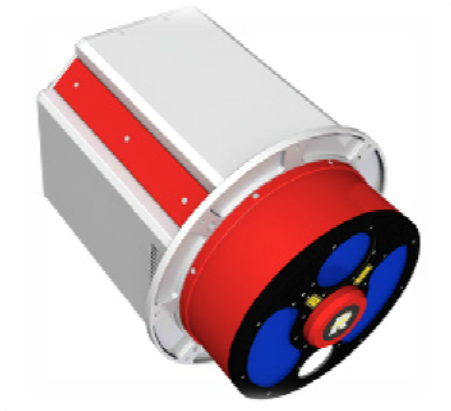

Figure 3-1
The RIEGL LMS-Q1560 fully integrated airborne scanning system (courtesy of RIEGL).



Figure 3-2
The RIEGL LMS-Q680i mounted on a helicopter (courtesy of RIEGL).

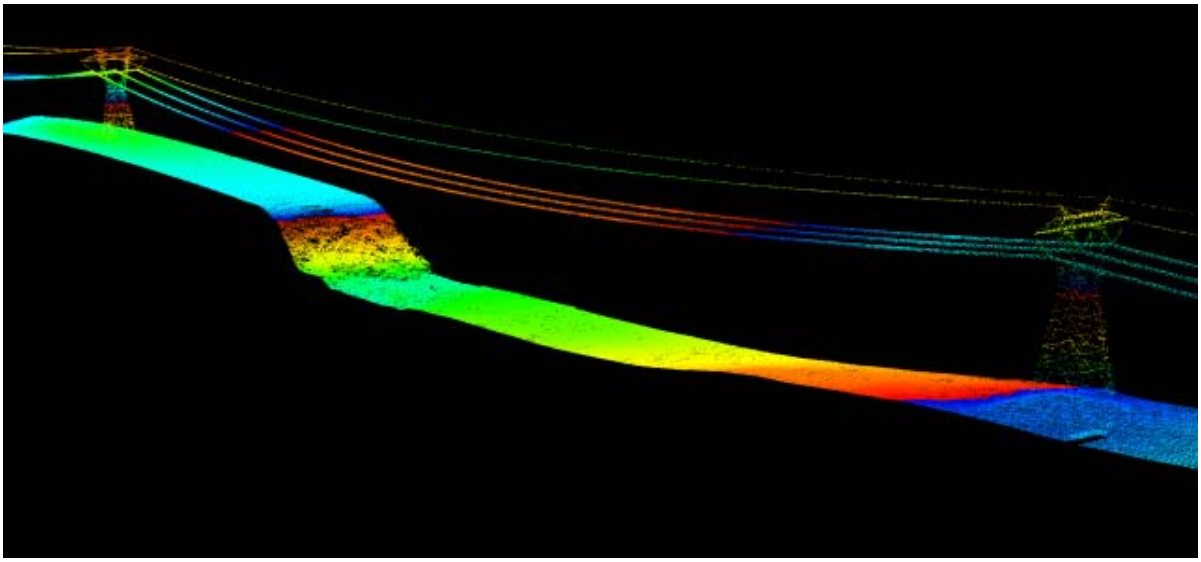

Figure 3-3
A screenshot of the power line point cloud using the LMS-Q680i (courtesy of RIEGL).

Other systems like the TopEye Mk III LiDAR unit by Blom (Figure 3-4) is a proprietary LiDAR unit used by Aerotec, North America and the Belgian company Eurosense Belfotop N.V., and most recently Airborne Laser Solutions in South Africa (3). The TopEye Mk III LiDAR unit is not available to other LiDAR data providers in the US.

The main components of the TopEye are the optic transmission (laser emitter) and reception element (sensor, receptor photodiode), and the control, viewing, storage and ancillary systems. t also includes an Inertial Measurement Unit (IMU) that improves performance by determining the aircraft's orientation, a Differential GPS (DGPS) receptor to calculate the position of the aircraft with precision, and a high resolution 39 Mega Pixel (MP) Applanix Rollei AIC digital camera. All these elements are embedded in a housing element, also called "pod," that is installed under the belly of the helicopter with the laser orifice pointing to the ground. The GPS receptor is installed at the tail of the helicopter to improve the signal reception capability of the unit. The control, power supply, and visualization and data storage elements are installed inside the helicopter.

Two GPS receptors are used to locate the position of the helicopter, and therefore of the LiDAR, camera and IMU. One receptor is placed on the ground, statically, to operate as base station and the other in the aircraft carrying the LiDAR system. The differential corrections to be applied to the GPS in the helicopter are taken from the data captured by the stationary ground station.

The Mk III has a patented elliptical scan pattern (Figure 3-5) that helps to detect small wires that cross transmission corridors and can penetrate vegetation for better ground definition. The TopEye unit has been mounted both on fixed-wing and rotor-wing applications as shown in Figure 3-6. Table 3-1 shows the main technical characteristics of the TopEye Mk III LiDAR.

The TopEye system can be used on slopes with vegetation due to the high density of the LiDAR points. An example of the LiDAR data resolution that may be obtained in areas with steep slopes and thick vegetation is shown in Figure 3-7.

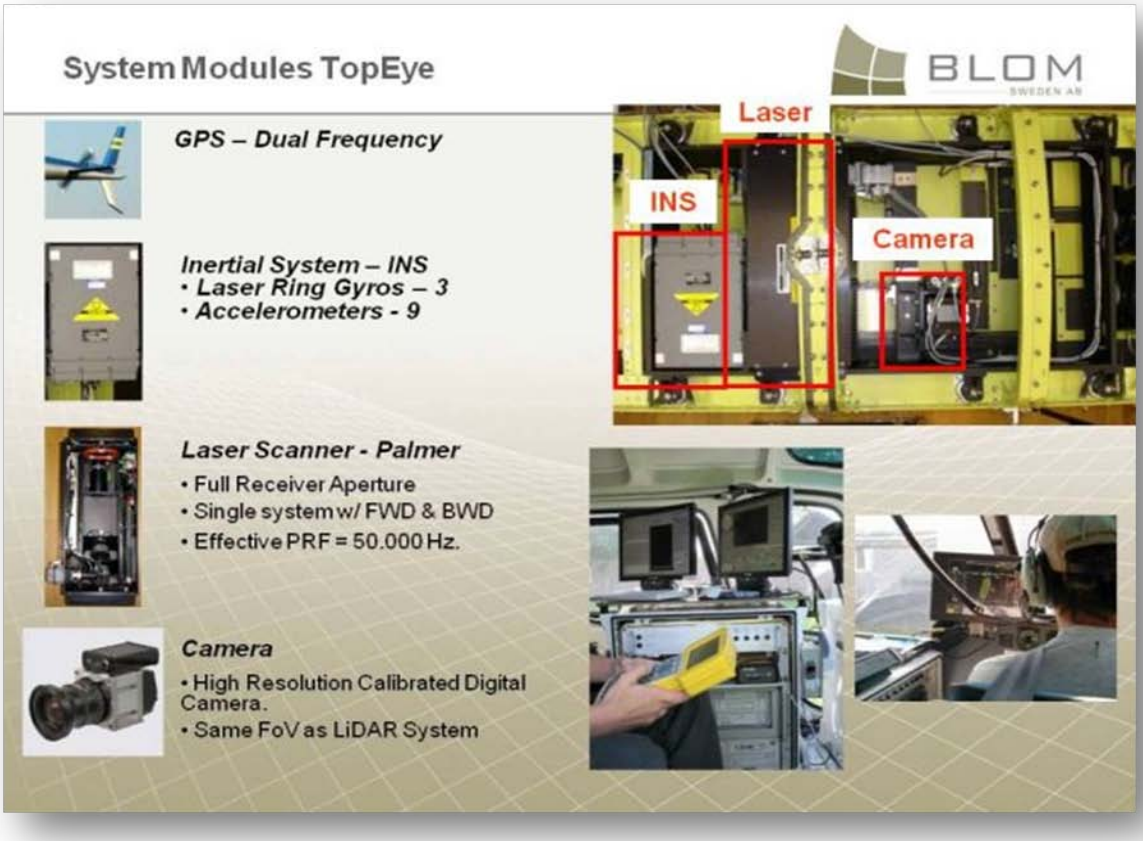

Figure 3-4
The complete hardware system of the TopEye Mk III (courtesy of Blom).

Table 3-1
The main characteristics of the TopEye Mk III LiDAR system (courtesy of Blom).

Parameter	Value
Operational altitude (AGL), altitude of flight above ground	Between 70 and 700 m of relative altitude
PRF, Pulse Repetition Frequency	210 kHz aggregated (50,000 Hz frp, the Palmer scanner + 160,000 Hz saw-tooth scanner)
Range capture (Number of measurements taken per pulse emitted)	Up to 4 returns including the first and the last
Intensity capture	1 intensity reading per return
Scan angle	Up to ±30º
Scan speed	Between 36 and 130 Km/h
Swath width	73 to 812 m
Resolution of camera images	GSD Between 1 and 7 cm/pixel
Density of LiDAR data per pass	Between 10 and 100 pts/m2
Vertical precision	Below 5 cm typically ±1-sigma

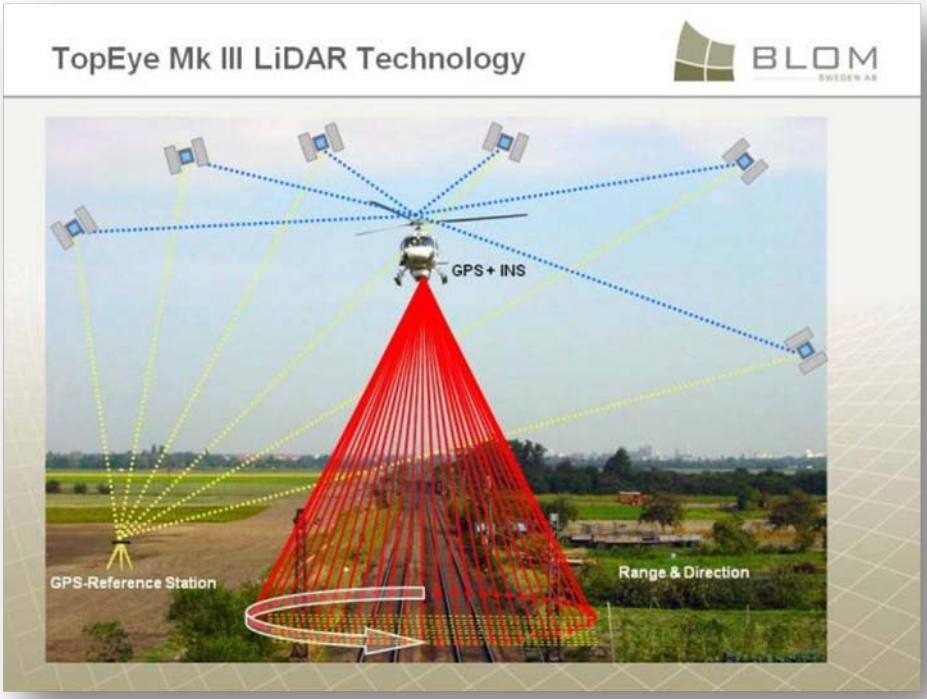

Figure 3-5
The TopEye Mk III LiDAR elliptical scan pattern (courtesy of Blom).



Figure 3-6
The TopEye Mk III device mounted on both rotor and fixed-wing applications (courtesy of Blom).

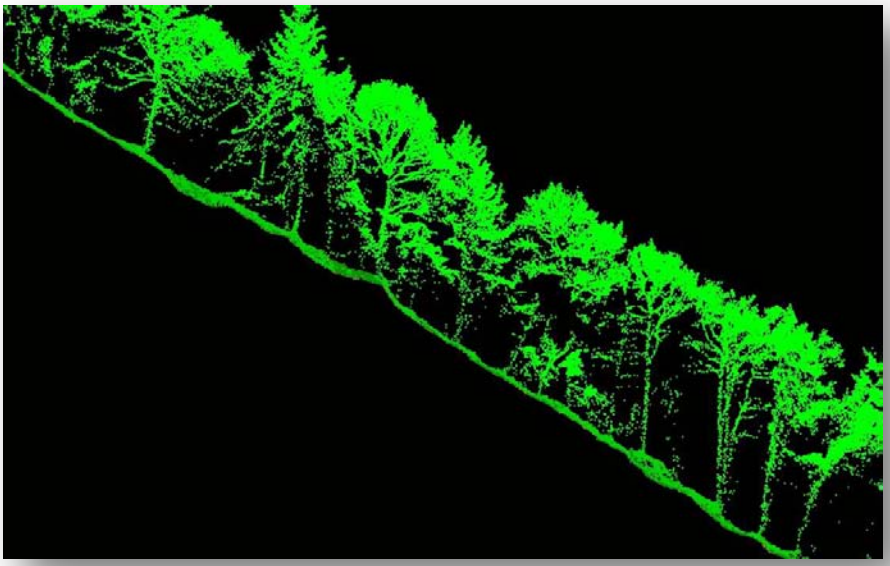

Figure 3-7
An example of data taken with the TopEye Mk III system on a site with a steep slope, covered by thick vegetation (courtesy of Blom).

New Developments with Airborne LiDAR

Many utilities use LiDAR to perform detailed surveys of transmission lines. Some utilities use LiDAR surveys together with engineering software, such as Power Line System Computer Added Design and Drafting (PLS-CADD), for vegetation encroachment and clearance for conductors.

Several vendors use LiDAR and other inspection technologies to determine conductor to vegetation clearances. These approaches need to be evaluated to determine their accuracy and feasibility to meet the North American Electric Reliability Corporation (NERC) regulatory alert.

Mobile mapping schemes and static terrestrial 3-D scanning have been incorporated in airborne LiDAR systems for transmission line applications. Experts are no longer needed to apply the data collected with LiDAR systems. Manufacturers have developed software that can integrate the LiDAR data into PLS-CADD software to show the location of structures, conductors, insulators and vegetation on overhead lines. Companies such as Aerotec, Clearion, GeoDigital, and Pictometry offer integrated inspection approaches. These are discussed in the next chapter (4). Typical accuracy of LiDAR systems for overhead transmission applications is approximately ± 1-inch/± 2.5 cm, depending on environmental conditions, the rate of data taken, speed of the aircraft, and elevation of the aircraft.

Utility Application of LiDAR

LiDAR systems are being used to detect encroachment, vegetation, conductor position, structures, and the location of components such as insulators. The technology is improving with higher data densities and smaller units and has evolved from a basic mapping tool to a sophisticated field data-collection system. LiDAR systems have migrated to being a technological necessity for transmission line maintenance.

LiDAR is also used by electrical utilities to map their rights-of-way and determine conductor position. They do this on an infrequent basis and use the results to design new lines or determine whether their lines meet the NESC's requirements for conductor to ground clearance. An important factor when processing the LiDAR data is the conductor temperature at the time of the survey. A number of approaches are used to determine the temperature, for example, positioning weather stations along the transmission line and calculating the conductor temperature at the time of the survey. Uncertainty remains as to the applicability of this approach.

Airborne LiDAR systems have been joined by mobile mapping schemes and static terrestrial 3-D scanning for application on transmission lines. These 3D applications are also starting to be used as an analytical tool in the substation. Note that for vegetation management applications not all LiDAR systems are created equal (3). Final deliverables provided to the customer vary from vendor to vendor and sometimes further processing is needed to make the data useful. It is therefore important to specify the type and format of information required. This could include requesting integrated information using LiDAR, PLS CADD and vegetation growth prediction.

Some smaller LiDAR systems are being deployed on other vehicles such as line-crawling robots and Unmanned Aerial Systems (UAS).

Future of LiDAR

Aerial LiDAR systems are accepted as a means of creating accurate digital elevation and terrain data. EPRI has evaluated the accuracy and feasibility of different vendor approaches using LiDAR, Infrared (IR) technologies and the integration of software to predict the sag of the line under different conductor temperatures and operating conditions. The effectiveness of the different approaches was inconclusive.

It is critical to the success of a LiDAR project that a customer knows how the system filters data and how it discriminates among vegetation, wires and other objects. Current commercial LiDAR processing software does not provide one magic filter for all terrains, vegetation, buildings or other man-made structures. For this reason, after automated filtering, human editing is typically required to ensure all the data anomalies have been removed or corrected. The manual processing is labor intensive and quality assurance ultimately dictates the pace at which accurate data can be provided to the client.

LiDAR Application Gaps

Gaps still exist in the application of LiDAR, especially in the integration of LiDAR data with other inspection technologies. One example is the integration of LiDAR with Infra-red and analytical tools to measure conductor temperature, vegetation clearances, vegetation growth, and integration into PLS-CADD software system. Another example is the integration of vegetation growth algorithms of trees and ground vegetation as a part of the LiDAR inspection. Another gap is that the format and type of data or information provided by vendors varies. Guidelines are needed to specify and procure LiDAR services.

Research Needed Based on the Gaps

The main gap is specifying the output data required from the vendor. It is the art of data processing and the ability to add value to the information that ensures utilities obtain what they need. The data processing function is most critical in creating the LiDAR end product. EPRI intends to continue to develop methodologies for utilities on what data and features to ask for,

and may provide a workshop to accomplish a better understanding of the different technologies and how they may be integrated. EPRI also intends in the future to provide guidance on how to specify and procure LiDAR services.

Mobile LiDAR System

Airborne LiDAR systems have been joined by mobile mapping schemes and static terrestrial 3-D scanning for application on transmission lines. Mobile LiDAR systems can be applied on transmission ROW in cities and urban areas and are being considered for several different applications such as:

1. Unmanned Aerial Systems
2. Robotic platforms
3. Cars

An example of the new compact, light-weight systems is the one developed by Velodyne LiDAR, Inc. located in Morgan Hill, CA. The Velodyne 3D, Real-Time LiDAR sensor is used in mobile applications such as measuring distance and the reflectivity of objects in the way or encroaching on the object of interest. The principle of operation is the same as in airborne systems discussed earlier. Velodyne has two models; a HDL-32E (Figure 3-8) and a HDL-64E S2 (Figure 3-9) (4).

The HDL-32E includes 32 lasers that allows for real-time analysis, highest point density of 700,000 points/sec and up to 1200 RPM with 80-100 meters/264-328 feet radius, 40-degree vertical field of view and typical accuracy of ± 2 cm/0.8 inches. The HDL-32E LiDAR sensor is small, lightweight, and features up to 32 lasers across a 40-degree vertical Field of View (FOV). The HDL-32E measures only 5.7 inches/14.5 cm high x 3.4 inches/8.6 cm in diameter, and weighs less than 2 pounds/0.9 kg.

The HDL-64E S2 includes 64 lasers that fire the laser pulses almost simultaneously recording data for future analysis. It has a full 360-degree high field of view (HFOV) by a 26.8-degree vertical FOV. Velodyne's multiple lasers allow for real-time analysis, highest point density of 1,300,000 points/sec and up to 1200 RPM with a range 120 meter/394 feet radius, 26.8-degree vertical FOV and typical accuracy of ± 2cm/0.8inches. The HDL-64E S2 is 10 inches tall and has an outside cylinder diameter of 8inches, and weighs less than 29 pounds/13.2 kg.

Velodyne is a hardware provider with the majority of its customers providing solutions to electric utilities. Three of Velodyne's customers are integrating the HDL-32E and HDL-64E S2 devices into specific applications for the task of inspecting the ROW for vegetation violations. Mandli Communications in Madison WI, LiDAR USA in Decatur AL, and Topcon Positioning Systems Inc. in Livermore CA have all developed a mobile application using the HDL-64E S2 for inspecting transmission ROW. Topcon has adapted a vehicle with the IP-S2 HD mobile mapping system as shown in Figure 3-8 for ROW inspection. This IP-S2 HD system integrates both software and hardware into a mobile inspection system. Topcon is working with utilities to maximize efficiency and production. Figure 3-9 and Figure 3-10 show examples of ROW inspections using LiDAR management software from Orbit Geospatial Technologies, a Topcon partner. These new mobile systems show great promise and will continually be upgraded and enhanced with experience (5).



Figure 3-8
HDL-32E (courtesy of Velodyne).

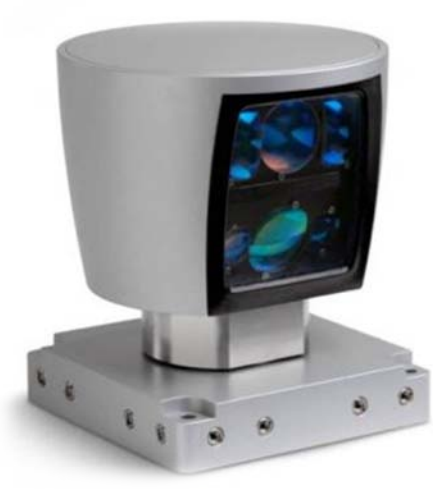

Figure 3-9
HDL-32E device (courtesy of Velodyne).



Figure 3-10
Topcon's integration of the HDL-64 S2 into the IP-S2 HD mobile inspection system (courtesy of Topcon).

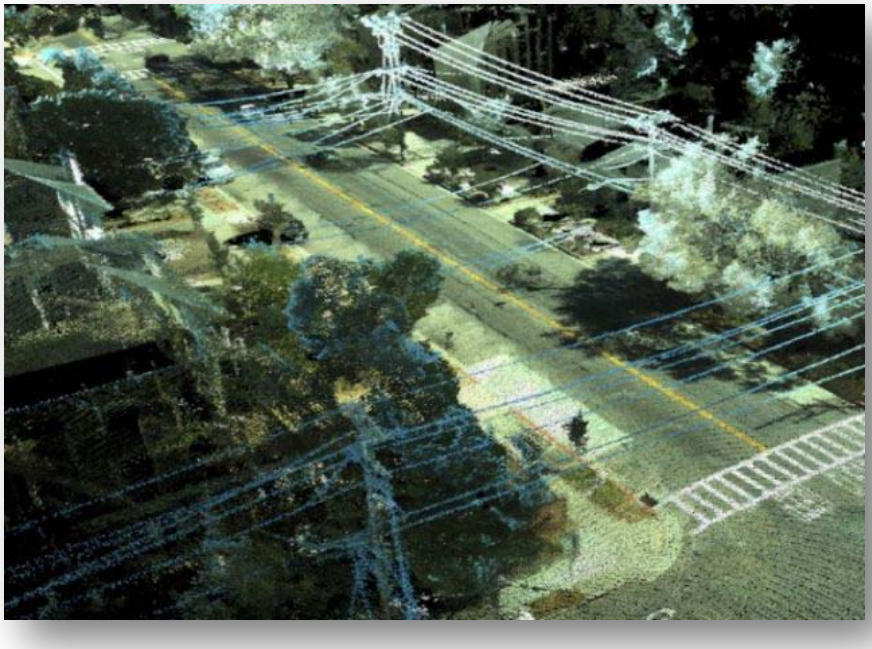

Figure 3-11
LiDAR view using the HDL-64E S2 (courtesy of Topcon and Orbit Geospatial Technologies).



Figure 3-12
LiDAR view using the HDL-64E S2 on mobile truck platform (courtesy of Topcon and Orbit Geospatial Technologies).

New Developments with Mobile LiDAR

Companies are looking at mobile LiDAR as an option. Companies such as Mandli, Topcon, and LiDAR USA are developing methodologies for inspection of ROW. These mobile LiDAR integrated systems are also being used to try and predict the temperature and location of the conductor with respect to the ground and vegetation. Claims of typical accuracy of existing LiDAR systems for Overhead Transmission are reportedly ± 1 inch/± 2.54 cm depending on environmental conditions, the rate of data taken, and the speed of the vehicle. EPRI is also developing a robotic system that will move along the shield wire with a high resolution camera and an IR camera.

Future of Mobile LiDAR

Mobile LiDAR systems are still in their infancy and their value to utilities has not totally been realized. Mobile LiDAR applications are still being developed for vegetation management. As more trials are completed this technology may find its place in the vegetation inspection process. Also, the cost and value of mobile LiDAR versus airborne LiDAR needs to be addressed for specific applications.

EPRI intends to evaluate the accuracy and feasibility of using mobile LiDAR, and the integration of software for the electric utility industry.

Gaps for LiDAR in Transmission

The main gaps are the integration of LiDAR and other technologies into a meaningful product and providing utilities with information not just data.

Research Needed Based on the Gaps

The main gap is validating the application of mobile LiDAR for vegetation inspection. As applications grow EPRI intends to evaluate different technologies, services and methodologies.

EPRI Transmission Line Inspection Robot

The application of robotics for transmission line inspection is not new. The earliest example found (1991) traveled along the overhead ground cable from tower to tower (6). Subsequently several robotic crawlers have been developed for specific tasks such as conductor or splice inspection.

Recently a robot that attaches directly to the transmission line shield wire or ground wire has been developed by EPRI (7). The transmission line inspection robot, known as Ti, is designed to deliver actionable information. Ti is permanently installed on a transmission line shield wire (Figure 3-13). It traverses structures and obstacles, e.g. marker balls, utilizing bypass systems that are permanently installed on the transmission line. The robot automatically disconnects itself from the shield wire and connects itself to the bypass system (Figure 3-16). Once it is has bypassed the obstacle or structure, it returns to the shield wire. These bypass systems are installed at the time of construction or may be part of the line hardware itself. Ti has high-definition visual and infra-red spectrum cameras with advanced image processing to inspect the ROW and component conditions. Ti is also equipped with a LiDAR sensor to measure conductor position, vegetation, and nearby structures. It will be able to determine clearances between conductors, trees, and other objects in the ROW. The cameras will also be able to compare current and past images of specific components to identify high-risk conditions or degradation (8).

Ti's on-board systems intend to support autonomous inspection of corridor segments at least twice annually and deliver data and images for vegetation inspection.



Figure 3-13
EPRI Ti transmission line Robot being tested at EPRI laboratory in Lenox, MA.

Figure 3-14 shows an example of an image generated by the Ti LiDAR system. The Ti robot is also equipped with a GPS, weather sensor, accelerometer and data reader to retrieve information from sensors installed on a line. An example of a conductor sensor is given in Figure 3-15.

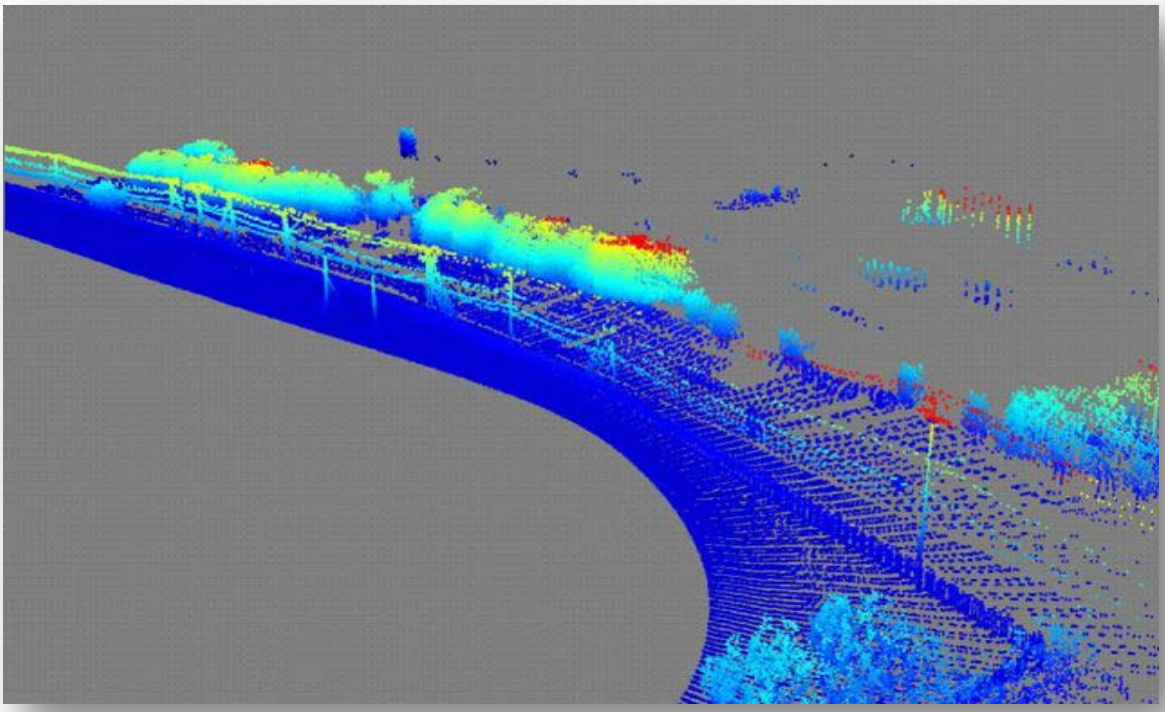

Figure 3-14
Image generated by the LiDAR system on the Ti robot.



Figure 3-15
Conductor Sensor – A suite of RF interrogated sensors for conductors, insulatorshas been developed to continually assess the condition of components and transmit to Ti when it is in close proximity.

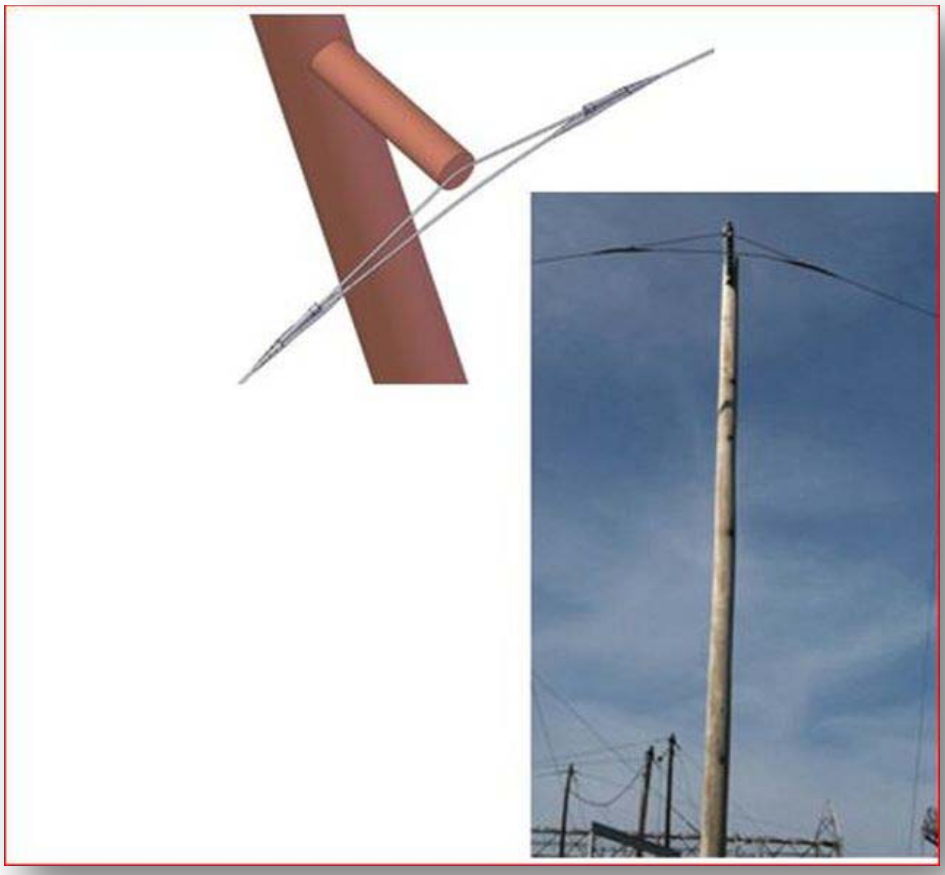

Figure 3-16
Bypass system around the obstacles along the shield wire.

Future for Robotic Crawler Platform

The Ti robot has been tested at EPRI's laboratory in Lenox, MA. Videos of the testing have been posted on EPRI's YouTube pages (see links below).

In 2014-15 a prototype device being built will be tested on the test loop and a test section of line at American Electric Power (AEP). The prototype will bring together the hardware, electronics, and sensor payload designs. New materials and designs will be evaluated to assess the best option over the range of operating conditions. Additional information is available at:

http://tdworld.com/transmission/ti-epri-transmission-line-robot-development

EPRI's Transmission Assets Inspecting Robots Enter Next Phase by: Andrew Phillips, Electric Power Research Institute, Electric Energy

http://www.electricenergyonline.com/?page=show_article&mag=80&article=663

Latest Development of EPRI's Transmission Line Inspection Robot by: EPRI videos

http://www.youtube.com/playlist?list=PLBBA3B1C5F6C07991

EPRI's prototype transmission line inspection robot

http://www.youtube.com/watch?v=noD6sTMJAGA

Handheld Lasers

Handheld lasers are used to measure distances in a variety of applications and have been on the market for a number of years. Advances in technology have made for lighter instruments with improved accuracy, an important consideration in a field tool to measure clearances.

An example of a new generation laser is the TopGun (Figure 3-17) by Aerotec LLC that integrates Laser Technology's TruPulse 360B rangefinder (Figure 3-18), Topcon's GRS-1 (dual frequency RTK GNSS receiver and field controller, digital camera, and cellular capabilities) (Figure 3-19), Esri's ArcMap GIS software, and Aerotec's proprietary LiDAR vegetation management solution software to enable the inspection of transmission system and ROW (9).



Figure 3-17
TopGun device (courtesy of Aerotec).



Figure 3-18
TruPulse 360B (courtesy of Laser Technology Inc.).



Figure 3-19
Topcon's GRS-1 (courtesy of Topcon).

Applications of Integrated Handheld Laser Inspection Technologies

TopGun can be used to identify span, sag, tension, buffer zones, and vegetation clearance, violations both inside and outside the ROW (Figure 3-20). From the LiDAR view, shown in Figure 3-21, the ROW potential violations can be identified. An example in Figure 3-22 shows captured points that appear as colored symbols on a GIS map. The symbols for each type of point (violation/clear/obstacle) can be changed using the ArcPad software. Default symbols are:

- Red Circle-Violation
- Green Circle-Clear
- Blue Circle-Obstacles
    1. "X" indicates structure location
    2. Blue/gray polygons indicate previously located violations (trees)
    3. Green lines indicate TL centerline
    4. Blue lines indicate ROW boundary



Figure 3-20
Inspecting ROW for violations (courtesy of Aerotec).

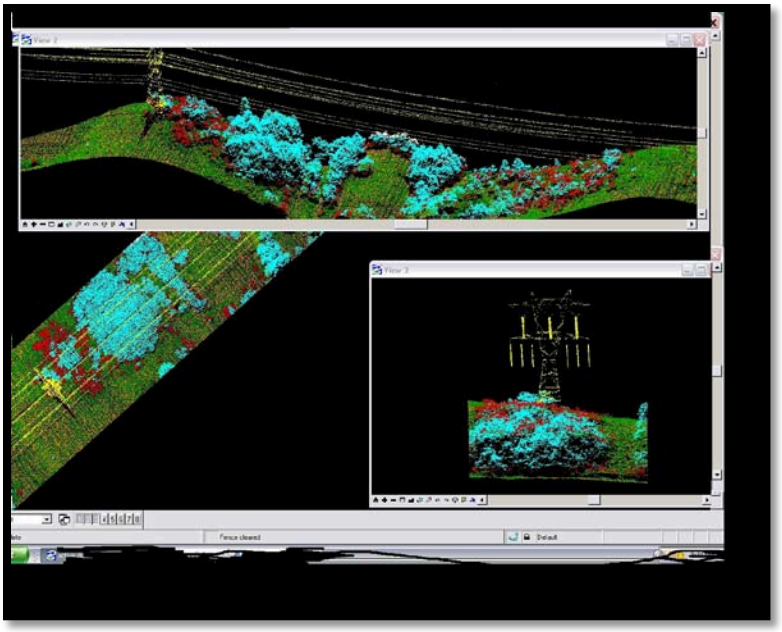

Figure 3-21
A example of a LiDAR plot (courtesy of Aerotec).

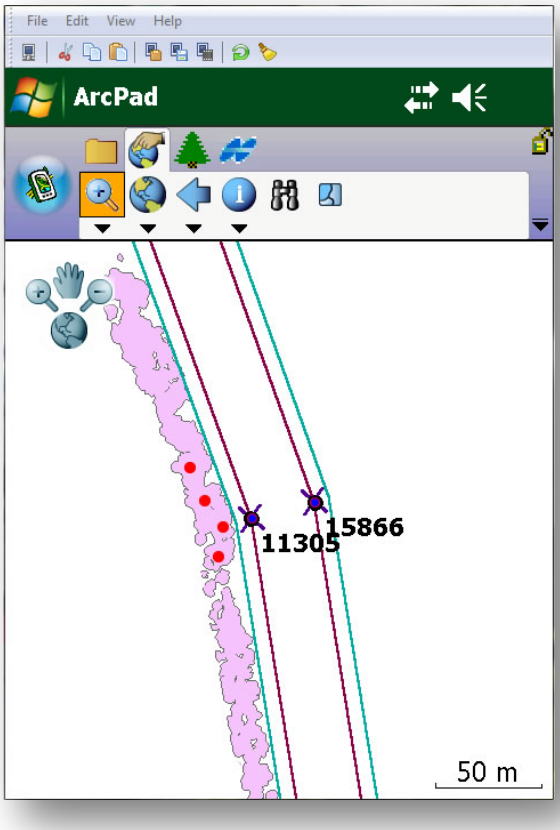

Figure 3-22
A example depicting several dots of violation (courtesy of Aerotec).

The TopGun device required inputs are a) a single laser "shot" from the TruPulse 360 rangefinder targeting a potential vegetation violation; b) the ROW geometry model produced from either an existing PLS-CADD model or from Plan & Profile Drawings (no LiDAR data required); and c) the utility clearance criteria.

It is not necessary to have flown the ROW using LiDAR in order to produce a TopGun ROW geometry data model. But the most efficient approach is to start with an existing LiDAR or PLS-CADD model of the ROW and use the TopGun Veg-Tool ROW geometry data model for the evaluation. The utility inspector can use the TopGun Veg-Tool from a single spot within a given span of an electric power transmission line to take a single shot measurement of multiple suspect trees, both inside and outside the span boundaries. The inspection provides PASS/FAIL results.

The TopGun device has been used by several electric utilities to meet the NERC regulations. Engineers compared TopGun results to physical hard copy and digital maps from a recent LiDAR clearance violation along portions of a 345kV transmission line in New Mexico. The objective was to determine that the appropriate violation trees had been flagged and marked (10). The results showed good correlation and highlighted several other features:

- Personal navigation aid to the locate previously identified violations
- Detection device to identify, analyze and report confirmed violations
- Location device to accurately mark/flag/map violations for remedial action
- Audit device to validate that the required work was adequately performed
- Reporting device to address accounting and regulatory issues
- Inspection device for future work related to the proper execution of a utility's vegetation management program.

Future for Integrated Handheld Laser (TopGun) on Transmission Lines and ROW Based on Current Research

The application of the TopGun integrated device on transmission lines and vegetation management of ROW inspections appears promising. Present literature suggests good results when comparing vegetation clearances with tape measurements. Further field testing and validation may be necessary to provide additional information, particularly under different environmental conditions.

Gaps for Integrated Handheld Laser on Transmission Lines and ROW Inspections

These include:

- Absence of line of sight inhibits the use of the rangefinder.
- The combined weight of the individual components could be made lighter and is an important consideration for field work.

Laser Range Finders

Rangefinders are used to measure distance in a variety of applications for various resource and information needs.

There are three distinct types:

- Ultrasonic distance-measuring devices use a wide band frequency from a transducer, sending out narrow beams of sound waves which bounce off an object. The return signal is picked up by a hand-held receiver processor. Accuracy of the data is affected by the position of the receiver and audible noise. Noise generated by wind through the trees or brush, streams, rain, crew conversations, road traffic,or birds chirping can effect readings. When a horizontal distance measurement is being taken, the inclination, or horizontal position, of the receiver is critical. An outgoing wide-band signal will be scattered, increasing the error, if the transducer is not positioned as close to horizontal as possible. This type of device is not suitable for vegetation management inspection.
- Optical distance-measuring devices typically use the coincidence method of determining distance. This method uses a series of lenses, mirrors and levers to produce a double image. The double images displayed in the eyepiece or viewing device are brought together by rotating a dial until both images merge into one, indicating the distance. The dial position has a distance indicator scale on it and the distance to the target is read directly off the dial. This instrument is considered to be analog. This type of device is not suitable for vegetation management inspection.
- Pulsed lasers are instruments which emit light in the form of optical pulses. Pulse lasers determine distance by measuring the amount of time required for a pulse of infrared light to travel to the target and back. The speed of light is constant, so the amount of time is directly proportional to the distance. Many pulses are sent out and returned for each "shot" or reading, improving the accuracy of the calculated value. Laser instruments are narrow band and require the operator to aim with some accuracy. The accuracy and maximum range of some laser instruments are dependent on the reflectivity of the target and the power of the laser (some laser instruments may require eye protection gear). Some laser instruments are affected by the power level of the batteries.

The size and weight of equipment carried in the field is a consideration for applications which entail walking long distances or on steep terrain or both (11). Two rangefinder lasers used for inspection of a transmission system and ROW are the TruPulse laser by Laser Tech Inc. and the Lasertape FG21-HA by RIEGL (Figure 3-23) (2).

The TruPulse 360B (Figure 3-24) and TruPulse 360R (Figure 3-25) are intended for handheld use. Both are small, compact, and have low power requirements. Both are suitable for transmission line and ROW inspection when used with GPS. The TruPulse 360R has a range of up to 6,500 feet/1,982 meters with the use of a reflective target (something that is painted, flat rock or sign) and 3,280 feet/1,000 meters non reflective target (something that is vegetation, furry or feathery) and an accuracy of ± 1ft / ± 2.5 cm in range and ± 0.25 degree for inclination. Measurement resolution is 0.5ft, 0.1m. It calculates height, horizontal, vertical, and slope distances, cumulative and difference distances, inclination and azimuth. It is equipped with data storage and retrieval via serial interface using an RS-232 port and is designed to run available data collection software (12).



Figure 3-23
Lasertape FG21-HA (courtesy of RIEGL).



Figure 3-24
TruPulse 360B (courtesy of Laser Technology Inc.).

Rangefinders are most often used to measure/identify span, sag, tension; buffer zones, and vegetation at ROW (SeeFigure 3-25). Laser Technology's TruPulse 360R has the ability to remotely measure distances, heights and azimuth, and calculates the distance between any two remote points. The TruPulse rangerfinders are used by several electric utilities in the USA to meet NERC regulation requirements.



Figure 3-25
TruPulse 360R (courtesy of Laser Technology Inc.).

The TruPulse 360B has long-range capabilities and the ability to lock on to small targets like power lines and vegetation. The tool integrates with a variety of field data collectors and third party software. The TruPulse 360 measures the "Missing Line (ML)" - the distance between two remote objects - such as the distance between conductor and vegetation as shown in Figure 3-26. It is a two-shot routine, one measurement to the conductor and the second to the tree.

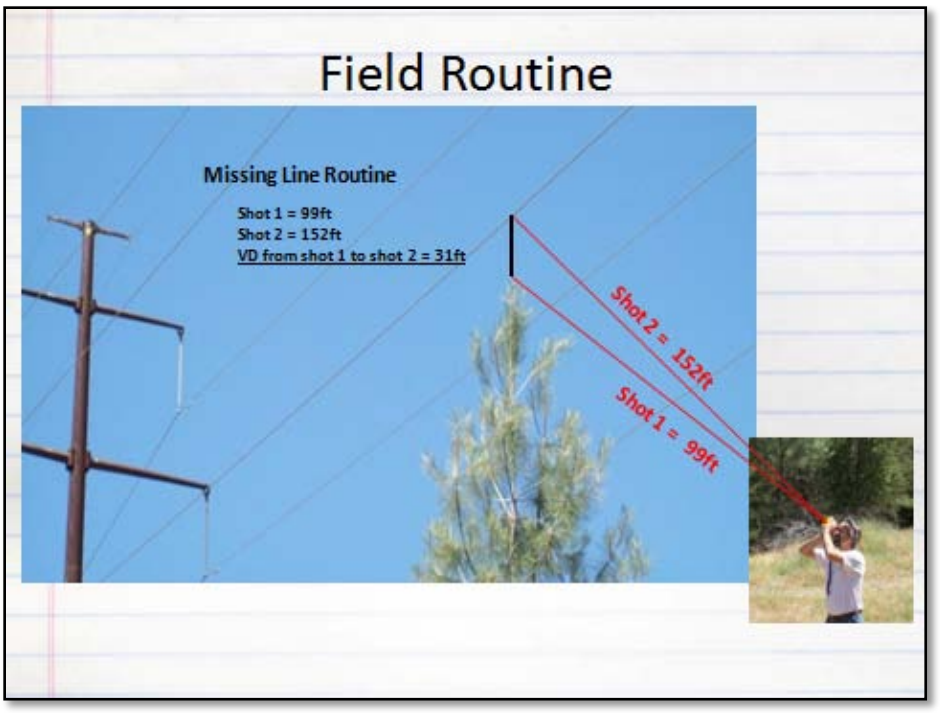

Figure 3-26
The TruPulse 360R measures the distance between two remote objects (courtesy of Laser Technology Inc).

Future for Rangefinders on Transmission Lines and ROW Based on Current Research

Industry experience suggests that there is a good correlation between rangefinder results and physical measurements for vegetation inspection applications. There needs to be on-going product development, such as integration of data into utility management systems, to the make this technology more versatile.

Gaps for Rangefinders on Transmission Lines and ROW Inspections

- Integrate rangefinder inspections of conductor clearances with routine ground vegetation inspections. An example is integrating rangefinder data with GPS, PLS-CADD and work management tools to reduce analysis and human error.
- Develop guidelines on how to apply the technology for determining the conductor position for different conductor temperatures at the time of inspection.
- Improve the resolution and accuracy of the rangefinders.

Hyperspectral Imaging

Hyperspectral imaging is a technique for characterizing physical material based on the absorption of different wavelengths of light. This has been used successfully to determine the characteristics of vegetation, amongst other applications.

Hyperspectral imaging collects and processes information from across the electromagnetic spectrum. Unlike the human eye which sees visible light in three bands (red, green, and blue),

spectral imaging divides the spectrum into many more bands beyond the visible eye. This allows for detailed quantification of vegetation properties whereby different plant species exhibit different characteristic reflectance spectra. The basic operation of hyperspectral imaging is given in Figure 3-27 (13). In remote sensing applications, scanning is provided by aircraft or satellite movement.

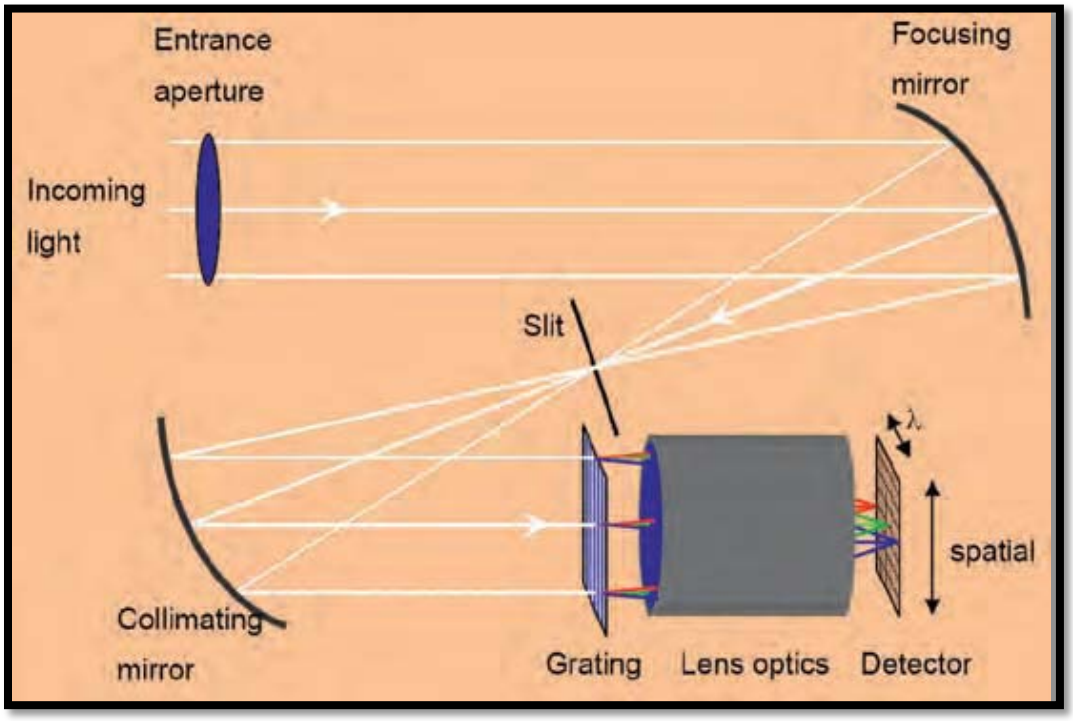

Figure 3-27
A schematic drawing of a hyperspectral sensor (courtesy of HySpex).

Hyperspectral sensors collect information as a set of images. Each image represents a range of the electromagnetic spectrum known as spectral bands. The images are then combined to form a 3D hyperspectral data cube for processing and analysis as shown in Figure 3-28. Hyperspectral cubes are generated from airborne sensors mounted on fixed or rotary wing aircraft or from satellites like NASA's Hyperion. Figure 3-29 shows an example of a hyperspectral system for airborne applications.



Figure 3-28
A hyperspectral image cube comprising a full monochrome image of each of the spectral bands. Here, the colors represent the intensity in each band (courtesy of HySpex).



Figure 3-29
An example of a hyperspectral sensor for airborne applications (courtesy of HySpex).

Developments with Hyperspectral Imaging Sensing

Recent advances in hyperspectral sensor design and processing speed has cleared the path for a wide range of applications, ranging from satellite-based and airborne remote sensing. Due to the amount of data collected, the technology is best suited for automated image processing for remote sensing applications. Figure 3-30 shows a 3D image made by combining airborne hyperspectral and LiDAR data.



Figure 3-30
3D image generated by the combination of a HySpex image and LiDAR data from the same scene (courtesy of HySpex).

Utility Application of Hyperspectral Imaging Sensing

At present, the inspection vendors only use multispectral imaging and not hyperspectral sensing due to the large amount of data, cost and complexity for transmission and ROW inspections.

Future of Hyperspectral Imaging Sensing

Aerial LiDAR systems with multispectral imaging sensors are accepted as an efficient and cost effective means of creating accurate digital elevation and terrain data. Hyperspectral imaging sensing and LiDAR are not yet applied by service providers for the following reasons: cost, large amounts of data, lack of experience, and integration into their platforms.

Advantages to using hyperspectral over multispectral imaging include:

- The entire spectrum is acquired at each point, and the operator needs no prior knowledge of the sample.
- All available information from the dataset to be mined is available for post processing.

Hyperspectral imaging can also take advantage of the spatial relationships among the different spectra allowing more elaborate spectral-spatial models to be generated for a more accurate

segmentation and classification of the image(s). There are several vendors that have taken advantage of these capabilities over multispectral imaging sensing with the use of airborne LiDAR and hyperspectral sensing for other applications such geology, mining, and land surveying. As experience and knowledge of this technology increases, transmission inspection vendors may consider applying it.

Gaps for Hyperspectral Imaging Sensing in Transmission

Hyperspectral imaging provides information on vegetation classification, and by extension, predicting the growth rates of various plant species in the ROW. For other applications it may need to be integrated with other sensing technologies such as LiDAR and geospatial information to provide additional information on vegetation heights and location. The fusion of data from all these sensors is a challenge.

Another potential hurdle is finding ways to program hyperspectral sensors to sort through data on their own and store the most important images. The effective use of hyperspectral images requires an understanding of the nature and limitations of the data and of various strategies for processing and interpreting it.

As technology advances and reduces the physical size of sensors, the full potential of hyperspectral imaging needs to be realized.

Satellite Imaging

Satellite imagery gives an effective and efficient means of observing and quantifying the complex topography of the earth's surface. Basic satellite imagery provides information on land cover, land use, habitats and landscape, and gives the capability to map and monitor changes to the earth's terrain. It fits well with GIS based processes. Although analysis of satellite images will not be a substitute for detailed close-in inspection, it could provide a cost effective method for detecting vegetation encroachment and identification of species. The cost of satellite images varies widely depending on the image adjustments required and the use of archived or new imagery. The cost is typically quoted in terms of area covered and can range from less than \$10/km^2 for basic archived images to several hundred dollars/km^2 for custom areas and processing.

Present Satellite Image Sensing

There are a number of companies, like DigitalGlobe Inc., that compile and distribute aerial photos, satellite imagery, and map data from their online spatial archive. DigitalGlobe's customers range from urban planners to the U.S. federal agencies, including NASA and the United States Department of Defense's National Geospatial-Intelligence Agency (NGA). Much of Google Earth's and Google Maps' high-resolution imagery is provided by DigitalGlobe, as is imagery used by TerraServer. DigitalGlobe provided written information and photos on their satellites, additional information was provided from their website. (14) Spatial Mapping currently market imagery from Landsat satellites or aerial photography services for municipal planning, forestry, and agricultural land use analysis and similar applications. The latest Landsat (number 7) is in sun-synchronous polar orbit that passes over any given location on earth roughly every 15 days, but its resolution of 15 meters/pixel is significantly less than the commercial satellite IKONOS. In 2001, NASA launched Earth Observing-1 Mission (EO-1) with a resolution of 10 meters/pixel, which is considered medium resolution.

The capabilities of these satellites differ in several important parameters:

- Resolution. Resolution is typically given in meters/pixel and refers to the area in the scene covered by a single image pixel. It is very difficult to detect any objects in the scene that are smaller than the image resolution. Panchromatic images have the highest resolution. They are formed by combining the optical energy from all wavelengths into a single black and white image.
- Spectral band. While panchromatic images do not distinguish different wavelengths (color), multispectral images provide image data at several wavelengths. Spectral bands may include several visible wavelengths so that color images can be formed. Infrared spectral bands are often used since this provides a strong signature for recognizing vegetation. Multispectral images are of lower resolution than panchromatic images but it is possible to combine them to produce color images at nearly the pan image resolution (pan-sharpened images).
- Orientation. Many satellites can be commanded to aim their cameras straight down (nadir view) or at an angle so that areas not directly under the orbital track can be imaged. The highest resolution images are obtained from nadir views but off-nadir views can show a side view of a tower.
- Swath width. The swath width is the width of the ground track as imaged by the satellite.
- Revisit time. Imaging satellites are generally in polar orbits and observe a changing ground track as the earth rotates. The revisit time is the interval between successive views of the same location on earth. The revisit time, typically measured in days, defines the time scale of events that can be observed from satellite images. Satellites with large swath widths typically have shorter revisit times than those with narrow widths. Most satellites offer the option (for an additional cost) of directing the camera at specific targets to provide more frequent observations.
- Radiometric resolution. Radiometric values refer to the energy of optical radiation or the intensity of the light. Satellite imaging cameras measure the intensity of light at each pixel in a digital representation of 10 to 11 bits.

Images from the NASA satellites are available and are marketed by companies such a Satellite Imaging Inc. (SIC), Magnolia, TX. They process the images to register strips, equalize lighting and correct for optical distortions.

IKONOS Satellite

The IKONOS satellite (Figure 3-31) is a high-resolution satellite operated by GeoEye. Its capabilities include capturing a 3.2 meters/10 feet multispectral, Near-Infrared (NIR) 0.82 meters/2.7 feet panchromatic resolution photograph. Applications include both urban and rural mapping of natural resources, natural disasters, tax mapping, agriculture and forestry analysis, mining, engineering, construction, and change detection. It can yield relevant data for nearly all aspects of environmental study. IKONOS images have also been procured by SIC for use in the media and motion picture industries, providing aerial views and satellite photos for many areas around the world. Its high resolution data makes an integral contribution to homeland security and coastal monitoring, and facilitates 3D terrain analysis.



Figure 3-31
The IKONOS satellite (courtesy of DigitalGlobe).

GeoEye operates the IKONOS satellite, launched in 1999. It is also in a sun-synchronous orbit at an altitude of 423 miles/682 kilometers and can provide monochrome images with a resolution of 1 meter/3.28 feet per pixel. This orbit passes over given geographical locations every three days.

SPOT Image Corporation, Chantilly VA, operates the SPOT-5 satellite, placed in orbit in 2002. SPOT-5 has a revisit time of two to three days and provides a maximum resolution of 2.5 meters/8.2 feet per pixel. Satellite Imaging Corporation (SIC) is an official distributor for SPOT Image Corporation.

GeoEye-1 Satellite

GeoEye-1 (Figure 3-32) was launched September 6, 2008 and represents the next step in commercial satellite imaging. GeoEye-1 acquires image data at 0.41 meters/16 inches per pixel for monochrome images and 1.65 meters/65 inches per pixel for multispectral images. GeoEye-1 has a revisit time of less than three days, as well as a 3 meters/9.8 feet positional accuracy. This satellite has the highest resolution of any commercial imaging system and collects images with a ground resolution of 0.41 meters/16 inches in the panchromatic or black and white mode. It collects multispectral or color imagery at 1.65-meter resolution or about 64 inches, a factor of two better than existing commercial satellites with four-band multistage imaging capabilities. While the satellite is able to collect imagery at 0.41 meters/16 inches, GeoEye's operating license from the U.S. Government requires re-sampling the imagery to 0.5 meters/20 inches for all customers not explicitly granted a waiver by the U.S. Government.



Figure 3-32
GeoEye-1 (courtesy of DigitalGlobe).

Higher resolution images (1 foot to 6 inches per pixel/15.24 to 30.5 cm per pixel) are available from some services such as GeoDigital and SIC, but these are obtained from aerial photography and are available only for limited locations at infrequent intervals. SIC acquires and processes imagery from the GeoEye-1 satellite sensor.

WorldView-2 Satellite

DigitalGlobe's WorldView-2 satellite (Figure 3-33), launched October 2009, is the first high resolution 8-band multispectral (1.85 meters/6 feet) commercial satellite with 0.46 meters/1.5 feet panchromatic only spatial resolution. The 0.46 meters/1.5 feet resolution of WorldView-2's panchromatic images allows the satellite to distinguish between objects on the ground that are at least 46 cm/18 inches apart. Similarly DigitalGlobe's QuickBird satellite provides 0.6 meters/2 feet resolution panchromatic images. WorldView-2 has an average revisit time of 1.1 days and is capable of collecting up to 1 million km^2/ 3.8610e+5mi^2 of 8-band imagery per day, greatly enhancing DigitalGlobe's multispectral collection capacity for more rapid and reliable collection.



Figure 3-33
The WorldView-2 satellite (courtesy of DigitalGlobe).

Spot Satellites

The 3 SPOT satellites in orbit (Spot 2, 4 and 5) provide images with a large choice of resolutions from 2.5 meters to 20 meters/3.3 feet to 65.6 feet. Spot Image also distributes multi resolution data from other optical satellites, in particular from Formosat-2 (Taiwan) and Kompsat-2 (South Korea) and from radar satellites (TerraServer-X, ERS, Envisat, and Radarsat). Spot Image is the exclusive distributor of data from the forthcoming very-high resolution Pleiades satellites with a resolution of 0.50 meters or about 20 inches. The company also offers infrastructures for receiving and processing, as well as added-value options.

RapidEye Satellites

RapidEye's constellation of five satellites, launched in August 2008, contain identical multispectral sensors which are equally calibrated. Therefore, an image from one satellite will be equivalent to an image from any of the other four, allowing for a large amount of imagery to be collected (4 million km²/1.5444e+6mi² per day) and daily revisit to an area. Each satellite travels on the same orbital plane at 630 kilometers/391 miles, and deliver images in 5 meter pixel size. RapidEye satellite imagery is especially suited for agricultural, environmental, cartographic and disaster management applications. The company offers their imagery and consults with their customers to create services and solutions based on analysis of this imagery.

Earth Resource Observation Satellites

Earth Resource Observation Satellites, better known as EROS satellites, are lightweight, low earth orbiting, high-resolution satellites designed for fast maneuvering between imaging targets. In the commercial high-resolution satellite market, EROS is the smallest very high resolution satellite. The satellites are deployed in a circular sun-synchronous near polar orbit at an altitude

of 510 kilometers (± 40 km)/316 miles (±25 mi). EROS satellites' imagery applications are primarily for intelligence, homeland security and national development purposes, but may also be employed in a wide range of civilian applications, including mapping, border control, infrastructure planning, agricultural monitoring, environmental monitoring, disaster response, training and simulations, etc.

GeoEye-2 Satellite Sensor

Following the merger of GeoEye and DigitalGlobe, GeoEye-2 will be held in storage until needed. GeoEye's third-generation satellite is capable of discerning objects on the Earth's surface as small as 34 cm/13.4 inch in the panchromatic or black and white mode. It will collect multispectral or color imagery at 1.36 meters/54 inch resolution. GeoEye-2 will have the highest resolution of any commercial imaging system. This advanced resolution will offer customers unprecedented, precise views for mapping, change detection and image analysis.

GeoEye-2 will be of the same general class as GeoEye-1. GeoEye-2 will offer high geolocation accuracy, which means that customers will be able to map natural and man-made features to better than 5 meters/16.4 feet CE90 (specification) and 3 to 4 meters/10 to 13 feet CE90 (expected) of their actual location on the Earth's surface without ground control points.

GeoEye-2 will make 15 orbits per day, flying at an altitude of 681 kilometers/423 miles, with an orbital velocity of 7.5 kilometers per sec/16,800 miles per hour. GeoEye-2 will be able to "revisit" any point on the globe every three days or sooner, depending upon the required look angle.

GeoEye-2 customers will have a choice of ordering BASIC (satellite projection), Geo (geometrically corrected), GeoProfessional (terrain corrected or ortho-rectified), or GeoStereo (stereo pair) products, as well as imagery-derived products, including Digital Elevation Models (DEMs), Digital Surface Models (DSMs), large-area mosaics and feature maps.

WorldView-3 Satellite Sensor

The WorldView-3 satellite (Figure 3-34) is expected to be launched in 2014 and is the first multi-payload, super-spectral, very high-resolution commercial satellite. Operating at an expected altitude of 617 kilometers/383 miles, WorldView-3 provides 31 centimeters/12.2 inches panchromatic resolution, 1.24 meters/4 feet multispectral resolution, 3.7 m/12.1 feet short-wave infrared resolution, and 30 meters/98.4 feet CAVIS resolution. WorldView-3 has an average revisit time of <1 day and is capable of collecting up to 680,000 km² /2.6255e+5mi² per day, further enhancing the DigitalGlobe collection capacity for more rapid and reliable collection.



Figure 3-34
An artist's rending of the WorldView-3 satellite (courtesy of DigitalGlobe).

New Developments with Satellite Imaging

Many utilities performing vegetation management surveys of their ROW are considering incorporating satellite imagery into the process. Right-of-way encroachment and hyperspectral imaging are applications for satellite imaging. These features are large enough to be detected and characterized with the image resolution currently available. They occur at a fairly slow rate so that multiple satellite images can be obtained. Current cost is one barrier that is limiting this technology. The use of high resolution cameras on fixed wing aircraft and helicopters provide utilities better results.

There are new satellite sensors being developed with multi-payload, super spectral, high resolution. Two satellites that are being scheduled for launch in the next few years (based on 2013/14) are the GeoEye-2 and WorldView-3.

Application of Satellite Imaging

New satellites with new high resolution satellite imaging systems will make it possible to detect a number of conditions along transmission line ROW's. With the current GeoEye-1 and WorldView-2 or comparable imaging systems with high resolution of 0.41 meters/pixel/16 inches/pixel it is still not possible to detect conditions such as damaged hardware or missing marker balls. But it will be possible to detect large bushes or small trees in the ROW or large avian nests on towers. Utilities will have to integrate the imagery into it system with a GIS.

Gaps for Satellite Imaging in Transmission

As the number of high-resolution satellites increase the cost to use the images will come down. There is an anticipated need for the development of a standard format of data and utility specifications for vendor services.

Research Needed Based on the Gaps

The main gaps are integration of the global data into the utility ROW data set; reduce the cost of the data; enhanced resolution; and the availability of data at a specific time. These gaps will improve over the coming years with the increase in the number of satellites, improvement in resolution, and refinement of software with more options. These satellites will have higher resolution and more attributes in the future. The governmental requirement to get higher resolution data from the satellite will have to be relaxed or the process streamlined. EPRI can play a role in supporting the development of a standard format for the data provided by vendors.

4
INSPECTION APPROACHES

This chapter provides the approaches, associated services, and software solutions provided by vendors. New approaches to vegetation inspection take advantage of different sensing equipment and in some cases vegetation growth algorithms to provide a detailed inspection.

It should be noted that the following provides information on service providers that could be located and contacted.

Aerotec

Aerotec LLC uses airborne remote sensing (data capture) and data analysis technologies to provide topographic maps and models to land-based customers throughout North America (9). Their primary technologies include Light Detection and Ranging (LiDAR)/laser-scan, digital photography, proprietary and commercial (off-the-shelf) software, and specialized engineering analysis packages. Using proprietary filtering and analysis software, Aerotec provides LiDAR and digital imagery as three-dimensional visualizations and models.

Aerotec Methodology

Aerotec uses:

- Airborne LiDAR systems from Blom of Norway
- TopEye camera systems
- MK II elliptical laser-scan airborne data acquisition system
- Two integrated 22 mega pixel color cameras.

Aerotec maintains its own fleet of rotor-wing and fixed-wing aircraft for airborne data acquisition.

- Two AS350BA helicopters equipped with MK II LiDAR systems, high-resolution color cameras for low-altitude vertical and oblique aerial photography, and dual (forward and downward looking) high-resolution video cameras.
- Does not use hyperspectral imaging due to large amount of data and costs of application.
- Two helicopters can be equipped with infrared or corona cameras (Figure 4-1).
- The Partenavia P68C fixed-wing aircraft that serves as a digital imagery platform for high altitude geo-referenced aerial photography (Figure 4-2).



Figure 4-1
Aerotec's AS350BA helicopters equipped with the MK II LiDAR system, high-resolution color cameras for low-altitude vertical and oblique aerial photography, and dual high-resolution video cameras (courtesy of Aerotec LLC).



Figure 4-2
The Partenavia P68C fixed-wing aircraft with a digital imagery platform (courtesy of Aerotec LLC).

Data collected along the ROW provides both geometry and vegetation information inside and outside of the ROW. The LiDAR data and associated imagery data are for a 400 feet wide path, generally; but wider swaths are possible (Figure 4-3 and Figure 4-4). The LiDAR vertical accuracy is 0.50 ft at1000 ft. or 0.15 m at 305 m (ranging distance) for critical design points such as: conductor attachment, shield wire attachment, conductor - shield wire impingement points, and aerial obstacles. Aerotec's LiDAR vertical accuracy is 0.25 ft.:1000 ft./0.08 m:305 m (ranging distance) for Non-Critical Design points such as ground obstacles, vegetation, and ground features. Airborne LiDAR nominal point density equals 20 points per square meter/yard (approx.) on the ground.

A Power Line System Computer Aided Design and Drafting (PLS CADD) model of the ROW is created from the data. The PLS-CADD model, the low-level aerial ortho photography, the Airborne LiDAR point cloud information –ground, conductor (including static wires), structures, and vegetation are imported into Aerotec's Vegetation Assessment Software (Figure 4-5).



Figure 4-3
Transmission line profile imagery (courtesy of Aerotec LLC).

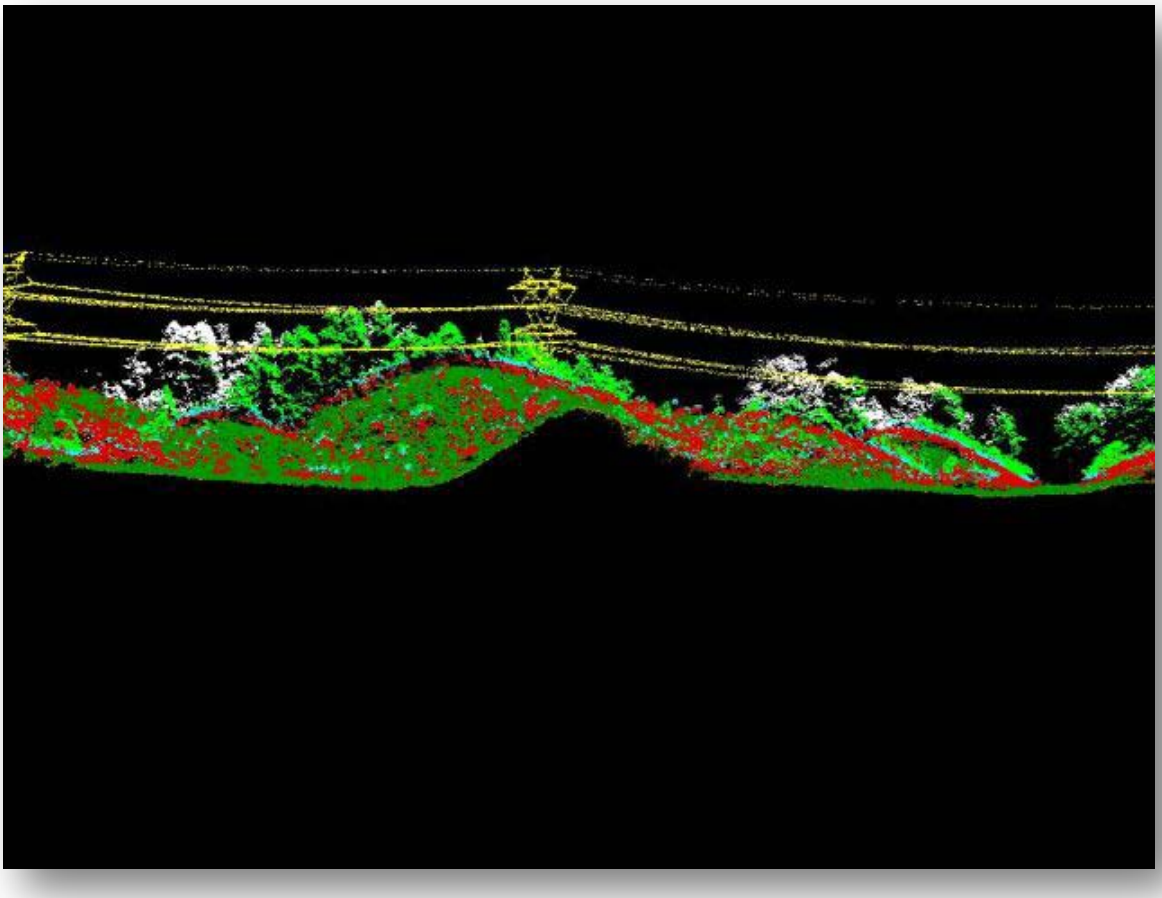

Figure 4-4
Color LiDAR and imagery of transmission line (courtesy of Aerotec LLC).

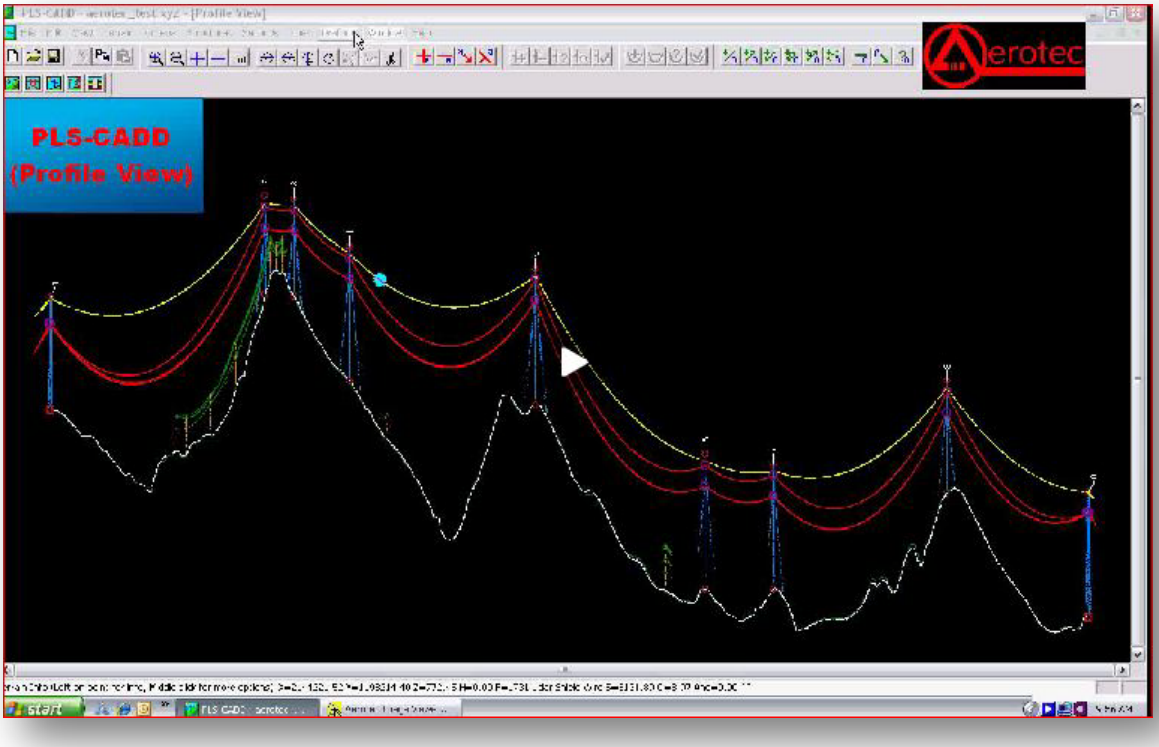

Figure 4-5
An example of Aerotec's enhancement of the PLS-CADD profile view (courtesy of Aerotec LLC).

Aerotec's vegetation clearance software is capable of importing PLS-CADD vegetation clearance assessment results and subsequently processing it together with LiDAR data into more meaningful results/reports. Aerotec Proprietary Veg Assessment Software (Figure 4-5 and Figure 4-6) shows how PLS CADD, LiDAR, and imagery data is integrated and viewed for the entire line or for individual structures. The vegetation clearance assessment results can be exported from PLS CADD and Aerotec's software to Aerotec's TopGun Veg-Tool for further evaluation and application (Figure 4-7). The results are also available to the utility as a hard copy of plots and maps, electronic (GIS compatible shape files) results, and TopGun Veg-Tool Data Model (for work in the field) as shown in Figure 4-7. The data is GIS-compatible, and violation inventory results can be assessed in the field using the TopGun Veg-Tool.

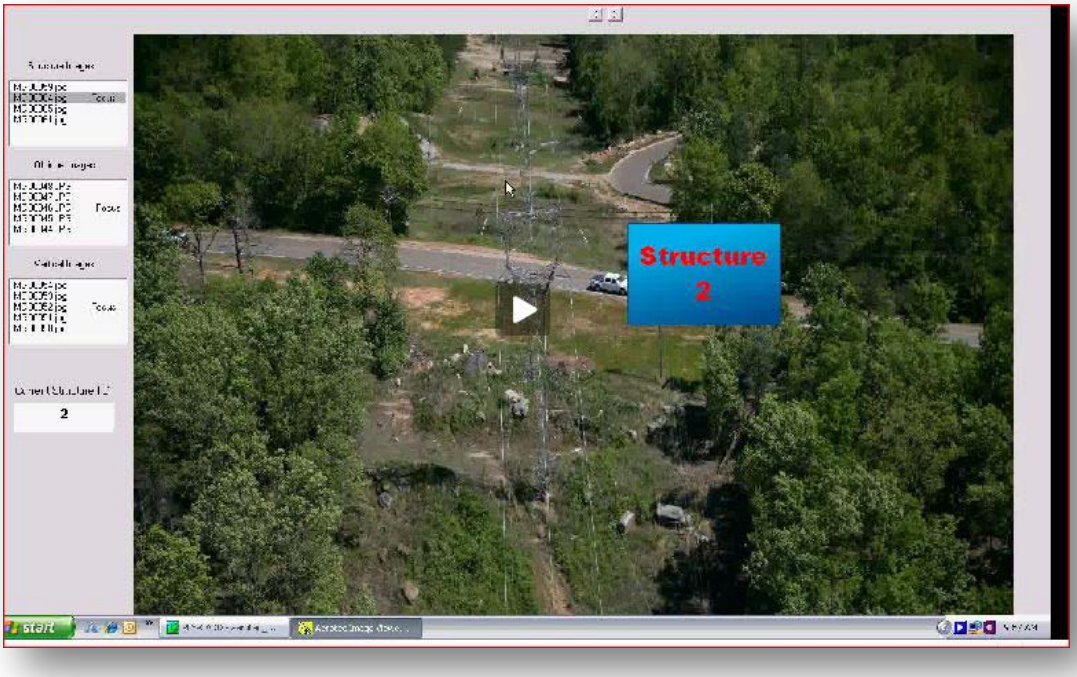

Figure 4-6
Aerotec software allows the user to zoom in and look at individual structures (courtesy of Aerotec LLC).



Figure 4-7
Inspecting ROW for violations using the TopGun tool (courtesy of Aerotec LLC).

For near real-time work management requirements, Aerotec has integrated its TopGun Veg-Tool with the REACT (Real-time Emergency Action Coordination Technology) system from NVision Solutions - http://www.nvisionsolutions.com/products/REACT.php

REACT is developed by NVision, located in Long Beach, MS for FEMA after hurricane Katrina; and it is used by FEMA, state and county governments, and some National Guard units.

REACT receives input (event notices) directly from the TopGun Veg-Tool instrument including smart phones and other devices. This allows the inspector, locating vegetation violations (e.g., marking vegetation for clearance action) to post violation events directly to the REACT system for issuance of geo-referenced "job tickets". Since the TopGun Veg-Tool/REACT system is GIS-based, the job tickets can be grouped spatially (e.g., grouped within a span or contiguous sets of spans) and efficiently issued to a clearing crew based on geography as well as other attributes. Additionally, REACT has the ability to track the crew/vehicle to the jobsite, on the jobsite, and returning from the jobsite. When the job ticket is completed, the crew can post notice of completion directly from the field.

REACT's other features, as applied to vegetation management, include:

1. Real-time weather monitoring for crew safety as well as work assignment.
2. Real-time reports of road closings for efficiently navigating to the work site.
3. Real-time reporting of water levels for all monitored streams, rivers, and lakes.
4. Summarization of crew activities for time/cost reporting.
5. Summarization of job tickets for paying vendors or regulatory reporting.

Aerotec has introduced additional products for electric utilities that use PLS CADD:

- LiDAR intensity images – black and white images constructed directly from the intensity of the LiDAR return signals. This form of digital imagery can be used as a background for PLS-CADD models.
- Continuous overlapping high-resolution geo-referenced digital frame imagery
    - Vertical (as non-orthorectified frames and/or geo-mosaic orthorectified background) as shown in Figure 4-8
    - Oblique as shown in Figure 4-9
- Geo-referenced video (vertical and oblique).
- Aerotec image/video player software for PLS CADD, capable of accessing and displaying all of Aerotec's digital imagery forms concurrently, inside the PLS-CADD work session.

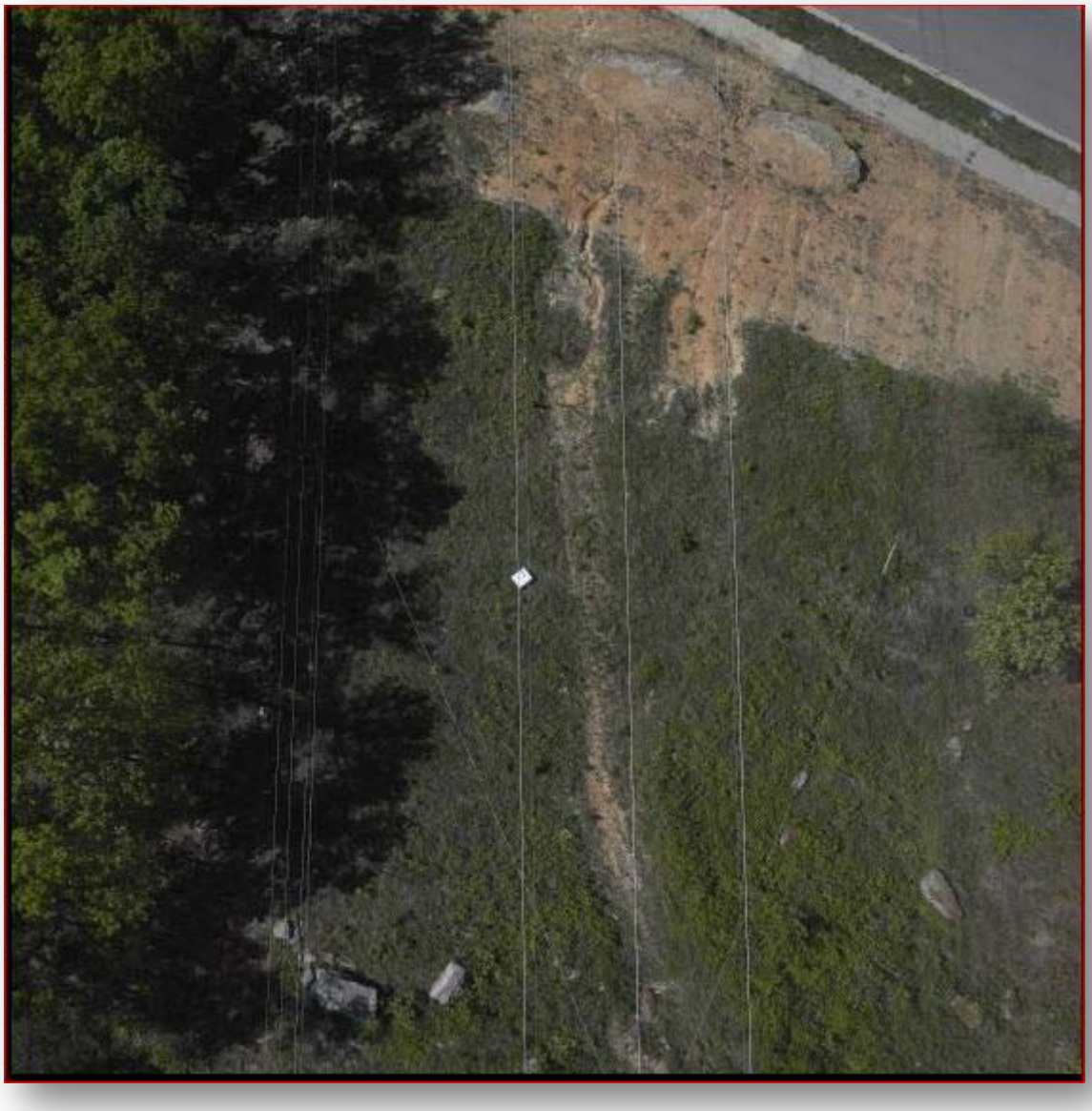

Figure 4-8
Continuous overlapping vertical imagery (courtesy of Aerotec LLC).



Figure 4-9
Continuous oblique imagery (courtesy of Aerotec LLC).

Future Developments

Future developments include continued hardware development using new LiDAR systems and cameras and enhanced LiDAR point clouds and image derived point clouds for generating 3D models. Reducing the volume of PLS-CADD data by developing new pre and post software tools are planned. Aerotec intends to update its user interfaces and look into hyperspectral imaging as the technology becomes mainstream.

Clearion

Clearion Vegetation Management LLC in Atlanta, GA provides a software solution for vegetation inspection and management that enables users to create, share, track, plan, schedule and audit vegetation work within a GIS database. The geospatial data management components are built using Esri's ArcGISTM technology, which are coupled with Clearion's work management and reporting toolset (15).

The software tool requires LiDAR and /or imagery surveys data and prioritizes and manages vegetation clearings based on that data. The tool uses data from ground-based patrols along with aerial visual inspections, which are often complementary to LiDAR. The software consists of enterprise and mobile vegetation management solutions.

Vegetation Management Software

Two principle products are available: field management and management tool set systems. These products provide the cross platform synchronization between GIS and Clearion VM as shown in Figure 4-10.

Users synchronize various types of GIS data on a laptop, tablet PC, or small-form handheld device and take it to the field, allowing the field inspector to include a comprehensive view of all pertinent enterprise data.

The software supports the use of a wide variety of LiDAR derived data and high quality ortho-imagery. As part of the LiDAR integration, LiDAR data can be imported and automatically trigger the creation of work orders. These work orders are actionable in the same manner as those which are manually created during a ROW patrol. Without the need for manual intervention, LiDAR patrols can automatically identify and initiate remediation steps (based on assignable business rules) in the Clearion VM workflow. Similar automation can be enabled using business rules that act on other data types, such as legacy maintenance plans.

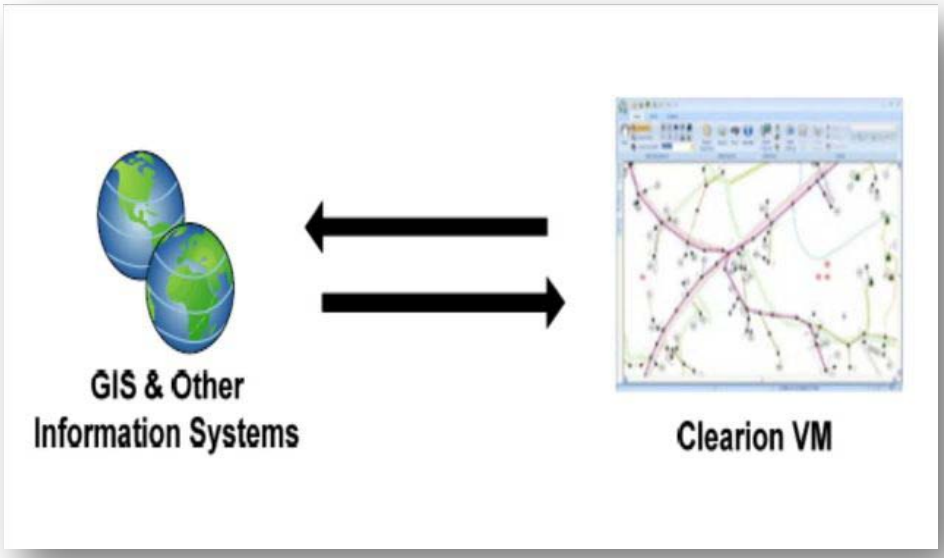

Figure 4-10
Integration inspection information from GIS to Clearion VM (courtesy of Clearion).

Field Management Systems – Clearion Mobile

For field application there is Clearion Mobile. This is a map-based application in the Clearion VM solution. This system has four basic displays:

- Patrol management workflow – Figure 4-11
- Field view - Figure 4-12
- Office view - Figure 4-13
- Pop-up interface screen - Figure 4-14

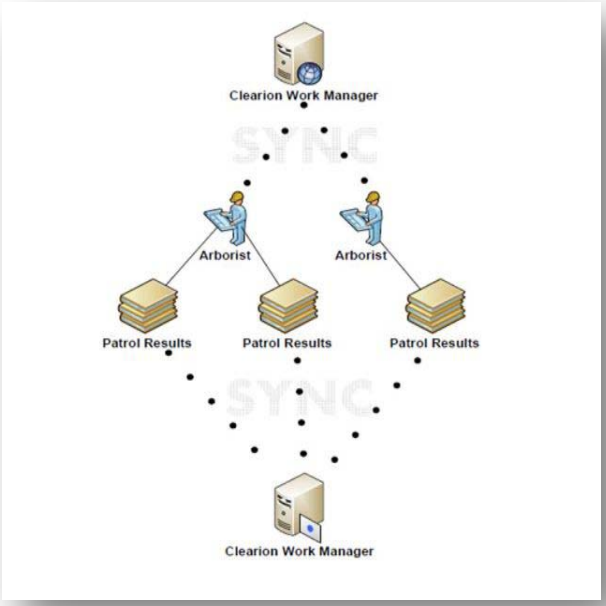

Figure 4-11
Field patrol workflow (courtesy of Clearion).

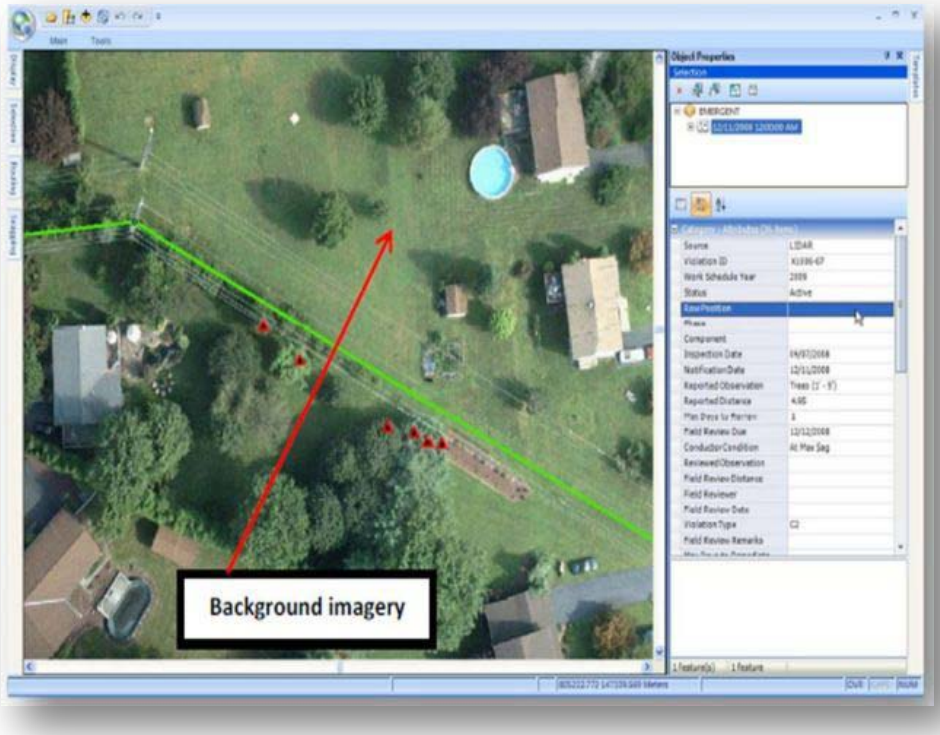

Figure 4-12
The Clearion Mobile field view of navigation, viewing, and inspection activities (courtesy of Clearion).

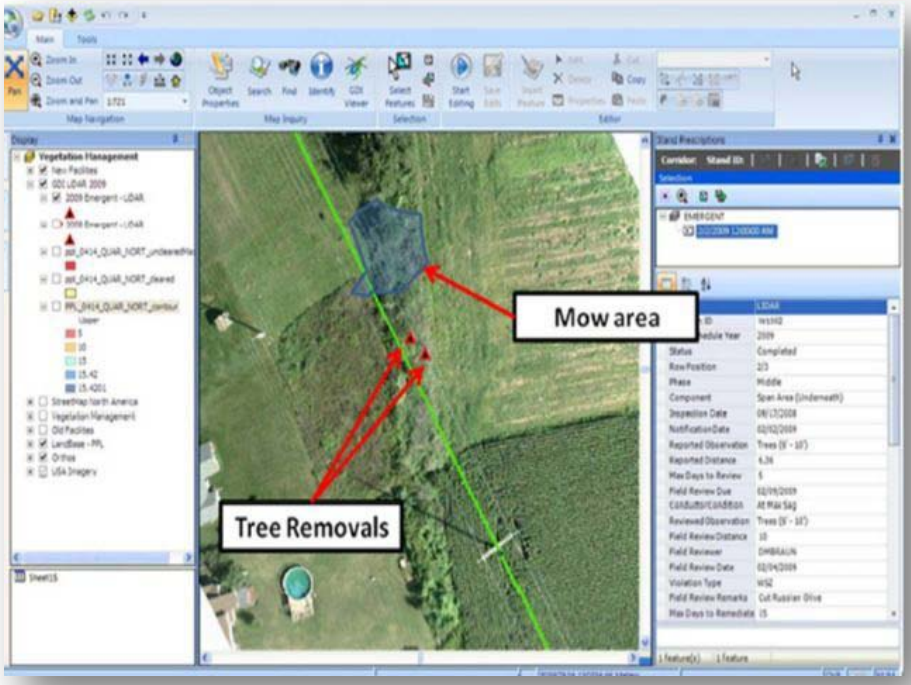

Figure 4-13
The Clearion Mobile office view, showing all toolbars for advanced application (courtesy of Clearion)

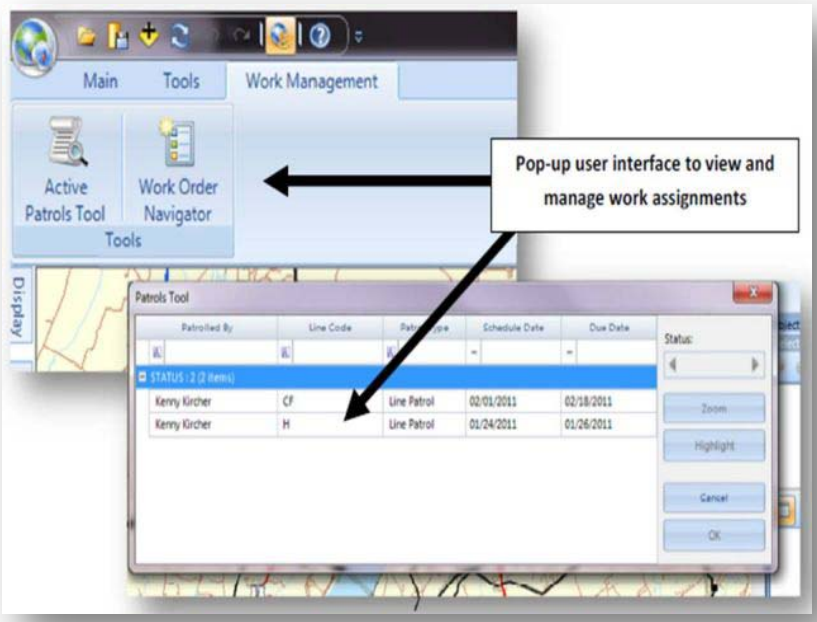

Figure 4-14
Work order example pop-up tools prepared in the field (courtesy of Clearion).

Patrol Management Workflow

Patrol management interfaces to Clearion Mobile software enabling workflow for field patrols (Figure 4-15):

- The process starts with the patrols being assigned to a specific arborists/forester/inspector
- Patrols are performed in the field with Clearion Mobile
- Patrol results are synced back to ClearionVM.

A screen shot with Clearion Mobile field view is shown in Figure 4-16 and an office view is shown in Figure 4-17. Clearion Mobile also provides a user interface where the user can receive patrol, inspection, and work order assignments and complete them on an ongoing basis.

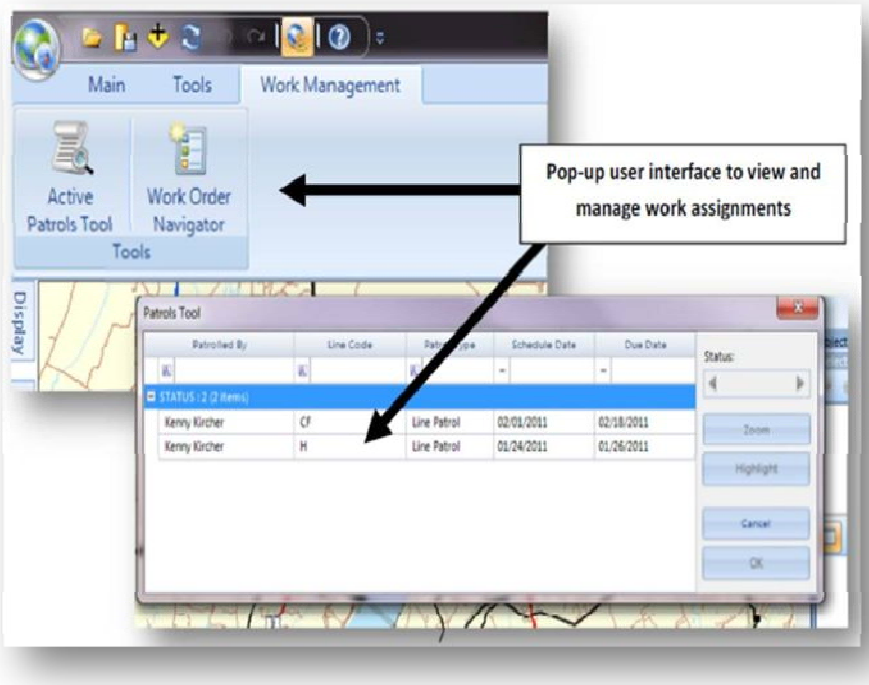

Figure 4-15
Work order example pop-up tools prepared in the field (courtesy of Clearion).

Work order example pop-up tools prepared in the field (courtesy of Clearion).

Clearion Mobile Crew

Clearion Mobile Crew is a map-based application. This feature allows the utility line crews and contractors to receive work assignments in the field, navigate with GPS, and open individual work orders for the work site. As the work is completed, the crew can check off the appropriate work orders. In the case that a crew does something other than what was prescribed in the work order, they can mark exceptions or add additional work items that were performed to the data base. Additional functionality also the allows crew to enter the hours worked on a work order/assignment, or add additional notes about what resources were required to complete the job. The Mobile Crew application is meant to create detailed work tracking information for the manager by automatically reporting on work status (how much of the work each crew has completed at any given time). A screen shot of Clearion Mobile Crew is shown in Figure 4-16. The user can record a new hot spot or click on a work order to view or edit information.

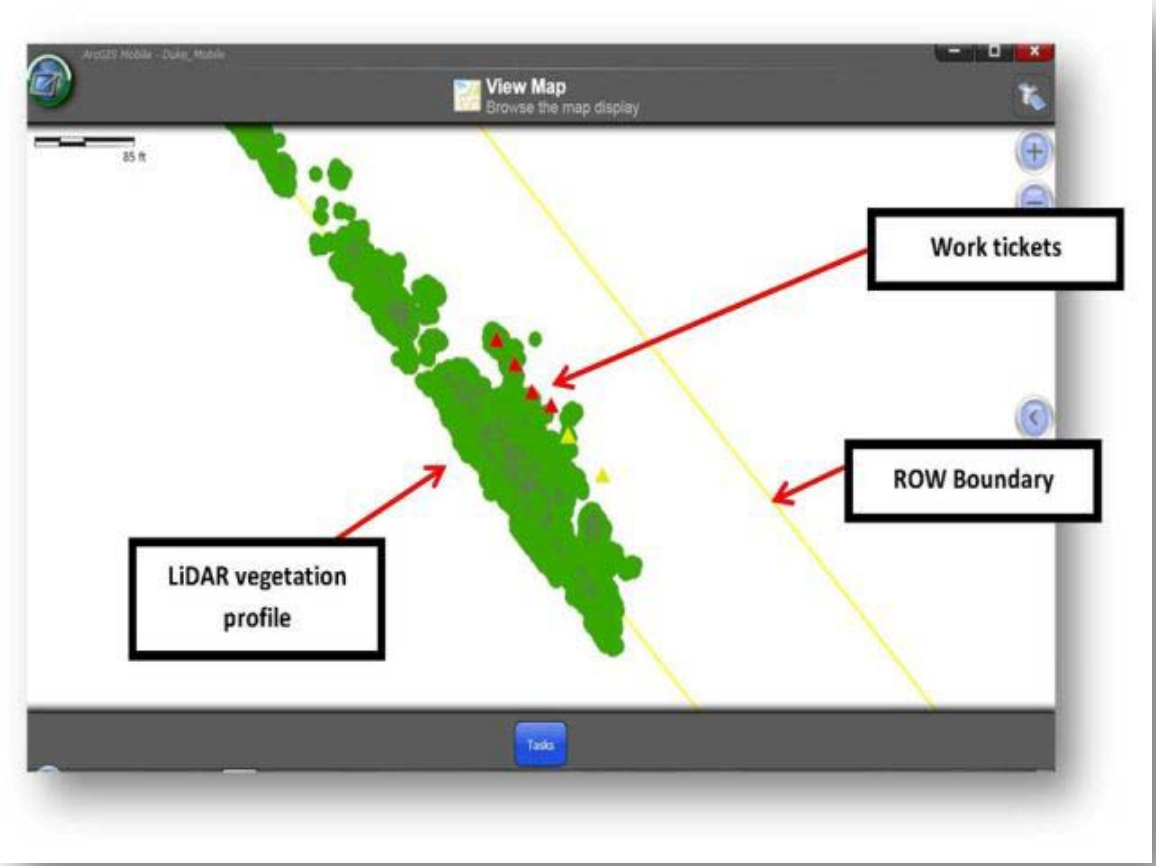

Figure 4-16
A screen shot of Clearion Mobile Crew (courtesy of Clearion).

Management Tool Set System – Clearion WM

Clearion WM is the core patrol management and work management tool. A vegetation management inspection/program can be planned, organized, executed and tracked by transmission line/corridor, feeder, or vegetation management area (VMA). User interface examples are given in Figure 4-17 and Figure 4-18. Examples show a record/list of new hot spots or the user can click on work orders to view/edit information and status.

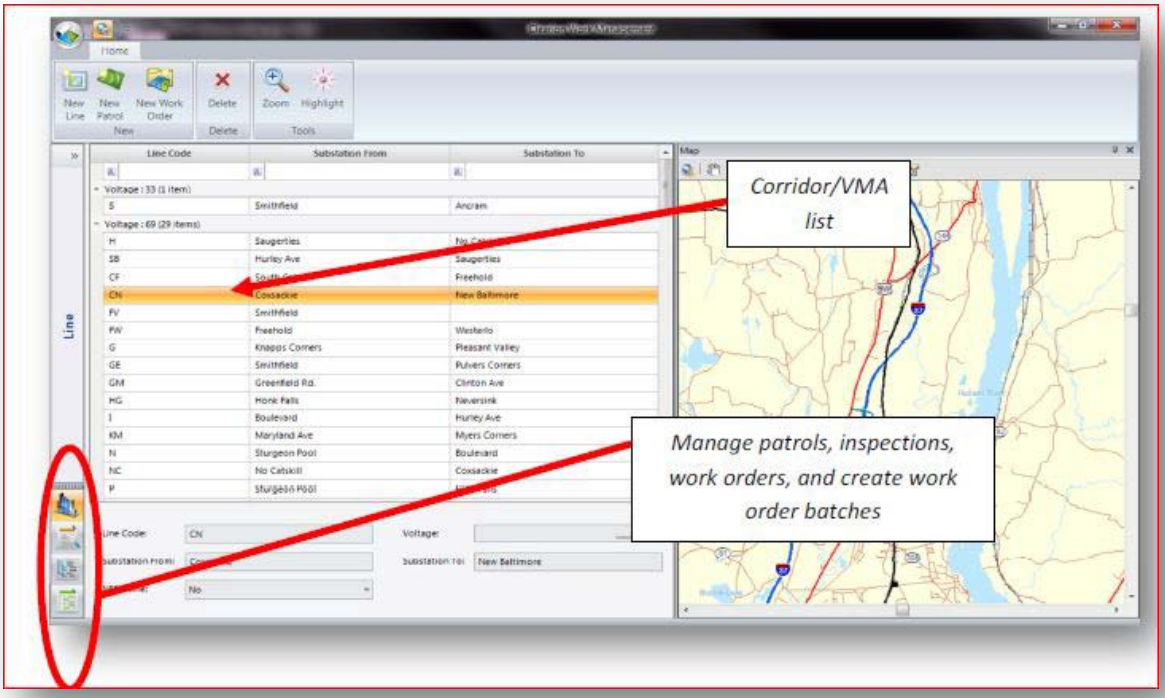

Figure 4-17
Clearion WM user interface (courtesy of Clearion).

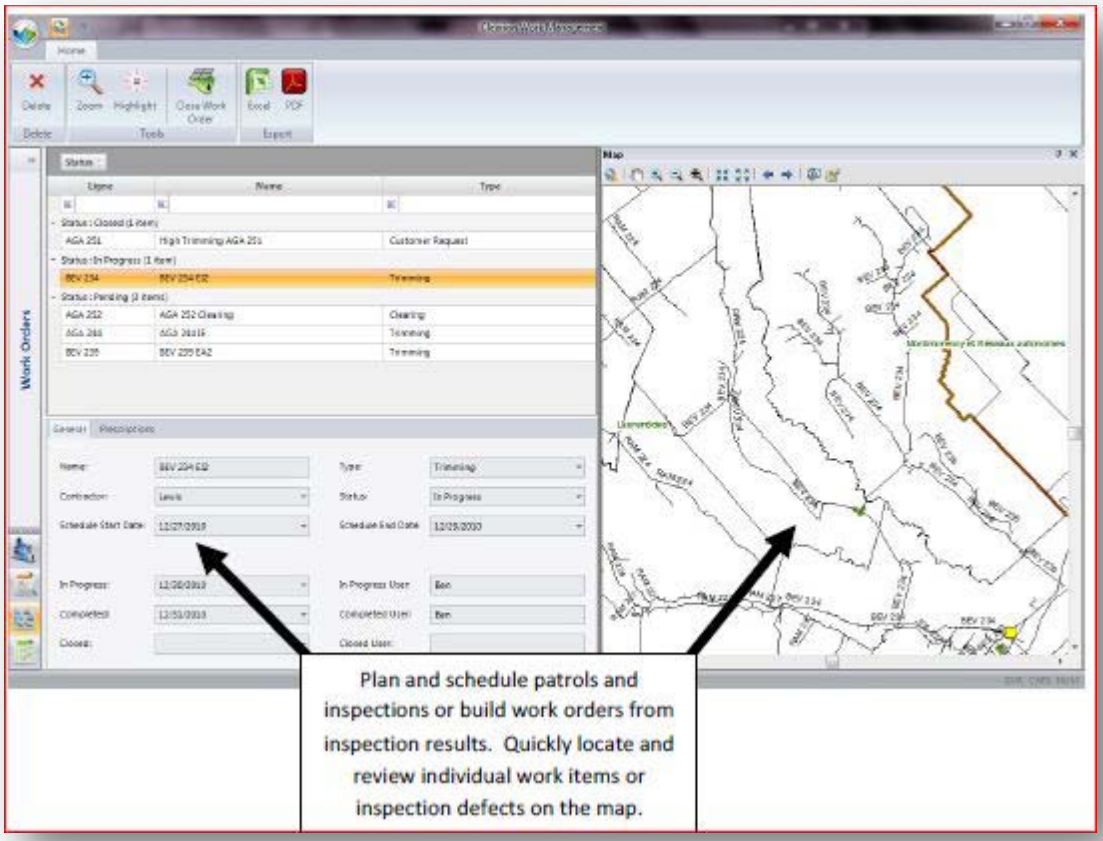

Figure 4-18
The Clearion WM user interface screen 2 (tab) (courtesy of Clearion).

Future Developments

Clearion intends to continue development based on new operating systems and customer needs. Clearion are investigating integrating data for new systems being developed, such as hyperspectral imaging, and intends to develop new management tools to streamline the inspection and reporting tools based on new and emerging technologies as they become available.

GeoDigital

GeoDigital provides airborne data collection service and analysis. Tools such as LiDAR, PLS-CADD and vegetation algorithms are integrated into a vegetation management inspection process. GeoDigital does not use satellite imagery except as background imagery in their Grid Intel Online application (16).

GeoDigital's inspection approach is as follows:

- Airborne laser imagery to generate a 3D point cloud
- The 3D cloud is fused with the LiDAR data (example shown in Figure 4-19)
- Data is converted into nine vegetation alerts (Figure 4-20)

- Infrared imagery or simple Color RGB (Red, Green, and Blue spectral bands) imagery collected during the flights (Figure 4-21 and Figure 4-22).
- Simulation modeling based on proprietary vegetation growth algorithms and LiDAR data along with geospatial analysis. In 2010 through 2012 GeoDigital carried out a study of a 40 mile/65 kilometer segment of ROW to determine the accuracy of their vegetation growth algorithm. The aim was to predict two years of growth on each canopy segment without using the second year's data. Examples of growth accuracy predictions are given in Figure 4-23 and the accuracy versus height is shown in Figure 4-24.
- The following growth attributes are considered:
  1. Tree growth based on:
     - Water
     - Nutrients
     - Shading
     - Species
  2. Physical attributes of structure to vegetation
     - Slope
     - Elevation
     - Aspect
  3. Simulations
     - Statistical methods to predict the risk of canopy heights
     - Trees with a high probability of becoming a violation within the next two years
- Determine ROW clearances. Clearance detection algorithms are used to measure radial distance from the conductor to vegetation LiDAR points. Any LiDAR point that fails the minimum clearance threshold is flagged as shown in Figure 4-25. The canopy segmentation algorithms are applied to all vegetation along the ROW as shown in Figure 4-26. Simulation models are developed using LiDAR data and geospatial analysis.
- The vegetation and LiDAR points are combined with the canopy segments creating a new level of information. This gives a basis for vegetation quantification. Vegetation LiDAR points can be isolated from canopy segments, generating estimates of tree count, tree height, tree diameter and volume with 5 cm claimed accuracy. Merging ROW boundaries with vegetation LiDAR allows projections of vegetation alerts by NERC FAC-003 Clearance Category as show in Figure 4-27.
- The distance from each vegetation canopy to the conductor at maximum sag can be projected as well as future growth of the risk trees. Figure 4-28 shows the baseline for this projected growth.



Figure 4-19
3D colorized and fused LiDAR imagery (courtesy of GeoDigital).

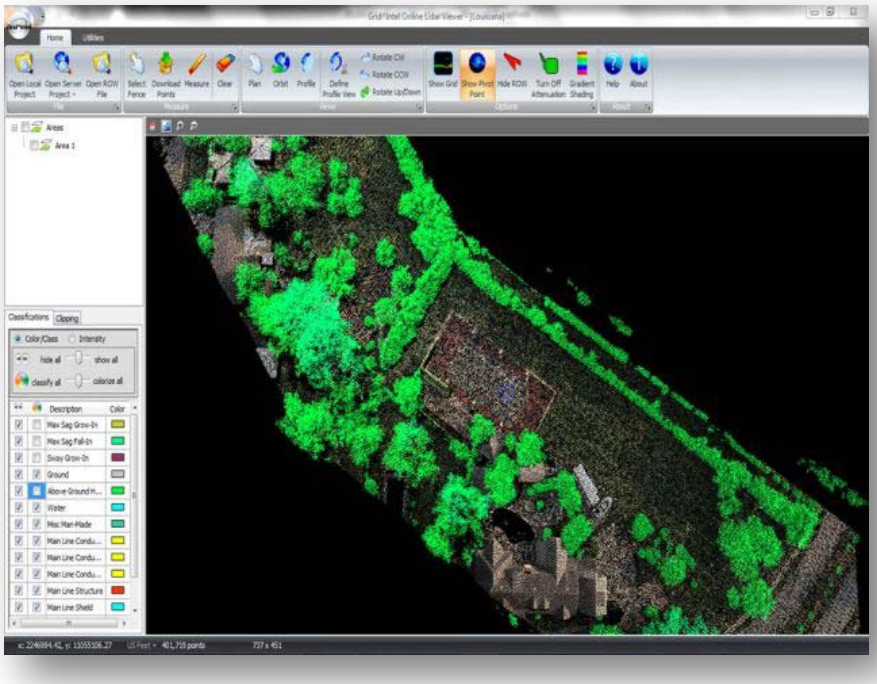

Figure 4-20
An example of 3D colorized and fused LiDAR imagery into 9 vegetation alerts (courtesy of GeoDigital).

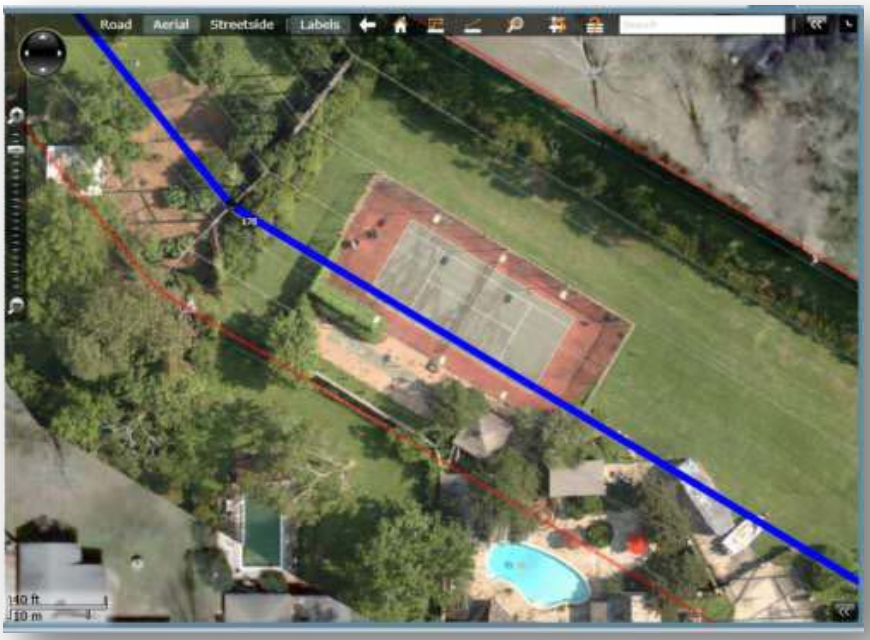

Figure 4-21
Color imagery RGB (courtesy of GeoDigital).

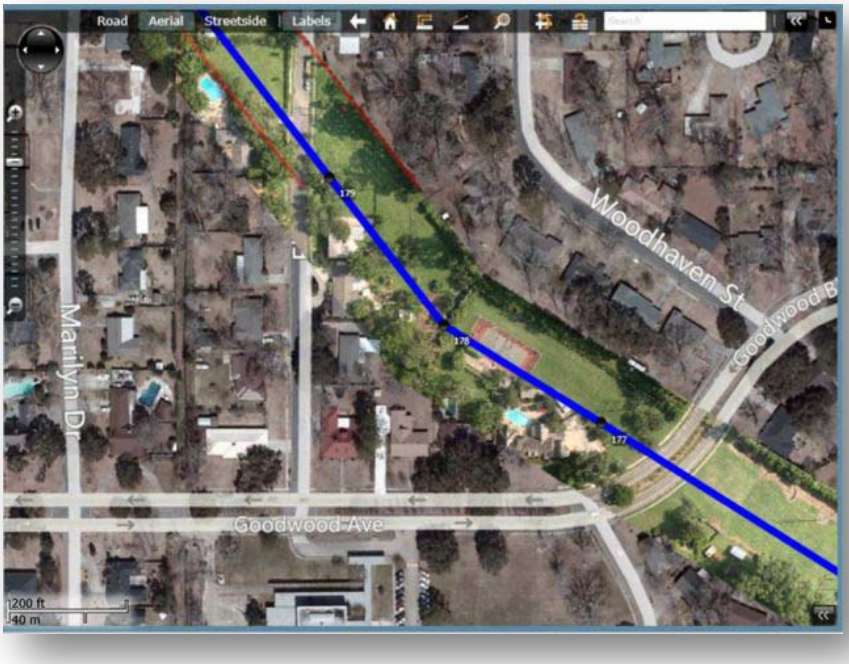

Figure 4-22

Satellite imagery is used as background imagery with embedded client RGB ortho-imagery of the ROW (courtesy of GeoDigital).

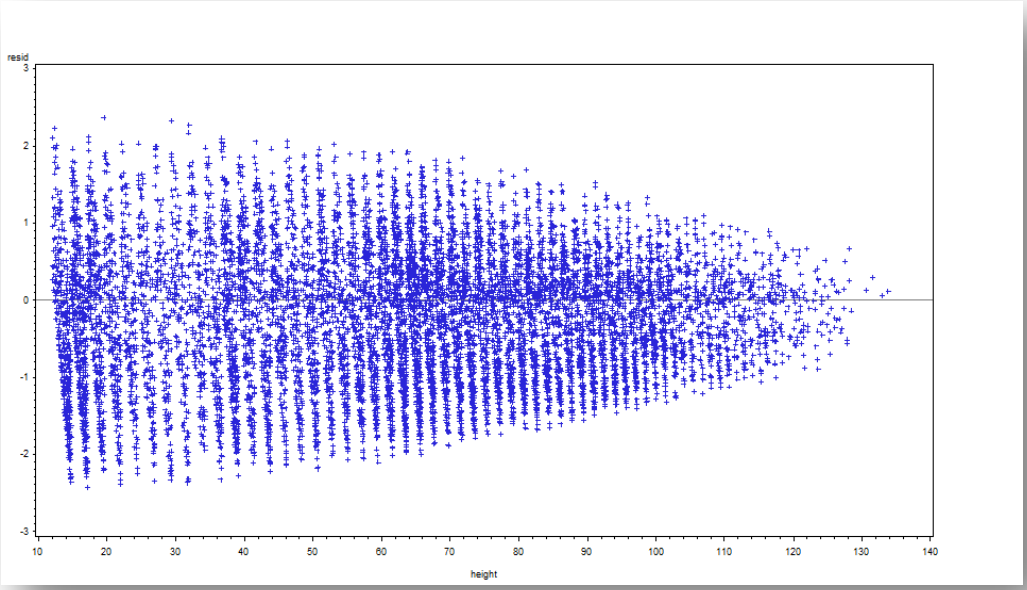

Figure 4-23
Accuracy of growth prediction on the Pennsylvania Study (courtesy of GeoDigital).

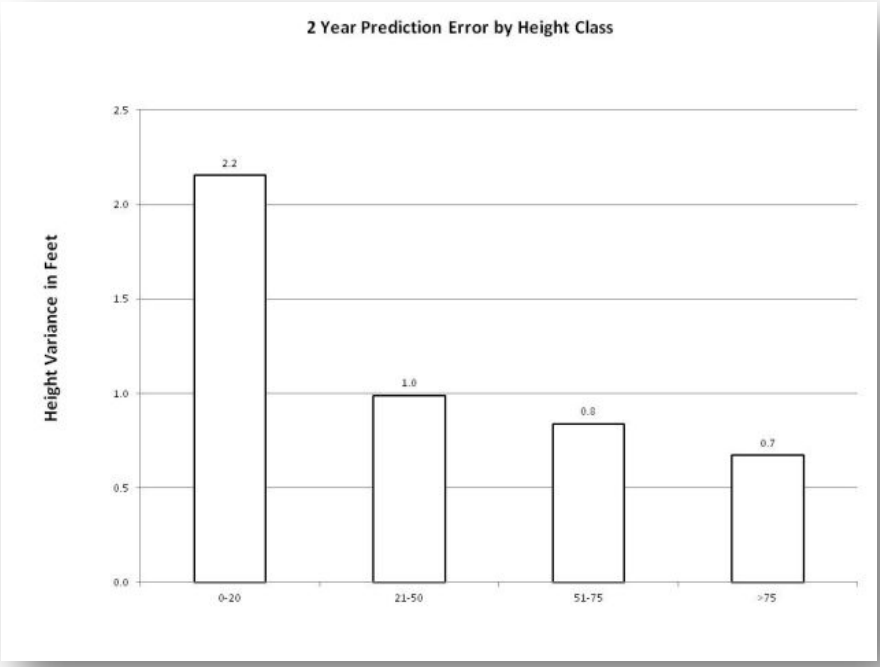

Figure 4-24
Accuracy of growth prediction vs. height (courtesy of GeoDigital).



Figure 4-25
LiDAR points that fail the minimum clearance threshold (courtesy of GeoDigital).

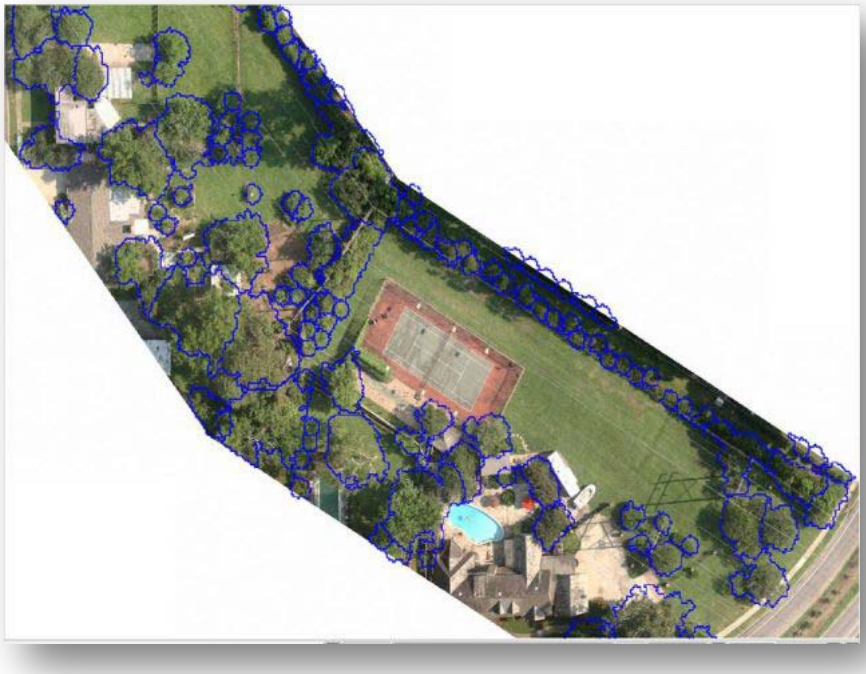

Figure 4-26
The canopy segmentation algorithm defines all vegetation on the ROW (courtesy of GeoDigital).

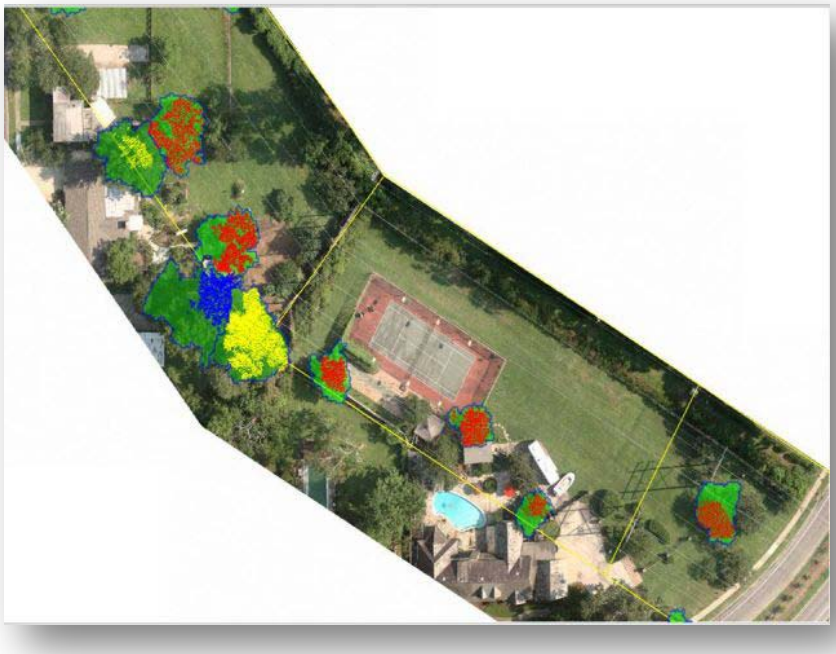

Figure 4-27
NERC FAC-003 projections (courtesy of GeoDigital).



Figure 4-28
Baseline of predicted growth (courtesy of GeoDigital).

Figure 4-29 shows the results of clearance detection algorithms applied against the LiDAR point cloud. This provides clients with NERC compliance information.

- Red = grow-in on ROW NERC category 1 conditions
- Yellow = Fall-in on ROW NERC category 2 clearance conditions.

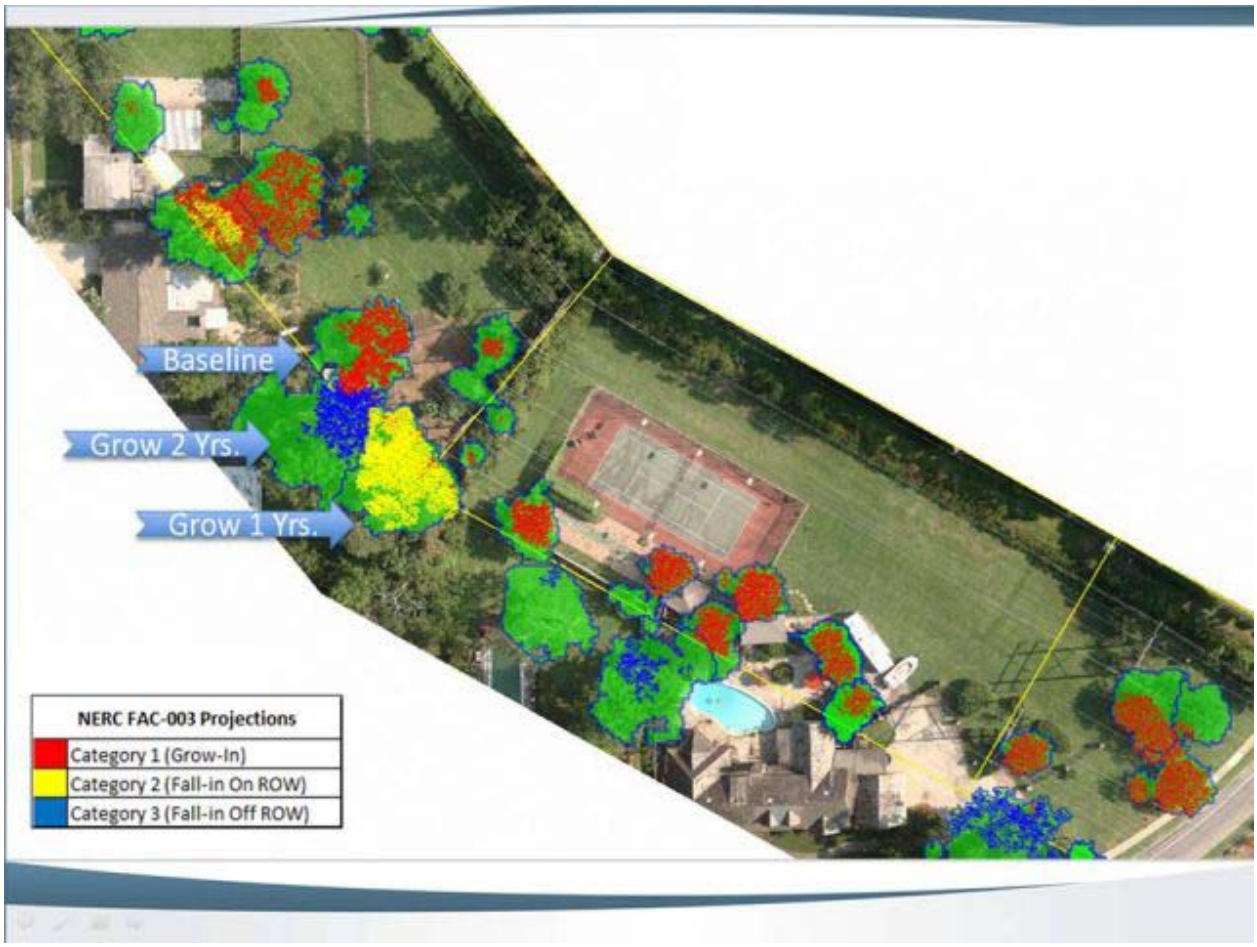

Figure 4-29
The predicted growth model and NERC FAC-003 projections (courtesy of GeoDigital)

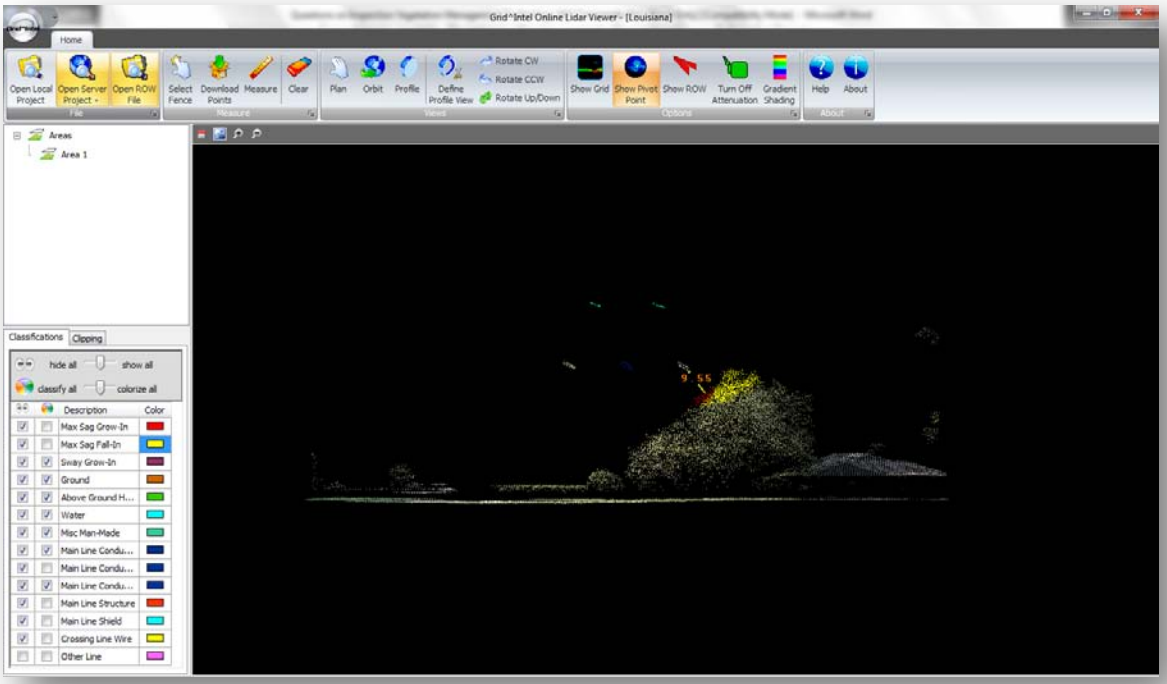

Figure 4-30
The results of clearances (courtesy of GeoDigital).

A work management platform for transmission and distribution utilities called WorkStudio (Figure 4-31) is a proprietary data acquisition and field reporting system that provides real-time reporting for a variety of compliance, maintenance and engineering activities. WorkStudio combines traditional corridor imagery and asset mapping products with LiDAR that provides the capability to survey transmission lines for clearance problems, danger vegetation and abnormal geometry. WorkStudio delivers actionable information in the form of task orders for immediate action by utility staff or contractors within hours of the survey flights.

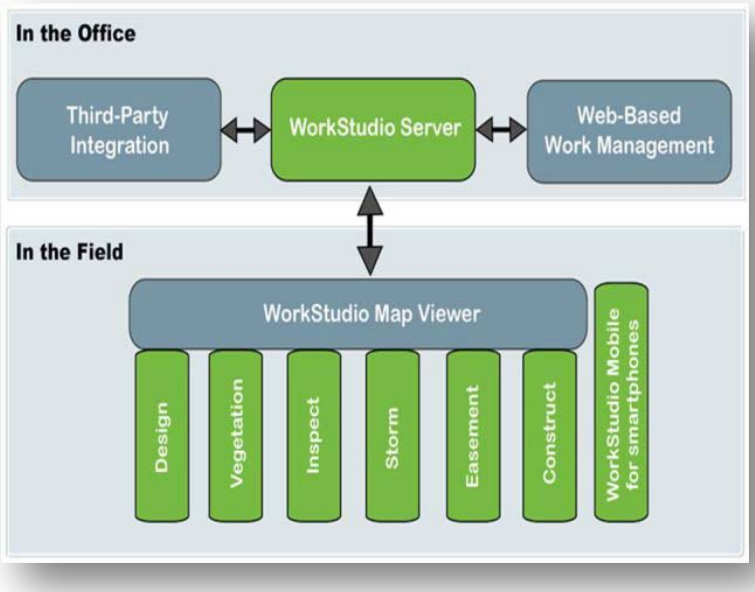

Figure 4-31
A WorkStudio block diagram of the flow of work (courtesy of GeoDigital).

Future Developments

GeoDigital intends to update their hardware with new a LiDAR system, such as the RIEGL LMS-Q1560, and incorporate new species of vegetation algorithms as new information becomes available. Currently GeoDigital only has algorithms for conifer and hardwood trees but intends to continue to development and investigate hyperspectral imagery as the technology becomes mainstream.

Pictometry International Corporation

Pictometry International's PentaView capture system is an aerial image capture process that produces imagery showing the fronts and sides of buildings, objects, and locations on the ground. Images are captured and processed using a fleet of 74 aircraft equipped with its PentaView capture system. The capture system is specially designed for ROW inspection by combining a RIEGL LMS-Q680i LiDAR system and 170-mm aerial photogrammetric lenses to capture fully geo-referenced ultra-high resolution imagery and dense LiDAR point clouds from fixed-wing aircraft. Pictometry's process fully geo-references the images, allowing for direct measurement and GIS data overlay without warping the image content. This allows analysts to discern details from the imagery (17). Pictometry's PentaView capture system consists of:

- One forward looking 29MP RGB camera with a custom 120-mm photogrammetric lens enabling it to capture between 1-inch/25.4-mm and 2-inch/50.8-mm GSD imagery, depending on flight parameters. GSD is the distance between pixel centers measured on the ground.
- One rear looking 29MP RGB camera with the same specifications as the forward looking camera.

- Two vertical camera systems with custom 85-mm photogrammetric lenses enabling it to capture between 1.5-inch/38.1-mm and 3-inch/76.2-mm GSD imagery, depending on flight parameters.
- One RIEGL LMS-Q680i LiDAR sensor capable of capturing between 5 and 10 points per square meter/square yard (approx.), depending on flight parameters, with its 170-mm aerial photogrammetric lenses.

Pictometry provides an online tool that displays third-party satellite imagery as a background at high elevations. When the user zooms in on an area of interest the satellite image is replaced with the full high-resolution ortho and oblique imagery collected during the inspection. Pictometry's processes allow analysts to extract 3D information directly from individual images. Figure 4-32 shows an example of high-resolution oblique imagery.



Figure 4-32
High resolution oblique imagery provides greater coverage across the corridor (courtesy of Pictometry Intelligent Images).

Data collected during inspections from both oblique and ortho perspectives are imaged/captured while the LiDAR data collection is performed using fixed-wing aircraft. Large areas of corridor data are collected in single flights, including:

- High- resolution imagery of the ROW.

- LiDAR unit information synced with the imagery for discrete vegetation modeling.
- Wide swath collection - imaging entire corridor in a single pass.
- Data processing is done by synchronizing the LiDAR data from the aircraft with the high-resolution oblique and ortho-imagery's as shown in Figure 4-33. This is followed by meshing a utility PLS-CADD file/ model (Figure 4-34) with new LiDAR vegetation point cloud data to make the control data set (Figure 4-35).

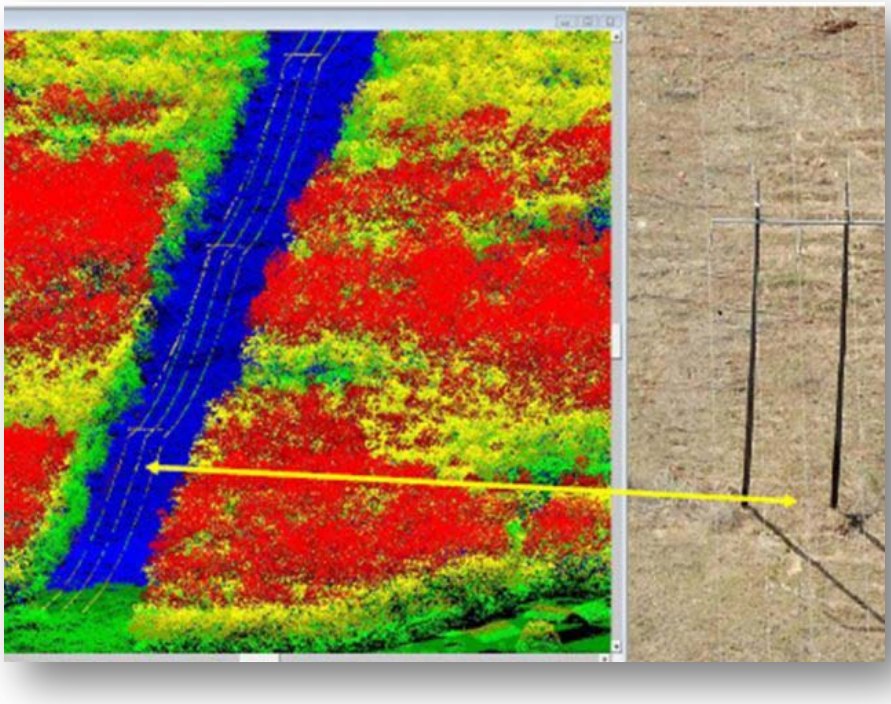

Figure 4-33
LiDAR from the aircraft is processed and synchronized with the high-resolution oblique and ortho imagery (courtesy of Pictometry Intelligent Images).

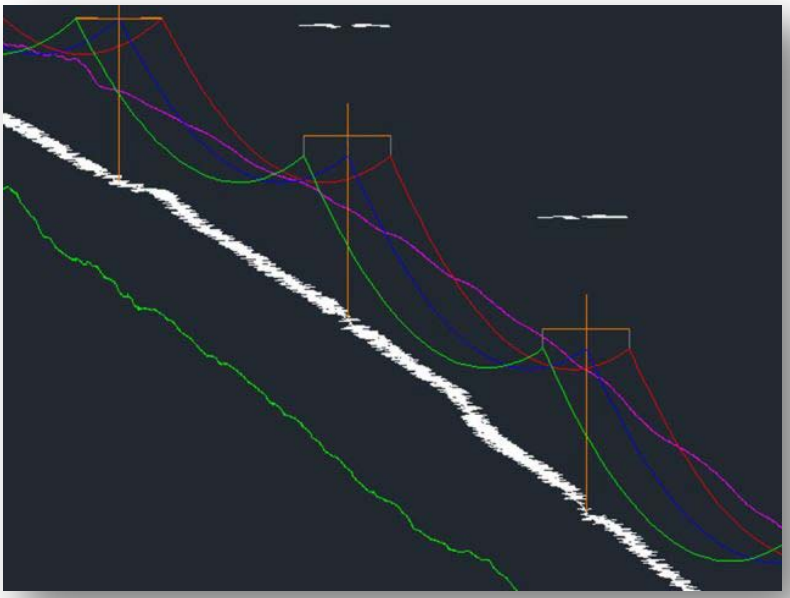

Figure 4-34
A customer's stick structure or PLS-CADD data (courtesy of Pictometry Intelligent Images).

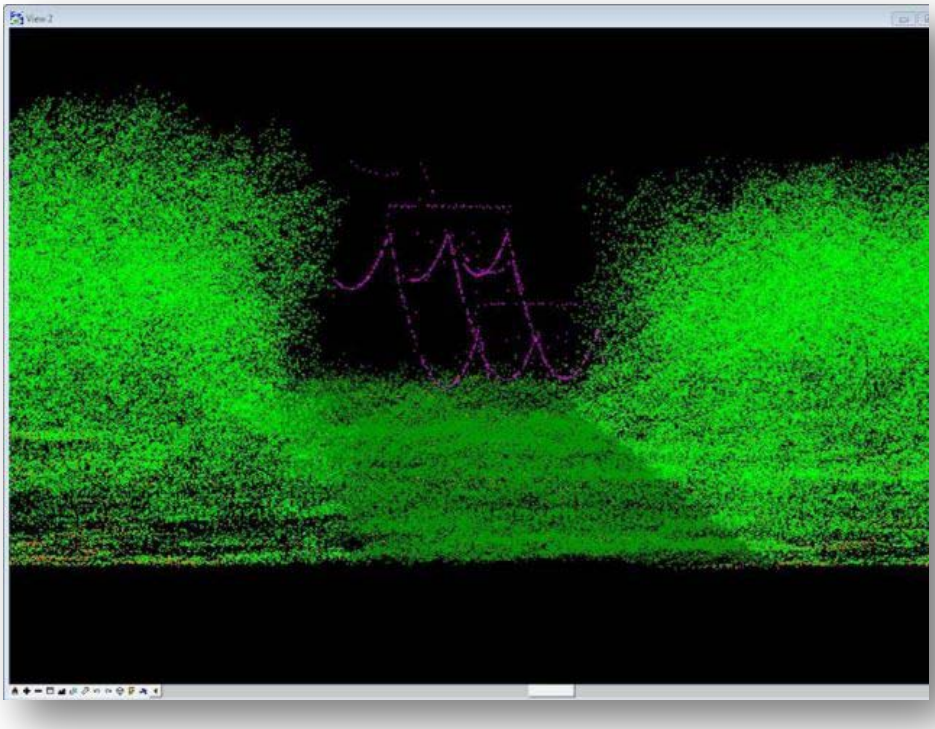

Figure 4-35
A new vegetation point cloud referenced to control data (courtesy of Pictometry Intelligent Images).

The analysis highlights areas of potential vegetation encroachment. The top of structures, cross arms and attachment points are verified and compared between the control and the new LiDAR model (Figure 4-36). A flagged area scan can be reviewed in greater detail using the oblique imagery. Inconsistencies are checked against the imagery and verified. Unclassified LiDAR points are verified through the use of synchronized imagery as shown in Figure 4-37. Where conflicting information is found, the high-resolution metric oblique images are used to verify the existence on new structures and attachment locations as shown in Figure 4-38.

Oblique and ortho-imagery is made available through a cloud-based deployment that allows both office based and mobile review of imagery. Software provided by Pictometry to the utility assists with the identification of the potentially encroaching objects. The ortho-imagery is provided on digital media for incorporation and utilization directly by a utility's GIS. Height and distance information can also be measured directly off the imagery using web-based deployments.

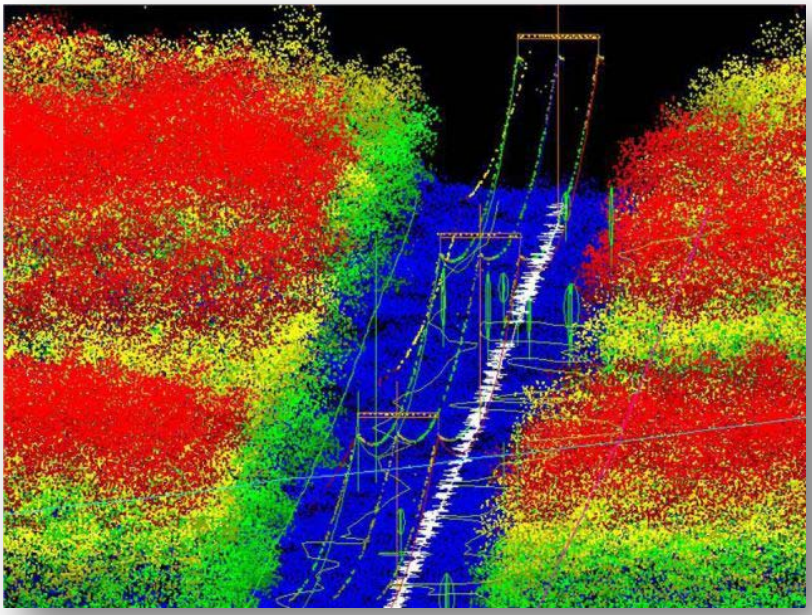

Figure 4-36
Data validation between the control file and a new LiDAR model (courtesy of Pictometry Intelligent Images).

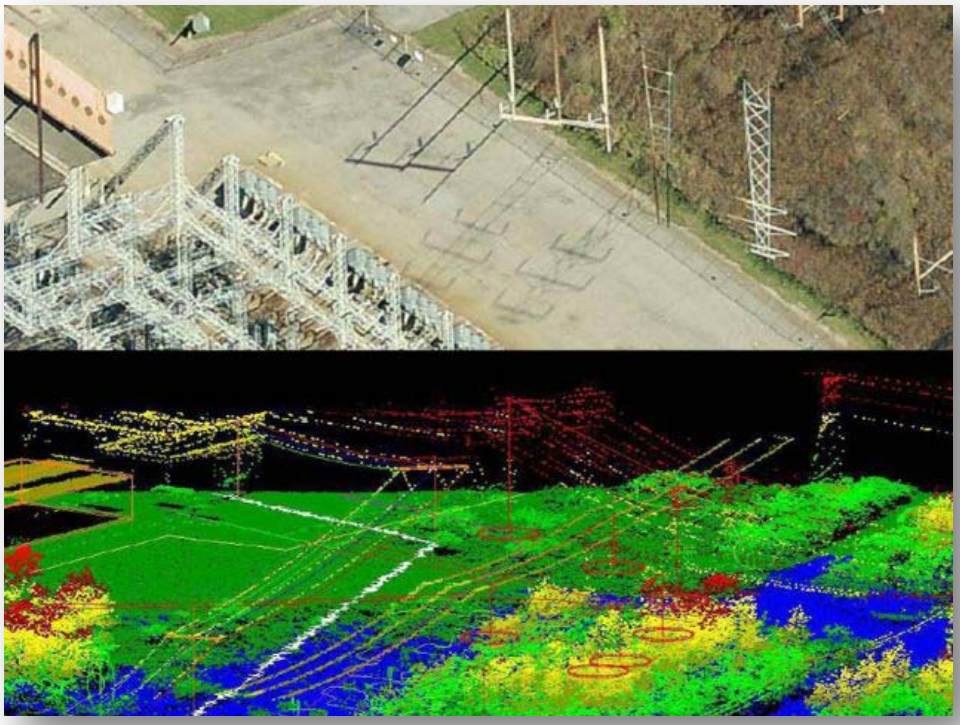

Figure 4-37
Data/image verification by synchronized imagery (courtesy of Pictometry Intelligent Images).



Figure 4-38
Imagery QA/QC verification of conflict (courtesy of Pictometry Intelligent Images).

The combination of imagery and LiDAR is used to create vegetation clearance reports. The full vegetation clearance analysis is undertaken on the joined datasets. Figure 4-39 and Figure 4-40 provide an example of one such a report. In addition to this, oblique and ortho-imagery is presented directly to provide a greater view of the corridor to analyze features from a viewpoint typically not provided by traditional rotary-based image collection. Inspectors can then concentrate their ground-based efforts in areas identified by this process. The imagery and software are also deployable throughout the enterprise and can be made available to others who wish to view and analyze the corridor for other mapping or inspection purposes.

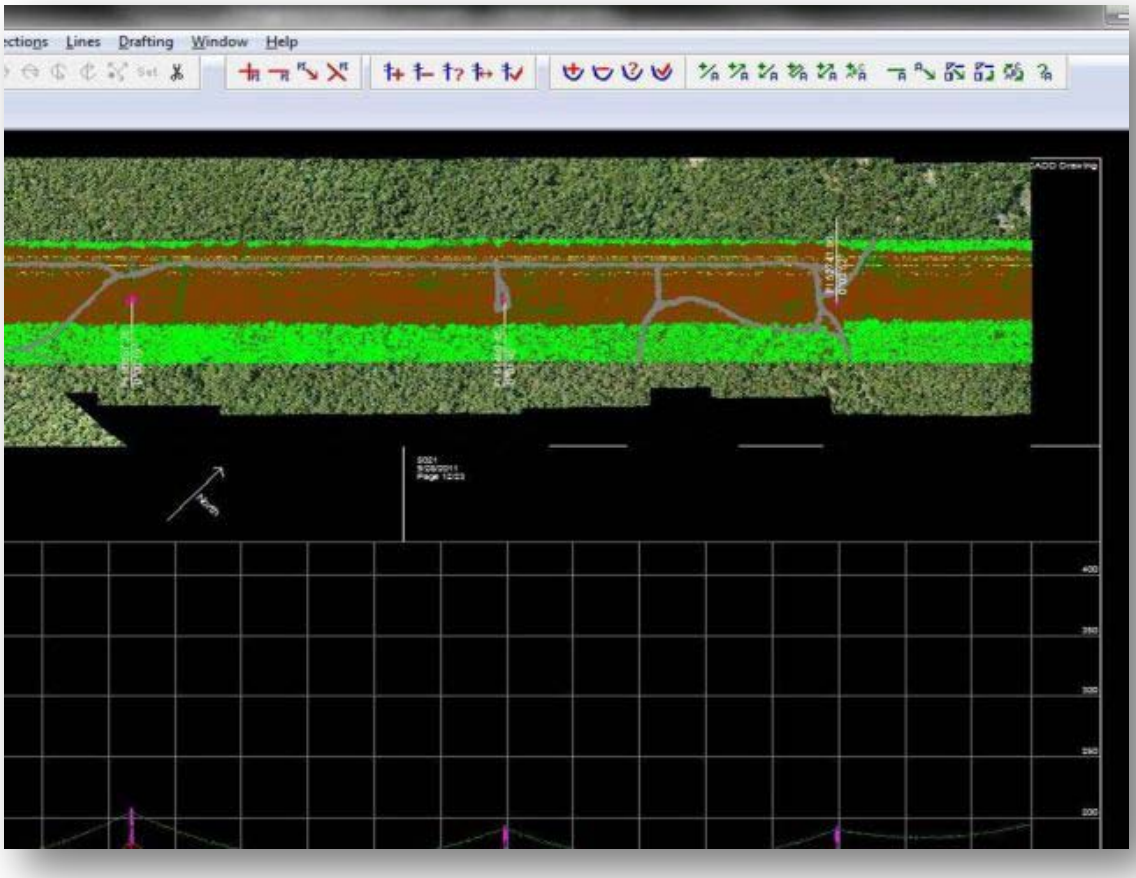

Figure 4-39
A standard vegetation clearance report, plan and profile is delivered to the customer (courtesy of Pictometry Intelligent Images).

Pictometry also provides a Critical Response inspection service for post-disaster flights based on its Real-time Airborne Management System (RAMS). RAMS delivers imagery to the ground in a matter of seconds. A new version of RAMS has been created that allows the utility customer to re-task the aircraft in the field to fly to affected areas quicker to assess storm damage. When the airplane lands, the system data drive is pulled from the airplane and plugged into a Ground Receiving Unit for immediate use by the company's enterprise GIS system through use of Esri's ArcGIS image server. Analysts throughout the utility can use the information to assist in the location and identification of storm or manmade disaster damage. In tests performed with utility customers, simulated damage was able to be identified/ spotted from the high-resolution imagery.

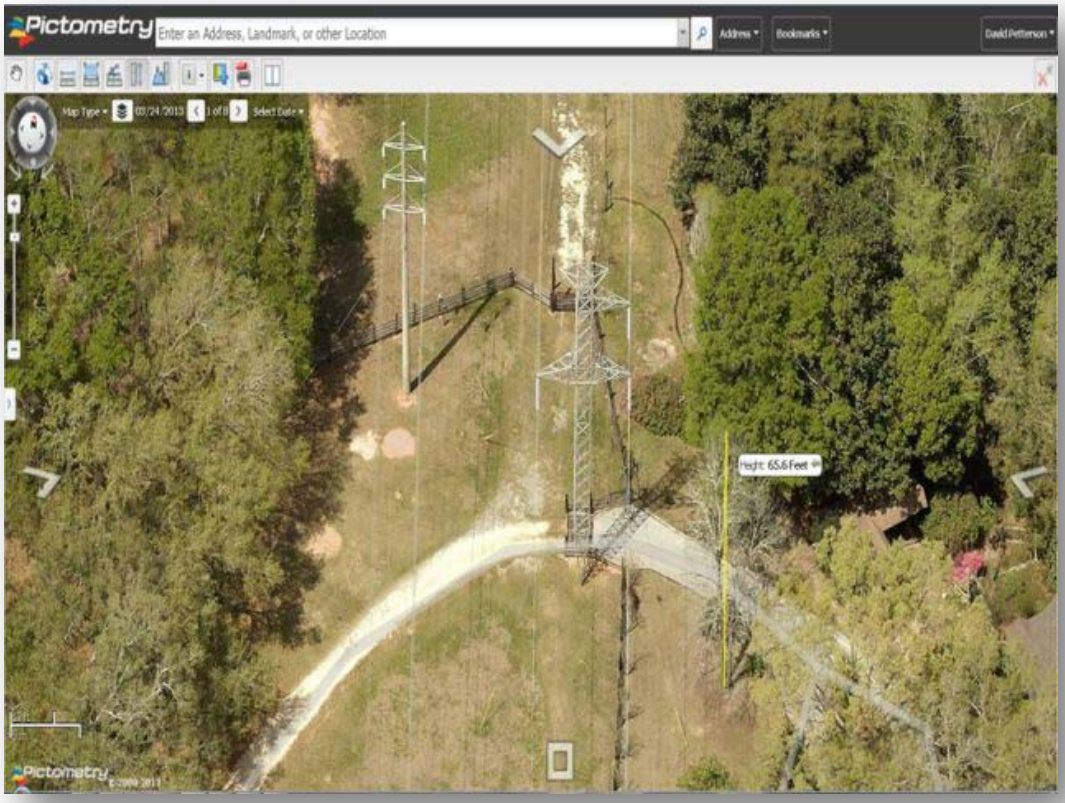

Figure 4-40
Accurate height and distance information are being measured directly off the imagery,using easy web-based deployments (courtesy of Pictometry Intelligent Images).

Future Developments

Pictometry intends to continue hardware updates including new LiDAR systems and cameras, and enhance LiDAR point clouds and generation of 3D models. Pictometry intends to continually update its user interfaces and investigate hyperspectral imaging as the technology becomes mainstream.

5
CONCLUSION

This report presents the findings into various vegetation inspection technologies and processes. As noted in the introduction, the state-of-the-art vegetation inspection technologies is ever changing and expanding as new technologies become available. The information represents a snapshot and should be updated on an ongoing basis in an effort to stay current with advancements in technologies. Inspection approaches differ depending on the vendor, but the basis of combining the use of high-resolution imagery, LiDAR and GIS appears to be similar.

Some key observations include:

- Utilities need to specify data and information requirements provided by vendors to ensure they receive the information they need in the format they want. Vendors need to supply examples of the deliverables and how (for North American utilities) they comply with the FERC regulations. This will insure that the utilities are getting what they need, not just data that they have to do more integration on.
- Similarly, manufacturers, software developers and LiDAR inspection providers need to focus on providing information that is easy to use.

6
REFERENCES

1. NERC FAC-003-3, Transmission Vegetation Management inspection requirement from NERC", http://www.nerc.com/files/FAC-003-3.pdf
2. RIEGL Laser Measurement Systems provided information and figures, http://www.riegl.com/nc/products/mobile-scanning/
3. TopEye (Blom) provided information and figures, http://www.airbornelasermapping.com/Features/ALMSpo01.html
4. Velodyne provided information and figures, http://velodynelidar.com/lidar/lidar.aspx
5. Topcon provided information and figures, http://global.topcon.com, http://www.topconpositioning.com/products/hand-held-devices/gnssgis-devices/grs-1-gis
6. J. Sawada, K. Kusumoto, Y. Maikawa, T. Munakata, and Y. Ishikawa, "A mobile robot for inspection of power transmission lines," IEEE Transactions on Power Delivery, vol. 6, pp. 309 - 315, Jan. 1991.
7. S. Peungsungwal, B. Pungsiri, K. Chamnongthai, and M. Okuda, "Autonomous robot for a power transmission line inspection," in Proceedings of the IEEE International Symposium on Circuits and Systems,vol. 3, (Sydney, Australia), pp. 121{124, 6{9 May 2001
8. US Patent# 20060114122 - Power Line Inspection Vehicle
9. Aerotec provided information and figures, http://www.aerotecusa.com/ept_veg_mgmt.shtm
10. Ryan Paulk, "LiDAR Technology and Handheld Vegetation Management Device Aid Transmission Group at El Pasco Electric" page 30 Electric Energy - Summer 2011, http://issuu.com/hungryeyemedia/docs/2011_issue2_rmel
11. Lois P. Sicking, "Forest Management Tech Tips - Rangefinder Comparison", United States Department of Agriculture Forest Service February 1998, http://www.fs.fed.us/t-d/pubs/html/98241307/98241307.html
12. LASER TECHNOLOGY, INC provided information an figures, http://www.lasertech.com/Professional-Measurement.aspx
13. HySpex provided technical information and figures, http://www.hyspex.no/index.php
14. DigitalGlobe provided technical information and figures, http://www.geoeye.com/; https://www.google.com/search?sourceid=navclient&aq=&oq=Who+owns+the+GeoEye-1+Satellite&ie=UTF-8&rlz=1T4GGHP_enUS517US517&q=Who+owns+the+GeoEye-1+Satellite&gs_l=hp....0.0.0.54099.....0.ruRQlIW2hyo
15. CLEARION Software provided technical information and figures, http://www.clearion.com/our-technology.html

16. GeoDigital provided technical information and figures of their process, http://www.geodigital.com/
17. Pictometry provided technical information and figures of their process, http://www.pictometry.com/index.php?option=com_content&view=article&id=66&Itemid=75

A

LITERATURE REVIEW SUMMARY OF INSPECTION TECHNOLOGIES FOR THE ELECTRIC UTILITY INDUSTRY

Table A-1
Articles/Paper/Reference material on Vegetation Inspection Technologies for the Electric Utility Industry

Ref. No	Title of Article	Author(s)	Summary/Abstract	Keywords	Source
1	ArcGIS API for Android App Streamlines Field Inspections	Jozef Kaslikowski, Tri-County Electric Membership Corporation	This article discusses an electric cooperative, Tri County Electric Corporation, developing an app with ArcGIS API for Android that moved its field equipment inspection process from a paper-based one to a streamlined operation using GPS-enabled tablets.	ArcGIS Android App Inspection	http://www.esri.com/news/arcuser/0312/arcgis-api-for-android-app-streamlines-field-inspections.html
2	A mobile robot for inspection of power transmission lines	J. Sawada, K. Kusumoto, Y. Maikawa, T. Munakata, and Y. Ishikawa	This article describes the development of a mobile robot that can navigate overhead power transmission lines completely unattended by a human operator.	Robot for Transmission Lines	http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=103753&url=http%3A%2F%2Fieeexplore.ieee.org%2Fiel3%2F61%2F3207%2F00103753.pdf%3Farnumber%3D103753 IEEE Transactions on Power Delivery, vol. 6, pp. 309, Jan. 1991.
3	Autonomous robot for a power transmission line inspection	S. Peungsungwal, B. Pungsiri, K. Chamnongthai, and M. Okuda	The article discusses an autonomous robot for transmission line inspection, and describes how the robot moves along a transmission line.	Robot for Transmission Lines	http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=921261&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D921261 In the Proceedings of the IEEE International Symposium on Circuits and Systems, vol. 3, (Sydney, Australia), pp. 121{124, 6{9 May 2001

Table A-1 (continued)
Articles/Paper/Reference material on Vegetation Inspection Technologies for the Electric Utility Industry

Ref. No	Title of Article	Author(s)	Summary/Abstract	Keywords	Source
4	A Tool for Vegetation Management New Uses for Geographic Software	Salvatore Salamone	This article discusses the usefulness of geographic information system software and the application of GIS based on the application to create and print digital maps for vegetation management.	GIS software Vegetation Utilities	http://www.energybiz.com/magazine/article/168735/tool-vegetation-management?quicktabs_4=1 EnergBiz Magazine November /December 2010
5	Compressive Collection	Don Talend	This article discusses the usefulness of geographic information system software and the application of GIS based on the application to create and print digital maps for vegetation management.	Mobile LiDAR	http://www.amerisurv.com/content/view/7742/153/ American Surveyor, Vol. 7 No.6 Copyright 2010
6	Dominion Electric Transmission – LiDAR as an Asset Management Tool	Brett Crable, PE Director – Electric Transmission	PowerPoint presentation by Dominion on the application of LiDAR, PLS-CADD and work management system of their system.	Asset management tool, LiDAR	http://www.eei.org/meetings/Meeting%20Documents/2010-10-03-TDM-Tuesday-2-Crable.pdf October 2010 http://www.lockheedmartin.com/us/news/press-releases/2012/january/isgs-0124-dominion-edge.html
7	GIS Enhances Hazard Tree Control	Comfort Manyame, Mid-South Synergy Electric Coop	The article discusses the use of GIS and soil data for identifying hazardous trees for removal.	GIS modeling, Soils Vegetation management	http://tdworld.com/print/vegetation-managem3-03-01nt/gis-enhances-hazard-tree-control Transmission and Distribution World, May 1,2013
8	For Vegetation Management, All LiDAR Is Not Created Equal	Roland Mangold	The article points out what customers (utilities) need to understand, what information they are asking for and how the final deliverables need to be presented for LiDAR surveys.	LiDAR NERC Image mapping	http://www.elp.com/articles/powergrid_international/print/volume-14/issue-2/features/for-vegetation-management-all-lidar-is-not-created-equal.html Electric Light & Power

Table A-1 (continued)
Articles/Paper/Reference material on Vegetation Inspection Technologies for the Electric Utility Industry

Ref. No	Title of Article	Author(s)	Summary/Abstract	Keywords	Source
9	How GIS works	Environmental Systems Research Institute, Inc.	The article explains how GIS works and how GIS interfaces with other layers of information.	GIS	http://www.sfu.ca/rdl/GIS/tour/gis_wrk.html
10	Is Your Vegetation Management Program Sustainable?	Nelsen Money	The article discusses the attributes that will make your Vegetation Management Program work. The article discusses the application of LiDAR.	LiDAR FERC	http://www2.dupont.com/Land_Management/en_US/assets/downloads/pdfs/Brush/SustainableVM_TDW_June2012.pdf
11	LiDAR Meets NERC Alert	Gene Wolf, Technical Writer	An article why NERC is pushing for new technology such as LiDAR to verify as built configurations of transmission lines to avoid future black outs.	LiDAR Blackouts NERC	http://tdworld.com/overhead-transmission/lidar-meets-nerc-alert TW World 2011-08-01
12	LiDAR Enters the Third Dimension	Gene Wolf, Technical Writer	A T&D article that discusses existing technologies and where they are trying to go in the future. The technologies that are explored are LiDAR, PLS-CADD, UAV's, robots and sensor devices.	LiDAR Robots NERC Unmanned Aerial Vehicles (UAV)	http://tdworld.com/smart-grid/lidar-enters-third-dimension TD World 2011-08-01

Table A-1 (continued)
Articles/Paper/Reference material on Vegetation Inspection Technologies for the Electric Utility Industry

Ref. No	Title of Article	Author(s)	Summary/Abstract	Keywords	Source
14	LiDAR for vegetation applications	P. Lewis and S. Hancock UCL, Gower St, London, UK plewis@geog.ucl.ac.uk	This provides an introduction to the topic of LiDAR remote sensing for vegetation applications.	LiDAR	http://www.google.com/url?sa=t&rct=j&q=&esrc=s&frm=1&source=web&cd=7&ved=0CFQQFjAG&url=http%3A%2F%2Fwww.geog.ucl.ac.uk%2F~plewis%2Flidarforvegetation%2FLiDARforVegetationApplications.doc&ei=jlaWUfmHCKf6yQHx6oC4Bg&usg=AFQjCNHd7_YGS2nWMwDNONi6Yksjd_oEBA&sig2=25wEOfQt6xJxkxJH8NUBmQ&bvm=bv.46751780,d.aWc January 23, 2007
15	LiDAR Technology and Handheld Vegetation Management Device Aid Transmission Group at El Pasco Electric	Ryan Paulk, Transmission Engineer, El Paso Electric Company	The article discusses the integration or coupling of LiDAR data with handheld technology for vegetation management for additional verification and inspection. It discusses the application of the TopGun Veg-Tool.	LiDAR Handheld Device Vegetation Management	http://issuu.com/hungryeyemedia/docs/2011_issue2_rmel page 30 Electric Energy - Summer 2011
16	NERC FAC-003-3	Website	A copy of the Transmission Vegetation Management inspection requirement from NERC.	Standards and Requirements NERC	http://www.nerc.com/files/FAC-003-3.pdf

Table A-1 (continued)
Articles/Paper/Reference material on Vegetation Inspection Technologies for the Electric Utility Industry

Ref. No	Title of Article	Author(s)	Summary/Abstract	Keywords	Source
17	NIPSCO Streamlines Vegetation Management	Jason Lietz, Northern Indiana Public Service Co. (NIPSCO), and Amy Fischbach, Contributing Editor	The article shows how utilities are shifting from paper-based record keeping to mobile technology to improve the productivity of its field workforce.	Mobile Devices for Vegetation Management GPS GIS	http://datasourcemobility.com/photos/psc-tb-tdworldcoverage-3-1-11.pdf March 2011 | www.tdworld.com
18	Pilot Highlights LiDAR Effectiveness	Geoff Helfrich, BC Hydro, and Darren T. Janzen, Bluewater Business Solutions	The article describes how BC Hydro uses a software application to capture accurate vegetation inventories, risk assessments and treatment plans. .	LiDAR Aerial LiDAR, Ground-based Survey	http://tdworld.com/vegetation-management/pilot-highlights-lidar-effectiveness TD World June 1, 2012
19	SAIC Assists Tacoma Power with 3-Dimensional Modeling of Transmission Facilities	Keith Kerzel, vice president for SAIC	This T&D article describe how SAIC, working with Tacoma Power, modeled transmission line segments using LiDAR and current meteorological data to determine appropriate line sags.	LiDAR PLS-CADD	http://tdworld.com/test-monitor-amp-control/saic-assists-tacoma-power-3-dimensional-modeling-transmission-facilities TD World, 2013-01-15

Table A-1 (continued)
Articles/Paper/Reference material on Vegetation Inspection Technologies for the Electric Utility Industry

Ref. No	Title of Article	Author(s)	Summary/Abstract	Keywords	Source
20	Technology Advances Vegetation Management Software solutions significantly advance Progress Energy's transmission right-of-way management processes	Paul Hurysz Jr. and Jon Crider, Progress Energy	This article discusses the development and integration of inspection software, GIS, and data collection hardware used in Progress Energy's Vegetation Management Inspection Program (VMP).	Technology Vegetation Management Tablet GIS Data Collection	http://tdworld.com/overhead-distribution/technology-advances-vegetation-management TD World October 1, 2009
21	Transmission and Distribution Utility Infrastructure Capital Planning; A LiDAR and GIS-Centric, Data Fusion and Risk-Based Prioritization Approach	Jason Amadori's LIDAR GIS Blog	This blog discusses the application and integration of LiDAR GIS centric asset management database. The blog provides steps in the process of LiDAR data collection, utility asset extraction and inspection data aggregation.	Aerial Photography Airborne LiDAR Asset Management Budget Forecasting, Capital Improvement Planning GIS Infrastructure LiDAR NERC	http://jasonamadori.com/tag/aerial-photography/ Posted in Airborne LiDAR, Asset Management | April 28, 2011

Table A-1 (continued)
Articles/Paper/Reference material on Vegetation Inspection Technologies for the Electric Utility Industry

Ref. No	Title of Article	Author(s)	Summary/Abstract	Keywords	Source
22	Understanding the Benefits of LiDAR Data	L. J. Chaput, business manager, W.I.R.E. Services (www.wireservices .ca), Winnipeg, Manitoba, Canada.	This paper discusses the value of the integrating LiDAR and PLS-CADD information to ensure compliance with NERC regulations.	LiDAR PLS-CADD Vegetation NERC	http://eijournal.com/2012/understanding-the-benefits-of-lidar-data Earth Imaging Journal, 2012
23	US Patent Application 20060114122 - Power line inspection vehicle	Inventor is David L. Jones	This article discusses a patent for a power line inspection apparatus and methods of inspecting power lines. Application was submitted on April 30, 2004 and published on June 1, 2006. The inventor is David L. Jones.	Robot Power Line Inspection Vehicle	http://www.patentstorm.us/applications/20060114122/description.html
24	Vegetation Management Takes to the Air: BC Hydro pilots use of LIDAR and PLS-CADD to identify vegetation encroaching on transmission lines.	Bryan Hooper, British Columbia Hydro	The article discusses the successful pilot project of aerial LiDAR and the use of PLS-CADD to determine the vegetation growth rates in different environments.	PLS-CADD FE Sag Tension Analysis LiDAR	http://pls-pole.com/vegetation.pdf September 2003 Transmission & Distribution World.

Table A-1 (continued)
Articles/Paper/Reference material on Vegetation Inspection Technologies for the Electric Utility Industry

Ref. No	Title of Article	Author(s)	Summary/Abstract	Keywords	Source
25	Vegetation Management - Pay Me Now, or Pay Me More Later	Sam Quattrocchi, Dow AgroSciences	Article on the value of pruning and how it will reduce the number of outages.	FERC	http://www.amostech.com/TechnicalPapers/2010/Posters/McKnight.pdf Utility Automation & Engineering T&D; Jul/Aug 2004, Vol. 9 Issue 4, p62
26	What Trees Cause Service Interruptions	Sig Guggenmoos	An article illustrating the benefits of collecting detailed data regarding tree-related outages.	Vegetation Service Interruptions Outage Events	http://tdworld.com/insights/what-trees-cause-service-interruptions?NL=TDW-08&ISSUE=TDW-08_20130514_TDW-08_591&YM_RID=GRAZIANO1992%40GMAIL.COM&YM_MID=1393942&SFVC4ENEWS=42 T&D magazine, *May 14, 2013*
27	Xcel Goes Airborne to Save Time and Money	Brad Weidenfeller, Xcel Energy	An article on the application of aerial saws for vegetation clearing.	Airborne Trimming Aerial Saw	T World June 1, 2012
28	Xcel Energy and LiDAR" Video at TDWorld	Jim Downie	A video describing Xcel Energy's use of LiDAR, which provides multi-layered data that enables Xcel Energy to actively and efficiently mitigate threats created by the Mountain Pine Beetle epidemic.	LiDAR Multi-layer Data Vegetation Management	http://videos.tdworld.com/video/Xcel-Energy-and-LiDAR;recent

B
LITERATURE SUMMARY ON THE APPLICATION OF INSPECTION TECHNOLOGIES

Table B-1
General Articles/Paper/Reference material on the Application of Inspection Technologies

Ref No.	Title of Article	Author(s)	Summary/Abstract	Keywords	Source
1	Aerial Photography: A Rapidly Evolving Tool for Ecological Management	JESSICA L. MORGAN, SARAH E. GERGEL, AND NICHOLAS C. COOPS	A paper on aerial photography, describing the benefits and challenges of using aerial photographs for ecological management.	Ecosystem Management Historical Information High Spatial-Resolution Imagery Digital Image Analysis and Interpretation Remote Sensing	http://courses.washington.edu/esrm304/pdfs/BioScience2010.pdf BioScience, January 2010, Vol. 60 No.1, pages 47-59.
2	A New Algorithm for Computational Image Analysis of Deformable Motion at High Spatial and Temporal Resolution Applied to Root Growth. Roughly Uniform Elongation in the Meristem and Also, after an Abrupt Acceleration, in the Elongation Zone1	Corine M. van der Weele2, Hai S. Jiang, Krishnan K. Palaniappan3, Viktor B. Ivanov, Kannapan Palaniappan, and Tobias I. Baskin*	A paper on the methodology used in the development of a root growth algorithm.	Spatial Distribution Tip-Tracking Algorithm Imaging	http://www.plantphysiology.org/content/132/3/1138.full.pdf+html

Table B-1 (continued)
General Articles/Paper/Reference material on the Application of Inspection Technologies

Ref No.	Title of Article	Author(s)	Summary/Abstract	Keywords	Source
3	A review of hyperspectral remote sensing and its application in vegetation and water resource studies	M Govender[1], K Chetty and H Bulcock	A paper on the differences between multispectral and hyperspectral data; spatial and spectral resolutions; and it describes the application of hyperspectral imaging in water resource studies.	Hyperspectral Multispectral Spectral Resolution Spatial Resolution Vegetation Classification Water Resources	http://www.ajol.info/index.php/wsa/article/view/49049 Available on website http://www.wrc.org.za ISSN 0378-4738 = Water SA Vol. 33 No. 2 April 2007 ISSN 1816-7950 = Water SA (on-line)
4	Color Aerial Photography	Jeffrey Gillan	A paper on aerial photography that examines the pros and cons of different U.S. agencies' experiences with divergent applications for rangeland science and natural resources management.	Satellite Sensors Unmanned Aircraft Systems	http://wiki.landscapetoolbox.org/doku.php/remote_sensor_types:color_aerial_photography http://www.landscapetoolbox.org/about/partners
5	Current Developments in the Technology- Airborne Topographic Laser Scanners	Gordon Petrie	An article on the progress and success of airborne laser scanners.	TopEye Mk II Elliptical Laser-Scanning System FLI-MAP 1000 LiDAR Sensors	http://www.riegl.com/fileadmin/user_upload/Press/Petrie_Airborne_Topographic_Laser_Scanners_GEO_1_2011.pdf GEO Informatics January/February 2011
6	Forest Management Tech Tips Rangefinder Comparison	Lois P. Sicking	Tech tips on different rangefinders and their attributes.	Lasers Rangefinder	http://www.fs.fed.us/t-d/pubs/html/98241307/98241307.html United States Department of Agriculture Forest Service February 1998

Table B-1 (continued)
General Articles/Paper/Reference material on the Application of Inspection Technologies

Ref No.	Title of Article	Author(s)	Summary/Abstract	Keywords	Source
7	Ghost in the Machine- Automating Methodologies for Advanced Asset Management	Ray Mandli	An article on the application of overlaying two mobile LiDAR data sets to reduce the time it takes to analize the data.	Asset Management Mobile LiDAR Geospatial	http://www.lidarnews.com/PDF/LiDARMagazine_Mandli-GhostInTheMachine_Vol3No3.pdf LiDAR Magazine • Vol. 3 No. 3 • Copyright 2013 Spatial Media
8	How does Satellite Imaging Work?	Webpage	A website on how satellite imaging works and some frequently asked question about it.	Satellite Imaging	http://answers.ask.com/business/telecommunications/how_does_satellite_imaging_work
9	Hyperspectral imaging	Wikipedia Website	Wikipedia's description of three types of hyperspectral imaging (HSI) devices and the differences between hyperspectral and multispectral imaging.	Hyperspectral Imaging	http://en.wikipedia.org/wiki/Hyperspectral_imaging
10	Information System for the Vegetation Control of Transmission Lines Right-of-way	M. G. M. Jardini, et al University of São Paulo;	A paper on how satellite imaging technology can be adapted to vegetation control along transmission lines.	Airborne Laser Scanning (ALS) Information System Transmission Line Right-of-Way Remote Sensing	http://www.labplan.ufsc.br/congressos/powertech07/papers/239.pdf Paper ID: 239
11	IDRISTI Taiga-Guide To GIS and Image Processing	J. Ronald Eastman Clark Labs, Clark University, August 2009	Guides on GIS and image processing.	GIS Image Processing	http://www.uwf.edu/gis/manuals/idrisi_taiga/taigamanual.pdf https://www.mtholyoke.edu/courses/tmillett/course/geog205/files/remote_sensing.pdf http://www.clarklabs.org/

Table B-1 (continued)
General Articles/Paper/Reference material on the Application of Inspection Technologies

Ref No.	Title of Article	Author(s)	Summary/Abstract	Keywords	Source
12	Introduction to Weather & Climate AOS 101 Satellites Course offered by the University of Wisconsin	Steve Ackerman Website	An overview of satellite imagery concepts offered by the University of Wisconsin.	Satellite Imagery	http://mapmaker.meteor.wisc.edu/~jbrunner/ackerman/satellite/satellitebkgrnd.html
13	LIDAR.COM	Website	Information on the efficient and effective application of LiDAR technologies. .	LiDAR	http://lidarcomm.com/index.html
14	LIDAR GUIDEBOOK: CONCEPTS, PROJECT DESIGN, AND PRACTICAL APPLICATIONS	Brian Raber and James Cannistra	Guidebook on the application and acceptance of LiDAR as an input tool for generating accurate terrain models that are used in a variety of GIS applications.	LiDAR GPS GIS Imagery Aerial	http://www.urisa.org/files/publications/lidar_guidebook/lidar_guidebook.pdf A Collaboration of: Merrick & Company http://www.merrick.com and Sanborn http://www.sanborn.com A Collaboration of: Merrick & Company

Table B-1 (continued)
General Articles/Paper/Reference material on the Application of Inspection Technologies

Ref No.	Title of Article	Author(s)	Summary/Abstract	Keywords	Source
15	LiDAR Best Practices- Following a few simple guidelines can unlock the cost-saving benefits of collecting and using LiDAR data.	Jason Caldwell, Director of Strategic Accounts	The article addresses what you should know and what you should expect from a LiDAR vendor.	LiDAR	http://eijournal.com/2013/lidar-best-practices Earth Imaging Journal 2013
16	LiDAR for DUMMIES, Autodesk and DLT Solutions Special Edition	James Young	LiDAR For Dummies spells out the basics of LiDAR and discusses capture techniques along with some details about how LiDAR is used.	LiDAR	https://cloud.sdsc.edu/v1/AUTH_opentopography/www/shortcourses/US-Egypt12/Young_LFD_book.pdf Copyright 2011 by Wiley Publishing, Inc.
17	LIDAR in the Driver's Seat	Brent Schwarz	An article on the future application of the LiDAR sensor for cars that can drive themselves. It discusses the coupling of novel roof-mounted LiDAR systems with vision cameras, advanced computer processing, and GPS to position the vehicle in global coordinates.	LiDAR Sensing LiDAR Sensors	http://velodynelidar.com/lidar/hdldownloads/opfocus_v12_s7.pdf Optics & Photonics Focus 2011
19	Mapping Individual Tree Species in an Urban Forest Using Airborne Lidar Data and Hyperspectral Imagery	Caiyun Zhang and Fang Qiu,	A paper on the development of a neural-network based approach to identify urban tree species at the individual tree level from LiDAR and hyperspectral imagery.	Hyperspectral Imagery LiDAR	http://www.utdallas.edu/~ffqiu/published/2012ZhangQiuPERS.pdf

Table B-1 (continued)
General Articles/Paper/Reference material on the Application of Inspection Technologies

Ref No.	Title of Article	Author(s)	Summary/Abstract	Keywords	Source
20	MOBILE LIDAR MAPPING FOR 3D POINT CLOUD COLLECTION IN URBAN AREAS – A PERFORMANCE TEST	Norbert Haala, Michael Petera, Jens Kremerb, Graham Hun	An article on the application of mobile LiDAR mapping for 3D point cloud collections in an urban area.	Three-dimensional Point Cloud Urban LiDAR Façade Interpretation	http://www.isprs.org/proceedings/XXXVII/congress/5_pdf/191.pdf
21	MOBILE MAPPING AND DATA COLLECTION	Michael Dunbar, Velodyne and Michael Neuman, Mandli Communications	An article on the application of a LiDAR sensor and the integration of software into a mobile system to collect highway data.	Mobile Mapping LiDAR	http://velodynelidar.com/lidar/hdldownloads/Geoconnexion%20article_4%2008.pdf April 2008 | GEOconnexion International Magazine
22	Organizational Results Research Report – Light Detection and Ranging (LiDAR) Technology Evaluation	Richard A. Vincent, Sanborn Map Company, and Michael Ecker, HDR Engineering and Missouri Department of Transportation	A LiDAR technology evaluation undertaken to provide an analysis of the current state of laser based technology and its applicability, potential accuracies and information content with respect to Missouri Department of Transportation (MODOT) applications.	LiDAR Aerial Inspections Mobile Inspections	http://library.modot.mo.gov/RDT/reports/TRyy1007/or11007.pdf October 2010

Table B-1 (continued)
General Articles/Paper/Reference material on the Application of Inspection Technologies

Ref No.	Title of Article	Author(s)	Summary/Abstract	Keywords	Source
24	Persistent Vegetation error in Aerial LiDAR DSMs: Impact on spatial models of inundation ris	S. Coveney National Centre for Geocomputation, NUI Maynooth Ireland Telephone: (00353-1-7086455) Fax: (00353-1-7086456) Email: seamus.coveney@nuim.ie	An article on the problem of persistent vegetation errors in LiDAR DSM data.	LiDAR Digital Elevation Model (DEM)	http://www.biodiverse.unsw.edu.au/geocomputation/proceedings/PDF/Coveney.pdf
25	THE Utilization of Satellite Images to Identify Trees Endangering Transmission Lines	Y. Kobaoyashi, G.G. Karady, G.T. Heydt, R.G.Olsen	A paper on a concept for the use of a multispectral stereo pair of satellite images to identify dangerous trees and plants along overhead transmission rights-of-way.	Satellite Images Tree Trimming Transmission Engineering Overhead Conductors Power Transmission	http://yoshikobayashi.com/wp-content/uploads/2012/05/Powerliner-Paper-10-21-08.pdf
26	Unmanned Aircraft Systems (UAS)	Andrea Laliberte	Application of Unmanned Aircraft Systems (UAS). The abstract gives a brief discussion about the FAA regulations and future uses of UAS.	Unmanned Aircraft Systems Sensors	http://wiki.landscapetoolbox.org/doku.php/remote_sensor_types:unmanned_aerial_vehicle

Table B-1 (continued)
General Articles/Paper/Reference material on the Application of Inspection Technologies

Ref No.	Title of Article	Author(s)	Summary/Abstract	Keywords	Source
27	USGS Webpage Experimental Advanced Airborne Research LiDAR (EAARL)	Webpage	The United States Geographical Society (USGS) website on latest LiDAR technologies .	LiDAR	http://ngom.usgs.gov/dsp/tech/eaarl/index.php
28	Using Color Infrared (CIR) Imagery - A Guide for Understanding, Interpreting and Benefiting from CIR Imagery	Prepared for the North Carolina Geographic Information Coordinating Council by the Statewide Mapping Advisory Committee, Working Group for Orthophotography Planning	A guide that describes the use of Color Infrared (CIR) in aerial imagery.	Color Infrared (CIR) Image GIS	http://www.nconemap.com/portals/7/documents/using_color_infrared_imagery_20110810.pdf July 2011
29	Using High Spatial Resolution Digital Imagery Funding by the U.S. Army Corps of Engineers	Michael V. Campbell, Robert L. Fischer, Timothy Pangburn and Mark J. Hardenberg	The document provides ways to assess the utility of high spatial resolution digital imagery to Corps civil works operations.	LiDAR, Imagery Airborne Multispectral Imaging Technology	http://www.crrel.usace.army.mil/library/technicalreports/ERDC-TR-05-1.pdf ERDC TR-05-1 February 2005

Table B-1 (continued)
General Articles/Paper/Reference material on the Application of Inspection Technologies

Ref No.	Title of Article	Author(s)	Summary/Abstract	Keywords	Source
30	What can satellites tell us About Earth?	NASA Website	This is a NASA training module that discusses satellites and how they work. The module demonstrates how satellite signals are connected to images and explore the ways in which different scientists use such images.	Satellites Imaging	http://er.jsc.nasa.gov/seh/Mission_Geography/k-4/Module_1/I-1-3.pdf
31	Wikipedia	Webpage	A brief explanation of the application and history of LiDAR technology.	LiDAR New Sensors Lasers	https://en.wikipedia.org/wiki/Lidar

C
LITERATURE SUMMARY OF VENDORS

Table C-1
Suppliers of Technologies – LiDAR, Airborne Inspections, Mobile Inspections, GPS, GIS, Handheld Tables, LiDAR Sensors, Handheld lasers, Work management Systems, Integration of Inspection Systems and Components, Application of Algorithms

Ref. No	Title of Article	Author(s)	Summary/Abstract	Keywords	Source
1	AeroMetric	Webpage	AeroMetric provides LiDAR, photogrammetry, orthophotography, 3D oblique images, and PLS-CADD documentation for the ROW depicting topography, vegetation, structure and lines.	Inspection Data Enterprise GIS Services Aerial Inspections	http://www.aerometric.com/solutions/transmission-line-mapping/
2	Aerotec	Webpage	Aerotec provides a vegetation inspection service that combines LiDAR and digital photography to support vegetation management inspections.	Inspection Data Aerial Service Handheld Laser LiDAR	http://www.aerotecusa.com/ept_veg_mgmt.shtm
3	Aerotec	Webpage	Aerotec provides a handheld laser tool called TopGun, used to verify LiDAR based vegetation violation inventory.	Handheld Laser Inspection Tool	http://www.aerotecusa.com/pdf/TD_World_Ad.pdf
4	CLEARION Software	Webpage	The Clearion Transmission Vegetation Management software solution provides an enterprise system that enables users to create, share, track, and audit map-based vegetation control information.	Arc GIS Inspection Data Management Budgeting	http://www.clearion.com/our-technology.html

Table C-1 (continued)
Suppliers of Technologies – LiDAR, Airborne Inspections, Mobile Inspections, GPS, GIS, Handheld Tables, LiDAR Sensors, Handheld lasers, Work management Systems, Integration of Inspection Systems and Components, Application of Algorithms

Ref. No	Title of Article	Author(s)	Summary/Abstract	Keywords	Source
5	DAVEY Consulting Services	Webpage	Davey offers a variety of services from integration of software, inspection, right-of-way maintenance programs, and GIS inventory to verification. They support other vendors such as Clarion.	Vegetation Management VM Software	http://www.davey.com/ http://www.davey.com/services/utility/vegetation-management-consulting.aspx
6	DigitalGlobe	Webpage	DigitalGlobe is the owner of the GeoEye-1 and several other satellites. They provide images to different reseller companies requiring satellite information, such as Satellite Imaging Corporation.	GeoEye-1 Satellite Imagery	http://www.geoeye.com/ info@digitalglobe.com https://www.google.com/search?sourceid=navclient&aq=&oq=Who+owns+the+GeoEye-1+Satellite&ie=UTF-8&rlz=1T4GGHP_enUS517US517&q=Who+owns+the+GeoEye-1+Satellite&gs_l=hp....0.0.0.54099.....0.ruRQlIW2hyo
7	Earth Eye	Webpage	Earth Eye provide LiDAR, hyperspectral sensors and orthophotography services.	Airborne/Mobile LiDAR Imagery Data Collection LiDAR Processing Orthophotography Mobile Imaging, PLS-CADD	http://www.eartheye.com/Services/Airborne Earth Eye LLC 3680 Avalon Park Blvd East Suite 200 Orlando, FL 32828 Phone: 407.382.5222 Fax: 407.382.5420

Table C-1 (continued)
Suppliers of Technologies – LiDAR, Airborne Inspections, Mobile Inspections, GPS, GIS, Handheld Tables, LiDAR Sensors, Handheld lasers, Work management Systems, Integration of Inspection Systems and Components, Application of Algorithms

Ref. No	Title of Article	Author(s)	Summary/Abstract	Keywords	Source
8	Ecosync: Economy through Ecology	Webpage	Ecosync offers several software inspection applications for use on a handheld PDA.	PDA Software for Inspection and Assessment	http://www.ecosync.com/vm.htm
9	EPRI's Transmission Assets Inspecting Robots Enter Next Phase	Andrew Phillips, Electric Power Research Institute (EPRI)	EPRI is developing an unmanned robot for inspection of a transmission line and for the inspection of the right-of -way (ROW). The robot has integrated LiDAR, IR, imagery sensors, and data acquisition .	Inspection Robot Transmission Assets	http://www.electricenergyonline.com/?page=show_article&mag=80&article=663
10	ESRI	Webpage	Esri is a provider of GIS software.	Arc GIS Mapping	http://www.esri.com/industries/electric/business/transmission
11	FLI MAP 400 Fugro Aerial & Mobile Mapping, INC	Webpage	Fugro offers both aerial and mobile transmission and vegetation inspections.	FLI-MAP 1000 Airborne Platforms LiDAR Sensors	http://www.flimap.com/site300.php
12	Galileo Group, Inc	Webpage	Galileo provides fused image data products which encompass high spatial resolution, LiDAR data, and the capability of hyperspectral imaging.	Hyperspectral Imaging LiDAR Satellite Imagery	http://www.galileo-gp.com/satellite_imagery.html

Table C-1 (continued)
Suppliers of Technologies – LiDAR, Airborne Inspections, Mobile Inspections, GPS, GIS, Handheld Tables, LiDAR Sensors, Handheld lasers, Work management Systems, Integration of Inspection Systems and Components, Application of Algorithms

Ref. No	Title of Article	Author(s)	Summary/Abstract	Keywords	Source
13	GeoDigital	Webpage	GeoDigital provides a vegetation management service which includes inspection using LiDAR, ortho images and high resolution oblique images.	Arc GIS Inspection Data management Budgeting Mobile Acquisition Platform Aerial Acquisition Platform Work Management System	http://www.geodigital.com/
14	GeoSpatial Innovations, Inc (GSI)	Webpage	GSI uses a handheld tablet device (Trimble) with GPS and integrated with Arc View to inspect for vegetation violations and transmission hardware problems. The Trimble Nomad collects, saves and transmits data to the utility's work management system.	GPS Trimble GPS	http://www.gsiworks.com/field-solutions/vegetation-management/
15	HySpex	Webpage of HySpex	HySpex is a manufacturer of high resolution, high speed, hyperspectral cameras for laboratory, industrial and airborne applications. They offer numerous publications on their website.	Hyperspectral Cameras	http://www.hyspex.no/index.php http://www.hyspex.no/hyperspectral_imaging/ http://www.hyspex.no/hyperspectral_imaging/about.php http://www.hyspex.no/publications/

Table C-1 (continued)
Suppliers of Technologies – LiDAR, Airborne Inspections, Mobile Inspections, GPS, GIS, Handheld Tables, LiDAR Sensors, Handheld lasers, Work management Systems, Integration of Inspection Systems and Components, Application of Algorithms

Ref. No	Title of Article	Author(s)	Summary/Abstract	Keywords	Source
16	LASER TECHNOLOGY, INC	Webpage	Laser Technology provides laser technology for use in field measurement applications.	Laser Measurement GPS GIS	http://www.lasertech.com/Professional-Measurement.aspx http://www.lasertech.com/blogs/Professional-Measurement/post/2012/07/10/Forestry-Webinar-Series-Tree-Hypsometry-Vegetation-Management-Video.aspx http://www.lasertech.com/blogs/Professional-Measurement/post/2013/06/18/Laser-Technology-Inc-to-Unveil-New-Laser-Rangefinders-and-Mobile-Mapping-Solutions-at-the-2013-Esri-User-Conference.aspx
17	Leica Geosystems	Webpage	Leica is a developer, provider, manufacturer and distributor of products, systems, and software that capture, visualize and process 3D spatial data. Products and services offered are LiDAR airborne sensors, cameras, laser scanners, software, etc.	LiDAR Laser Sensors Rangefinders	http://www.leica-geosystems.com/en/Leica-ALS60-Airborne-Laser-Scanner_57629.htm
18	LiDAR USA	Webpage	LiDAR USA is a company focusing mostly on ground based LiDAR.	Mobile LiDAR	http://www.lidarusa.com/index.php
19	MANDLI	Webpage	MANDLI provides a mobile LiDAR system used for inspection of highways and railroads. They have integrated LiDAR, GPS, and asset management into a package for vegetation inspection.	LiDAR Mobile LiDAR	http://www.mandli.com/

Table C-1 (continued)
Suppliers of Technologies – LiDAR, Airborne Inspections, Mobile Inspections, GPS, GIS, Handheld Tables, LiDAR Sensors, Handheld lasers, Work management Systems, Integration of Inspection Systems and Components, Application of Algorithms

Ref. No	Title of Article	Author(s)	Summary/Abstract	Keywords	Source
20	MERRICK & COMPANY	Webpage	Merrick provides scientific and engineering services, which include LiDAR, terrestrial LiDAR sensors, surveying, and hyperspectral imagery.	LiDAR Hyperspectral Multisensor Data Fusion Satellite Imagery MARS Software	http://www.merrick.com/merrickandcompany/media/Resources/Geospatial/Misc/Merrick-GeoSpatial-Solutions-Power-Delivery-SOQ.pdf?ext=.pdf http://www.merrick.com/Geospatial/Services/Hyperspectral http://www.merrick.com/Geospatial/Services/MARS-Software
21	MicroImages Introduction to Hyperspectral Imaging	Webpage of MicroImages Randall B. Smith, Ph.D., 5 January 2012	A general introduction to hyperspectral imaging.	Spectra Characteristics Hyperspectral Imaging	http://www.microimages.com/documentation/Tutorials/hyprspec.pdf http://www.microimages.com/index.php
22	Network Mapping	Webpage	Network Mapping provides inspection of lines and vegetation management using aerial LiDAR, terrestrial LiDAR, GIS software, and PLS-CADD.	LiDAR PLS-CADD Vegetation Vegetation Management Inspection of Transmission Lines	http://us.network-mapping.com/home.html http://www.network-mapping.com/assets/files/Flyers/NM%20Digital%20Electricity%20Flyer.pdf http://us.network-mapping.com

Table C-1 (continued)
Suppliers of Technologies – LiDAR, Airborne Inspections, Mobile Inspections, GPS, GIS, Handheld Tables, LiDAR Sensors, Handheld lasers, Work management Systems, Integration of Inspection Systems and Components, Application of Algorithms

Ref. No	Title of Article	Author(s)	Summary/Abstract	Keywords	Source
23	NVision Solutions	Webpage	NVison Solutions is a provider of a work management tool called Real-time Emergency Action Coordination Technology (REACT). REACT combines the visual power of GIS mapping and analysis with the DHS-mandated reporting and organizational requirements of the National Incident Management System.	Work Management	http://www.nvisionsolutions.com/products/react.php
24	Optech	Webpage	Optech is a manufacture of LiDAR equipment.	LiDAR Sensors Aerial Digital Cameras Mobile	http://www.optech.ca/cameras.htm http://www.optech.ca/pdf/ILRIS-LR-Spec-Sheet-130215-WEB.pdf Tel: +1 905-660-0808 Fax: +1 905-660-0829 E-mail: inquiries@optech.ca Web: www.optech.ca
25	Pictometry	Webpage	Pictometry is a vendor that offers inspection services using LiDAR GIS, 3D models for a variety of applications in industry, including transmission inspection.	GIS LiDAR NERC	http://www.pictometry.com/index.php?option=com_content&view=article&id=66&Itemid=75
26	Power Line Systems Inc.	Webpage	Power Line Systems develops, sells and supports software for the design of transmission lines and their structures. They have supported utilities on PLS-CADD analysis for the FERC regulations.	PLS-CADD PLS-POLE and TOWER	http://www.powline.com/index.html

Table C-1 (continued)
Suppliers of Technologies – LiDAR, Airborne Inspections, Mobile Inspections, GPS, GIS, Handheld Tables, LiDAR Sensors, Handheld lasers, Work management Systems, Integration of Inspection Systems and Components, Application of Algorithms

Ref. No	Title of Article	Author(s)	Summary/Abstract	Keywords	Source
27	Practical Programs	Webpage	Practical Programs offers program integration expertise.	Geospatial Document Management CAD	http://www.practicalprograms.net/demo.htm http://www.practicalprograms.net/Ind_Utilities.htm
28	RIEGL Laser Measurement Systems	Webpage	RIEGL provides several LiDAR devices for both mobile scanning and airborne scanning.	Airborne LiDAR Mobile LiDAR	http://www.riegl.com/nc/products/mobile-scanning/
29	Sanborn	Webpage	Sanborn is a transmission inspection company that offers both mobile and aerial LiDAR inspection of transmission lines. The Sanborn Oblique Imagery Solution provides the ability to see multiple aerial views of any location.	LiDAR Aerial Imaging Mobile LiDAR	www.sanborn.com/ http://library.modot.mo.gov/RDT/reports/TRyy1007/or11007.pdf http://www.sanborn.com/products/mobilemapping
30	SATELLITE IMAGING CORPORATION	Webpage	Satellite Imaging Corporation is a vendor that retrieves information from different satellites depending on the request.	Satellite Imaging	http://www.satimagingcorp.com/about.html
31	Space Computer Corporation – An introduction to Hyperspectral imaging technology	Webpage	Space Computer Corporation provides processing services associated with advanced sensor systems. Their specialty is the full exploitation of hyperspectral sensor data.	Hyperspectral Imaging Sensing	https://www.spacecomputer.com/systems.html http://cant.ua.ac.be/sites/cant.ua.ac.be/files/courses/oe/Introduction_to_HSI_Technology.pdf
32	SpecTIR	Webpage	SpecTIR provides hyperspectral and geospatial solutions for vegetation, emergency response and defense, intelligence and security customers.	Hyperspectral Geospatial Vegetation Security	http://www.spectir.com/applications/vegetation-airborne-hyperspectral/

Table C-1 (continued)
Suppliers of Technologies – LiDAR, Airborne Inspections, Mobile Inspections, GPS, GIS, Handheld Tables, LiDAR Sensors, Handheld lasers, Work management Systems, Integration of Inspection Systems and Components, Application of Algorithms

Ref. No	Title of Article	Author(s)	Summary/Abstract	Keywords	Source
33	Terra Spectrum Technologies	Webpage	Terra Spectrum Technologies (TST) provides a VM Suite of software for utility vegetation management (UVM) workflow.	VM Software Vegetation Management LiDAR	http://www.terra-spectrum.com/
34	TopEye	Website	TopEye is a provider of LiDAR systems for airborne inspection.	LiDAR Airborne Inspection Tools	http://www.airbornelasermapping.com/Features/ALMSpo01.html
35	Topcon	Website	Topcon is a supplier of mobile LiDAR systems and mobile GIS mapping systems that are used in several vegetation inspection applications.	Mobile LiDAR Vegetation Inspection	http://global.topcon.com/ http://www.topconpositioning.com/products/hand-held-devices/gnssgis-devices/grs-1-gis
36	Tukman Geospatial LLC Digital Mapping	Webpage	Tukman is a geospatial service company that provides vegetation mapping. Their knowledge of vegetation types is used in fuels and fire management as well as fire suppression.	Geospatial GIS Mapping Vegetation Maps	http://tukmangeospatial.com/services.html

Table C-1 (continued)
Suppliers of Technologies – LiDAR, Airborne Inspections, Mobile Inspections, GPS, GIS, Handheld Tables, LiDAR Sensors, Handheld lasers, Work management Systems, Integration of Inspection Systems and Components, Application of Algorithms

Ref. No	Title of Article	Author(s)	Summary/Abstract	Keywords	Source
37	URMC	Webpage	URMC is a company that provides an empirical measurement of actual conductor temperature using aerial LiDAR and then applying the data to PLS-CADD to determine the conductor sag. The process is explained in detail on URMC's website.	LiDAR NERC PLS-CADD Conductor Temperature	http://www.utilityrisk.com/index.php?option=com_content&view=article&id=80&Itemid=78 http://www.google.com/patents/US8374821
40	Velodyne	Webpage	Velodyne is a provider of two mobile LiDAR sensors that can be integrated into other systems. The sensors are being used in mobile LiDAR systems.	High Definition Sensors LiDAR	http://velodynelidar.com/lidar/lidar.aspx
41	WIRE Services	Webpage	WIRE Services provide a vegetation management program using LiDAR and Danger Tree Algorithms to identify hazard, simulating growth and falling conditions.	LiDAR Danger Tree Algorithms Thermal Rating and Vegetation Management, Hyperspectral Imaging	http://www.wireservices.ca/about-us/resources http://www.wireservices.ca/our-services/vegetation-management
42	Xplore Technologies iX104C[4]	Webpage	Xplore Technologies provide an ultra rugged tablet PC for vegetation inspection which can be used to feed data into work management systems.	Tables Vegetation Management Inspection Data Collection Devices	http://ruggedpcreview.com/3_slates_xplore_ix104c4.html

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