LIDAR DERIVED ELEVATION DATA TO SUPPORT FLOOD PLAIN MODELING

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ABSTRACT:

LIght Detection and Ranging (LIDAR) remote sensing technology has been evolving for a number of years. Resultant Digital Elevation Models (DEMs) require coordinated processing of the laser range data, along with platform positioning information. Typically, positioning information includes the Global Positioning System (GPS) signals along the flight path, and the Inertial Measurement Unit (IMU) values at frequent regular intervals. Many processing techniques have been developed, but are often problematic when used to derive a true bare earth surface from the LIDAR geo-referenced 3-D mass points. Techniques that use smoothing algorithms do not accurately reflect the true terrain surface and yield an interpolated surface rather than the true bare earth surface. This is especially true in areas that contain heavy vegetation and/or man-made features in high-density urban areas. Early processing capacity studies demonstrated the need to develop improved automated processing techniques that preserve the original random point data, to create a bare earth surface.
The paper will describe the results of a series of LIDAR feature processing filters that were developed under the auspices of the U.S. Army, Small Business Innovation Research (SBIR) program. The LIDAR processing capability created under the SBIR effort has produced an efficient set of bare earth DEMs for use in support of the Federal Emergency Management Agency (FEMA) map modernization plans. Selected areas in broad river bottomland and mountainous areas subjected to flooding have been used as target study areas for flood mapping revision. A description, with illustrative examples of products from the projects, initial accuracy results, cost considerations, and time response-related results with future implications, are presented.

1. INTRODUCTION

As a result of their response to the natural disasters of the 1990s, the Federal Emergency Management Agency (FEMA) designed a plan in 1997 to modernize the FEMA flood-mapping program. Since that time, the plan has continually evolved as new airborne remote sensing products, processes, and technical specifications have been developed and implemented. Since the information element of "elevation" is so critically important in many flood mitigation planning and preparation scenarios, the collection, processing, and use of multi-use information has the highest priority. Another parallel objective for this effort is to evolve a suite of remote sensing system options that can be used during a single flight pass to collect many types of data which could be combined to support multi-hazard mitigation and rapid response needs.

During this period the Topographic Engineering Center (TEC), one of the laboratories of the Engineer Research and Development Center (ERDC) of the U.S. Army Corps of Engineers, provided technical support to FEMA-initiated projects to perform a comprehensive evaluation of remote sensing technologies applied to multi-hazard management requirements. One emphasis within this project has been to use LIDAR in an operational manner to reduce the cost of flood map production. A specific area of evaluation has been the use of Digital Elevation Model (DEM) results produced by these sensors to improve the accuracy and completeness of useable DEMs over required geographic regions. Different levels of vertical accuracies are often required within the same DEM. Areas within the flood zones often need to show a finer degree of vertical change between DEM points then is required in areas outside the flood zones. FEMA map modernization requires bare earth DEMs accuracies in the sub-foot range.

Presently, LIDAR data is being processed using several methods: manual editing, spatial and statistical filtering, and techniques using multiple return analysis. Manual editing techniques are time-consuming and expensive, primarily due to the large number of points that need to be removed. Spatial and statistical filters tend to physically alter and/or smooth the derived LIDAR elevation values, resulting in an overall loss of data accuracy. Multiple LIDAR return techniques, as they are generally used, involve the use of 2 or 3 returns as a best-fit representation of the bare earth surface. These returns are then edited for the removal of non-bare earth features. These techniques appear to work well in low to moderately vegetated areas and where the density of cultural features is relatively low. The disadvantage of using this technique is that large amounts of representative ground surface points are being excluded from the data, due to the fact that all multiple return layers contain bare earth surface points.

Further investigation revealed that many of the developed LIDAR processing applications have focused on supporting the generation of two-dimensional data sets (surface generation for the development of digital orthophotography and the generation of digital elevation contours). These processing algorithms have quickly become overwhelmed by the large volumes of data generated by the LIDAR collection systems and by the complex data processing requirements. There needs to be a higher focus on the extraction of digital elevations outside the context of the bare earth surface.

In support of FEMA and the Corps of Engineers bare earth DEM mapping requirements, TEC initiated a Small Business Innovation Research (SBIR) topic under the auspices of the U.S. Army SBIR Office. The SBIR topic was initiated to address the automated filtering of feature data from LIDAR technologies. During the Phase I effort the SBIR contractor, EnerQuest Systems, evaluated several aspects of LIDAR data processing that relate directly to digital feature extraction, classification and LIDAR filtering techniques. The development of data integration tools within an image processing and GIS environment provided the capability to digitally extract 3-D earth surface feature information from LIDAR data. This included digital elevations of bare earth surfaces, vegetation, cultural features, 3-D tree canopy structures, 3-D building footprints; and other man-made structures processed within an automated environment over varying terrains. The initial SBIR Phase I and Phase I Option were used to evaluate the proposed techniques, and to design and implement a functional and commercially viable data processing workstation using real-time LIDAR data. Each technique was evaluated to document its functionality and limits as a function of terrain type, vegetation type and density, and cultural features.

2. BLACK RIVER

The Corps Little Rock District's review of an updated water control plan for Clearwater Lake in southeast Missouri revealed an adverse impact on bottomland hardwood forests along the Black River. To further assess these environmental impacts a request was made to acquire higher resolution and more accurate topographic elevation data for the area along the Black River. The topographic data acquired was required to produce an accurate surface model capable of generating 2-foot contours. The collected elevation data and resultant contours will be used in hydrologic analysis to more accurately quantify and assess the potential impacts from the water control plan.

The Black River project area encompasses approximately 277 square miles of the Black River watershed in the states of Missouri and Arkansas, figure 1. The project area includes the Dave Donaldson/Black River Wildlife Management Area, which covers approximately 40 square miles in the southernmost end of the project area. The topography of the project area is a broad flood plain with the Black River meandering throughout. The area surrounding the Black River itself is dense deciduous forest intermingled with small ponds and marshes. The remaining project area consists of agricultural land use with sparse planimetric features, such as occasional residential areas, drainage channels, and paved and unpaved road networks.

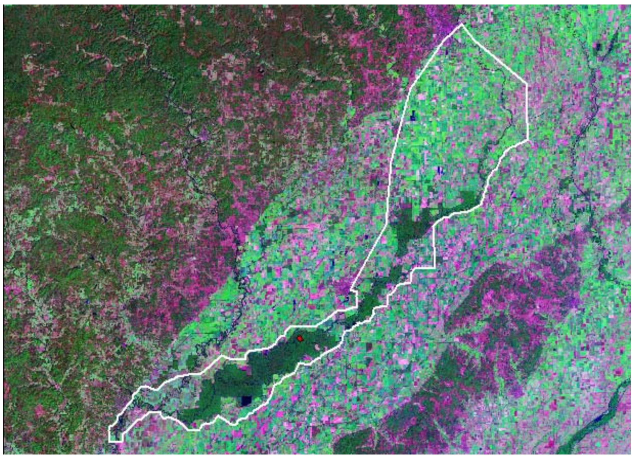

Figure 1. The Black River project area

3. MULTIPLE RETURN ANALYSIS

The Black River elevation data were acquired with the EnerQuest Remote Airborne Mapping System (RAMS™) LIDAR system. Under the right terrain and vegetation canopy conditions, the RAMS™ LIDAR system detected up to three returns from any single emitted laser pulse. This multiple return data environment presented sufficient data density and distribution, when coupled with the application of the Multiple Return Analysis (MRA) methodology, to begin the mapping of bare earth terrain within the heavily forested areas of the Black River Wildlife Management Area.

Using the MRA techniques, a low-resolution generalized terrain model was constructed with a set of single return data that best approximates the ground surface. The generalized terrain model is then repopulated using the other returns. Repopulation is achieved using a Boolean-based threshold filter that compares each value of the generalized terrain model with each multiple return elevation. The result is a representative bare earth surface in figure 2 that contains ground surface elevations from each return. The digital ortho on the left shows the current path of the Black River. The bare earth LIDAR DEM surface on the right reveals the hidden ancestral river paths along with the existing river path

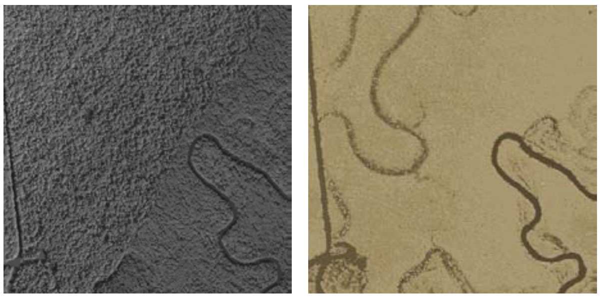

Figure 2. Black River digital ortho and bare earth DEM

The use of cross-sectional and 3-D profiles has proven to be a useful tool in selecting which return layer can be used to build such a model. It should be noted that the selected return layer must have a statistically significant sampling of points from which to generate a representative bare-earth surface model. This is dependent on the size of the forested area and the resolution one is trying to achieve in the output data. In heavily forested terrain, the decreased number of ground returns must be considered in order to determine the actual accuracies one can attain with limited ground elevation point densities and spacing.

3.1 Multiple Return Selection Procedures

The selection procedures from which a generalized terrain model can be created depend on accurately summarizing the vegetation coverage densities over the study area. This can be determined using remote sensing techniques and Landsat Thematic Mapper satellite imagery. The study area is primarily composed of dense deciduous forest and agricultural land use. The area has a mean Albedo of 0.24 and a mean vegetation density of 85%. Vegetation density was determined using a Calibrated Normalized Vegetation Index (CNDVI). The CNDVI was calibrated using a series of supervised sample points (water, bare earth, and areas with 0% to 99% vegetation density) collected within the surrounding area of the Landsat scene.

4. WEST VIRGINIA FLOODING

As the result of heavy rainfall in 2001 and again in 2002, wide spread flash flooding occurred in six counties within southwestern West Virginia. The hydrologic and geomorphic response to these events was regionally diverse. The low–lying communities located in the narrow valleys of the Appalachian Plateau were impacted by high-velocity stream flows with little warning.

The effects of these intense localized rainfall caused extensive flooding and landslides with many communities sustaining severe infrastructure damage to bridges and roadways. The floodwaters from these multiple events moved hundreds of residential structures off their foundations and flooded the first floor of thousands of homes, figure 3. The Corps' Huntington District estimates that approximately 650 buildings will be turned over for demolition.

Figure 3. Residential home with eroded foundation

The Appalachian Plateau landform that dominates this region is heavily dissected with many areas in a mature phase of erosion. The drainage divides are reduced to sharp ridges, resulting in a minimum of interstream uplands. This produces the maximum possible relief and results in very narrow building areas that results in many residences being directly sited next to headwater streams. Most of the damage stemmed from these floods and resulting debris flows. The impact of these debris flows is being studied, but it is not yet clear whether their distribution relates to local geology and geomorphology or to variation in rainfall intensity.

5. FLOOD MAPPING REVISION

In response to these flooding events, FEMA Region III conducted a damage assessment of the impacted counties. The flood recovery data collection effort indicated that several restudies would be needed to develop more effective flood control measures and to help communities rebuild safely. Intense localized rainfall events, combined with steep mountainous terrain, produced non-uniform peak flows in many of the impacted watersheds. Very high flows have been recorded in many of the upper portions of the impacted watersheds, followed by drastically attenuated peaks downstream. These conditions have complicated the analysis and verification of the flood recovery data, but will almost certainly result in the expansion of the flood hazard boundaries.

The extensive flooding that occurred in Wyoming County, West Virginia, resulted in a natural disaster declaration, figure 4. As a result of these events, FEMA Region III appropriated disaster funding for a recovery-mapping project. The local disaster declaration combined with the out-dated Flood Insurance Rate Maps (FIRMs) met the criteria established by FEMA to expand the project scope to include a LIDAR collection. This flood mapping activity will result in a modernization of the existing FIRMs to meet FEMA's new Digital Flood Insurance Rate Map (DFIRM) specifications.

Figure 4. Wyoming County, West Virginia

The complex topography of the Appalachian Plateau posed a significant challenge for LIDAR collection aimed at obtaining a high-resolution and high-accuracy topographic data. The EnerQuest RAMS™ LIDAR system was used for the topographic collection and covered an extent of 510 square miles. The LIDAR data collected will be used to refine the mapping of existing flood studies and as the basis for new engineering studies of previously unstudied streams to develop a more comprehensive understanding of the regional flooding dynamics.

6. KNOWLEDGE BASED ANALYSIS

To efficiently model the topography of the Appalachian Plateau, an advanced Knowledge Based Analysis (KBA) methodology was employed. The concept behind the KBA approach is centered on the development of decision rule-based techniques used in the processing of LIDAR data over complex terrains. The KBA methodology allows the user to build complex decision rules that are used in tandem with various techniques, including the integrated use of Fast Fourier Transformations (FFT), the MRA generalized terrain modeling techniques, and other relevant GIS data sets (slope, aspect, vegetation type, geology, etc.). A representative example of heavily dissected terrain with dense vegetation cover is shown in figure 5. After applying the KBA methodologies the resulting bare earth DEM reveals the geomorphology of the region, figure 6.

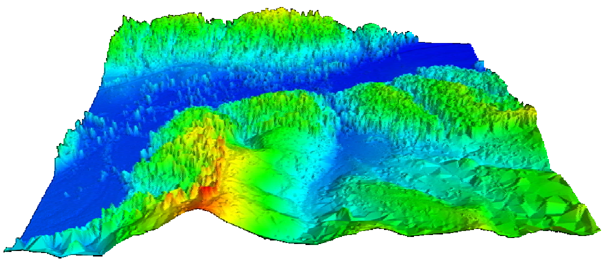

Figure 5. LIDAR reflective surface DEM

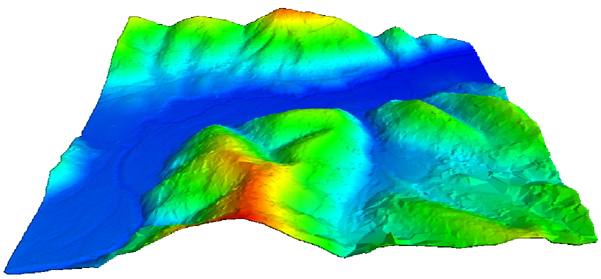

Figure 6. LIDAR bare earth DEM

The second approach to KBA is linked to the use of digital imagery as a knowledge-based classifier, for the extraction of both building and vegetation features. This approach, using Digital Imagery for LIDAR Classification (DILC), has been tested for its suitability for feature extraction. The concept behind a knowledge-based classifier is the establishment of a set of decision rules and/or set of conditions that can be used to extract surface features from a LIDAR reflectance surface. These decision rules or conditions aid in the extraction of features using ancillary data layers set to operate under specific conditions.

7. CONCLUSIONS

The operational basis of the MRA technique is the ability for a single LIDAR return layer to model the terrain under-lying a heavy vegetation area. Using this single return layer, a generalized terrain model is constructed and used to model the ground surface. Using a set of Boolean-based decision rules, the generalized terrain model is used as a threshold surface in order to eliminate non bare-earth points and retain elevation points that represent the ground surface. The resultant data is one that is characterized by return data consisting of ground surface points.

The KBA techniques can prove to be an effective means of processing LIDAR data in areas that have more complex terrains and environments. KBA has proven to be a promising technique whose implementation has only been slightly tested. This technique employs a unique methodology that can be applied in the more complex and challenging areas of steep terrain and dense vegetation cover mapping. KBA also lends itself to be implmeneted within an automated environment, where a KBA process can be established and implemented within a step by step batch environment.

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