Flight Rehearsal Scene Construction from LiDAR and Multispectral Data Using ARC Spatial Analyst and 3D Analyst

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Abstract

HyPerspectives specializes in the collection and analysis of remotely sensed data in and around the greater Yellowstone National Park area. This region is of great interest to the military because of its similarity to the terrain and vegetation found in active theatres such as Afghanistan and the Balkans. Because of our extensive ground truth and knowledge of the local vegetation, we have been contracted to provide realistic scene construction of the Yellowstone area to be used in military low-level flight mission rehearsals. These scenes need to be as accurate as possible, right down to 3D vegetative models of shrubbery. In addition to multispectral data available from sources such AVIRIS, we have also been supplied with 3D LIDAR data from the client's recent flyover. The first step is to create a bare earth model (BEM). Next, the other data are brought in and features are identified. Once all the various data are coregistered, Spatial Analyst and 3D Analyst is used to verify the registrations and construct the actual scene, including many of the supplied 3D vegetation, vehicle, building, and structure models. After the accuracy of the scene is verified, it is exported to the OpenFlight format for use in sophisticated military flight simulators.

Introduction

This paper outlines and discusses the process we developed and used to recreate scenes from LiDAR data. The ultimate use of this process is for the military to collect LiDAR data for an area of interest, process the data to create a realistic scene, and then export the scene to military flight simulators for mission rehearsals. These mission rehearsals result in lower casualty rates and therefore are important to today's warfighter. The accuracy of the resulting scene is paramount, and we at HyPerspectives were selected for the SBIR Phase I due to our extensive ground truthing of the study area. The work is based on a set of algorithms that extend the ENVI remote sensing tools. These algorithms, known as the ELF (<u>E</u>xtracting <u>L</u>iDAR <u>F</u>eatures) codes, extract terrain, natural (e.g., trees and forests) and man-made features (e.g. buildings) for insertion into a visual database. The process involves four major steps; feature extraction and classification, creation of a Bare Earth Model (BEM), template matching, and scene reconstruction. Once the scene has been reconstructed, it can then be exported to the OpenFlight format for ingest into the flight simulator. The SBIR Phase I work to date has been a proof-of-concept effort and Phase II will involve the automation of the process, better feature classification, and more photo-realistic scene construction. The ESRI 3D products utilized proved to be very useful tools for our purposes. Our process is summarized in Figure 1, below.

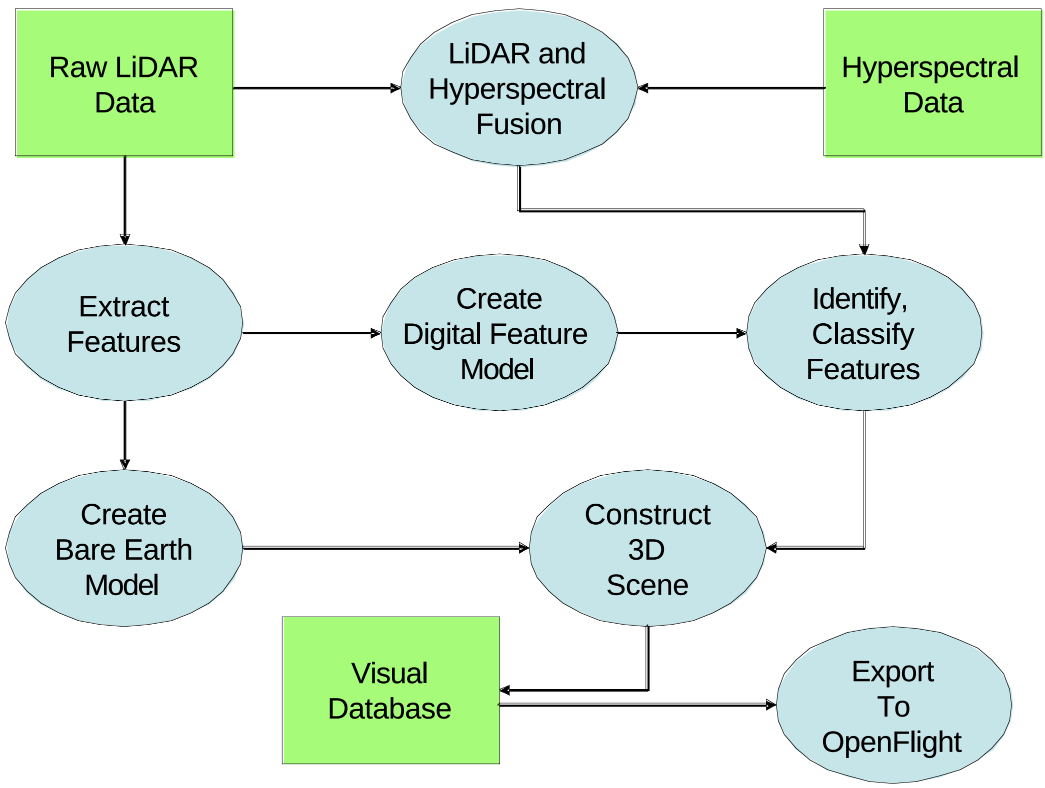


Figure 1. The "A to Z" processing for surface feature extraction and validation from LiDAR data developed by HyPerspectives.

About the Data Set

HyPerspectives' development of an "A-to-Z" process for creating visual databases from raw LiDAR data is uniquely strengthened by the availability from past and on-going work of (a) excellent remote sensing datasets from multiple sensors, including LiDAR, and (b) extensive ground truth of the areas covered by the remote sensing datasets. For Phase I, HyPerspectives has employed existing single return LiDAR from the highly successful Yellowstone Optical and SAR Ground Imaging (YOGI) 2003 data collection.

The YOGI 2003 study area, from which HyPerspectives in-kind LiDAR (and hyperspectral) data was derived lies near the northeast corner of Yellowstone National Park (Figure 2). This area offers a range of terrain relevant to NAVAIR visualization efforts, including open and forested landscapes, flat meadows and highly dissected mountainous terrain, and an urban area (Cooke City, MT). This combination of open, forested, and urban types offers an ideal surrogate for areas of potential conflict around the globe (Lee Moyer, DARPA, personal communication), plus an excellent testing ground for the developmental LiDAR software extraction software.

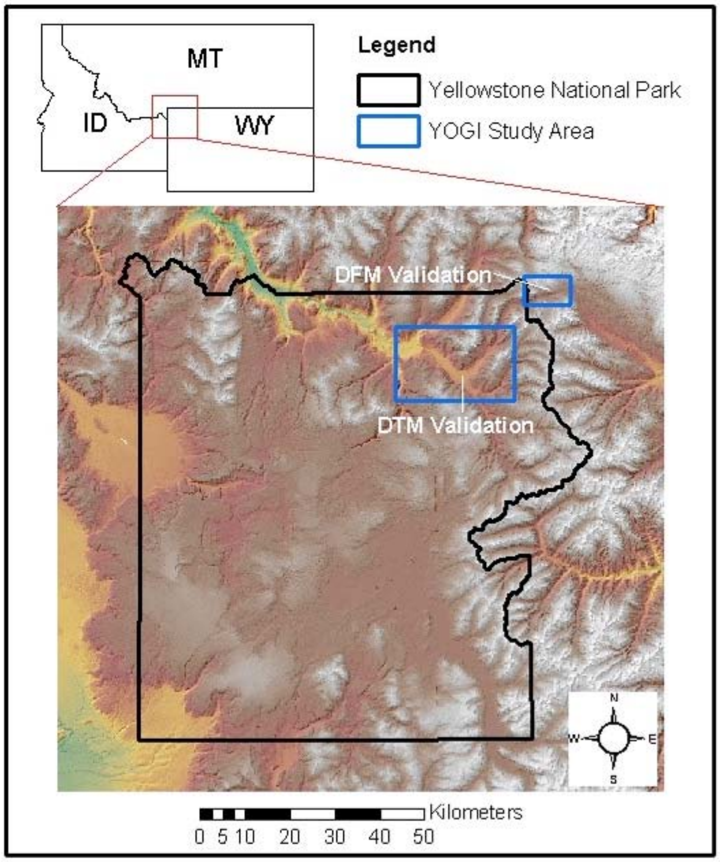


Figure 2. YOGI Collection, Digital Feature Model (DFM) Validation, and Digital Terrain Model (DTM) Validation Areas.

In total, the July 2003 YOGI data collect alone provided high-resolution data from 13 high resolution sensors flown on 7 airborne platforms. YOGI 2003 was a logistically challenging undertaking in large part organized by Dr. Robert Crabtree of HyPerspectives. It included 15 organizations (military and natural resource oriented; public, private, and academic) (Table 1) and multiple passive and active sensors (Table 2).

Table 1. Groups represented in the 2003 YOGI Data Collect.

▪ NRL ▪ HyPerspectives ▪ YERC ▪ AFRL / SN ▪ AFRL / VSBT ▪ Army NVL ▪ JPSD RTV ▪ DUSD	▪ Army CECOM ▪ NASA/JPL ▪ DARPA ▪ US Forest Service ▪ National Park Service ▪ MIT / LL ▪ SOLERS

Table 2. Sensors for 2003 YOGI Data Collect

- dual band EO/IR, VNIR HSI, SWIR HSI
- HyMap HSI sensor
- FOPEN SAR (HH VHF and full polarimetric UHF)
- IFSAR
- AirSAR (polarimetric multi-band and IFSAR)
- LiDAR (single and multiple return sensors)

The YOGI 2003 data collect was especially important to this SBIR effort because of the exhaustive ground truth collected by HyPerspectives staff to support the remote sensing analyses already completed in Phase I, and to be completed in Phase II. For example, almost 8,000 features were cataloged and entered into a Geographical Information System (GIS), including multiple vegetative attributes (e.g., height, species, and location) and numerous anthropogenic features. Similarly, a study of trafficability for the Naval Research Lab (NRL) included extensive ground truth collection at almost 400 locations over a 4000 m^2 area (Figure 3).

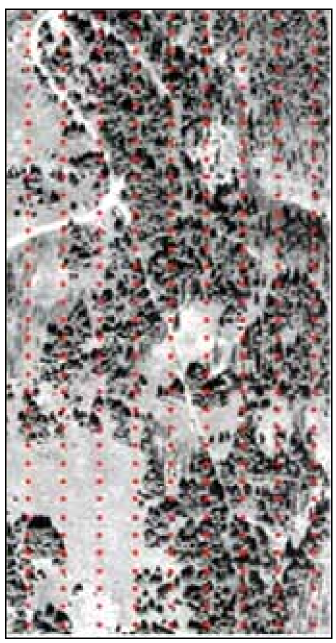


Figure 3. Example of extensive HyPerspectives ground truth collection during the YOGI 2003 collect (here data were collected along 400 m transects on a 20 m x 10 m grid).

HyPerspectives maintains ready access to the YOGI test site for any further ground truth validation and extension needed for Phase II, via staff located at the permanent YERC (Yellowstone Ecological Research Center) Field Station in Cooke City, which is in the center of the YOGI study area. This intimate knowledge of and access to the study area allowed HyPerspectives to certify our accuracy of our modeling effort.

Feature Extraction, Hyperspectral Data Fusion and Classification

The feature extraction was performed using HyPerspectives' proprietary ELF tools, developed as a set of ENVI IDL plug-ins. There are two sets of ELF tools, ELF1 and ELF2, which operate on the LiDAR data in a two-step approach. Once the hyperspectral data was co-registered to the LiDAR imagery, the LiDAR/hyperspectral data fusion analysis followed the general flow of processing using the ELF algorithms. ELF1 module was used to calculate a DTM (Digital Terrain Model) and DFM (Digital Feature Model, Figure 4) from first-return LiDAR and associated LiDAR intensity images. ELF2 was then used with a height threshold value of 2 m to delineate feature boundaries and to store features in the ESRI shapefile format.

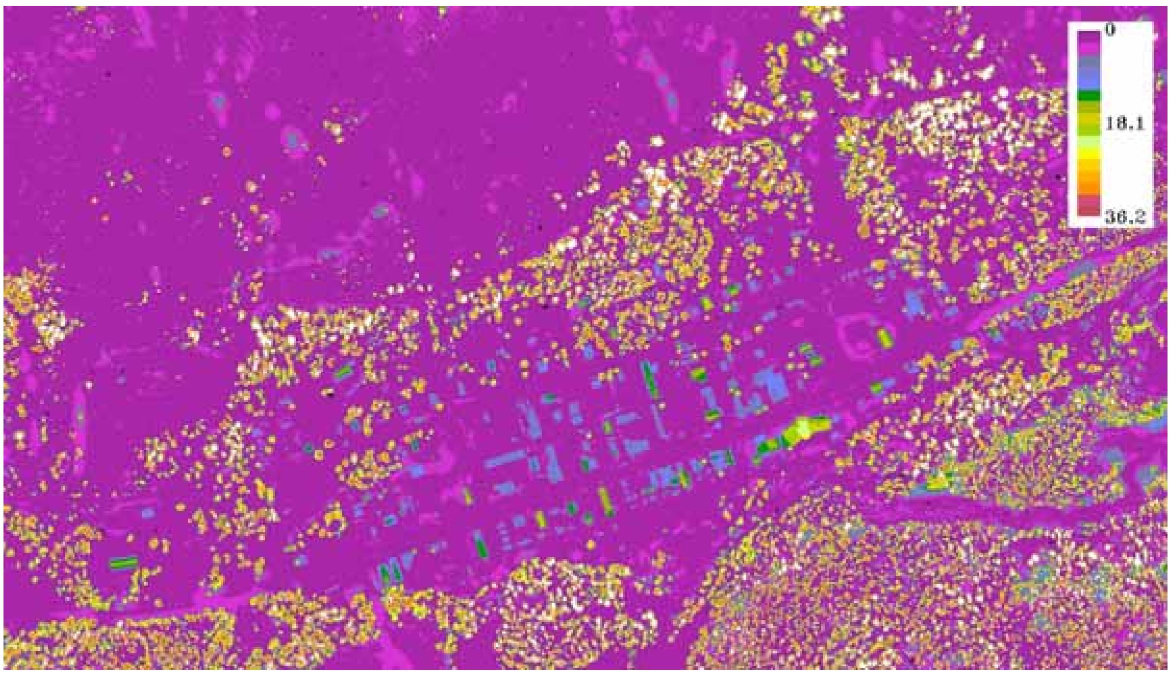


Figure 4. Extracted features color-coded for elevation above ground of the Cooke City, MT test area.

Delineated features representing four major feature types were selected from the set of all features using ground validation, reference data, and expert knowledge of the Cooke City environments, for an exemplary training dataset of 18 features (Table 6). Features were then categorized as one of the following classes: solitary trees, forest patches, single story buildings, and multiple story buildings. Feature boundaries were used to calculate LiDAR-derived DFM metrics (e.g., mean, max, variance, and skewness) and feature geometry metrics (e.g., area, perimeter, and perimeter to area ratio). The feature boundaries were then used to extract relevant information from the co-registered data. This extracted information was then added to the shapefiles as feature metadata, to be used later in the classification and template matching steps.

Creation of the Bare Earth Model

Once the features have been identified, they can be eliminated from the scene, leaving the base elevation data which represents a Bare Earth Model (BEM , Figure 5) of the data set. The BEM is the foundation and starting point for the construction of the 3D scene, the final product of the effort.

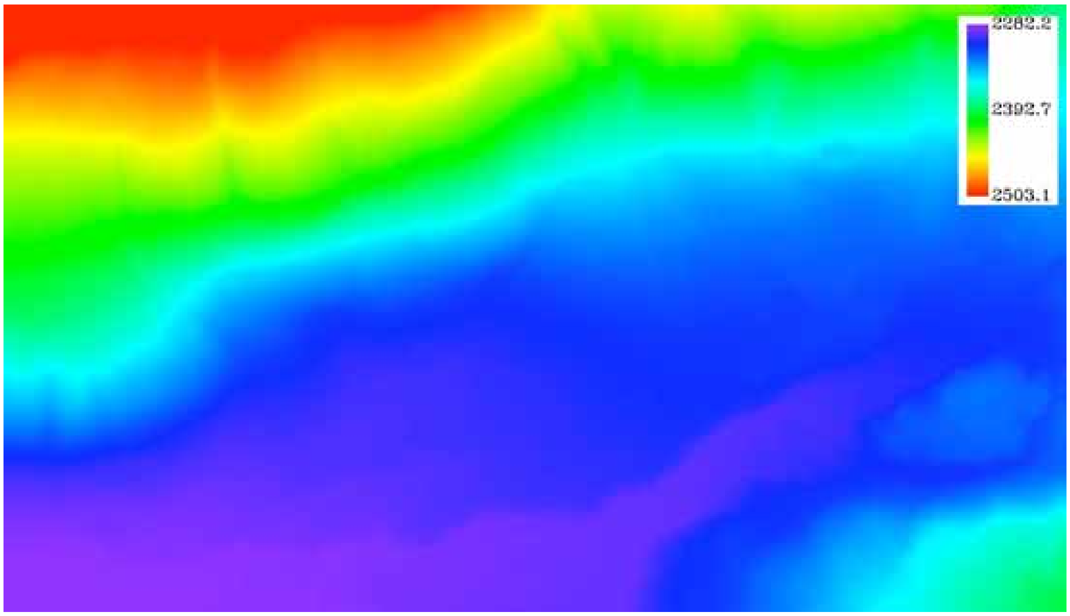


Figure 5. The Bare Earth Model of the Cooke City, MT. area in meters above sea level.

Template Matching

After the features are classified, they can be matched to their respective templates. For proof of concept, only trees and buildings were used for the scene construction. The templates used were pre-supplied from ESRI and worked well for our purposes. They consisted of two building templates, one for single story buildings and another for two-storied buildings, and a generic tree template. Since the majority of the trees in the Cooke City study area are of the conifer type, we used the single tree template for all standalone trees. We did not attempt to model entire tree canopies, but will address that in Phase II. Templates are matched to features via the metadata resulting from the ELF operations. We know from the metadata a feature’s centroidal location, bounding box extents, height and classification type. This information is then used to match a template to the appropriate feature type. The templates are then scaled proportionately to the feature’s metadata. Once the templates have been matched, located and scaled, they are ready for insertion into the 3D scene. In the future, we will extend our feature classification to include many other feature types such as roads, streams, bushes, etc., and will match them with more realistic templates. We have experimented with other classification techniques such as neural classifiers and decision trees, and found them quite promising.

Scene Creation (Putting It All Together)

The construction of the visual database, or scene construction, is the final step in the A to Z process (Figure 1) developed to show feasibility under this work. For this step, HyPerspectives combined classified features with their respective metadata to create a realistic template of the features for representation in the visual database. The steps in this process, shown schematically in Figure 6, include matching classified features to three-dimensional templates, scaling the selected templates according to the feature metadata (e.g., three-dimensional bounding box), importing the Bare Earth Model, and adding the templates to the scene at their respective coordinates.

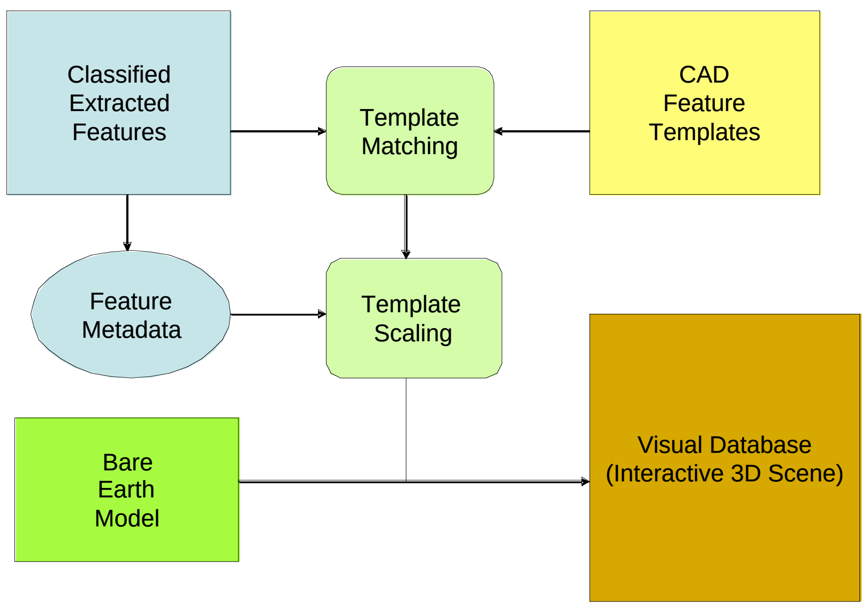


Figure 6. Scene Creation Process

The scene creation was performed using AutoCAD and ESRI's 3D Analyst and Spatial Analyst extensions to ArcGIS 9. ESRI's supplied three-dimensional templates of trees and buildings were used in building the scene. The LiDAR imagery, BEM, and two-dimensional shapefiles created from features extracted from the LiDAR imagery were collected from prior project work. The templates and shapefiles were then processed for display in the ESRI ArcGIS software package as follows:

1) The two-dimensional extracted feature shapefiles were given base-elevation values acquired from the BEM.

2) The two-dimensional extracted feature polygon shapefiles were next converted to three-dimensional polygon shapefiles via ArcScene, using the height (stored as an attribute in the tabular data of the shapefile) as the Z value.

3) The three-dimensional shapefiles were then overlaid onto the three-dimensional BEM surface as reference features.

4) Two-dimensional point shapefiles were created from the two-dimensional extracted feature polygon shapefiles, using the centroid of each polygon as the (X, Y) location for its insertion into the corresponding point shapefile (Figure 7).

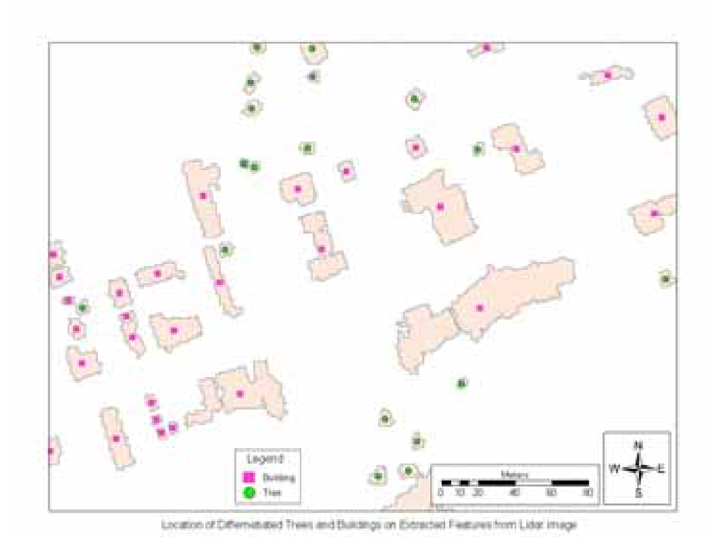


Figure 7. Feature centroids matched to extracted feature footprints.

5) The resulting point shapefile was used to properly locate the CAD templates in the scene. These point shapefiles were initially defined by two individual groups, trees or buildings, based on prior feature classification. Buildings were then broken into two groups, single or double story, based on the feature's height data.

6) The point shapefiles were then plotted on the BEM (Figure 8).

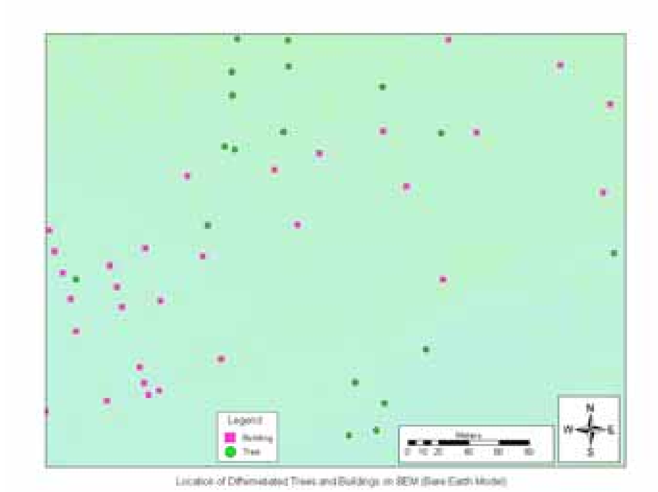
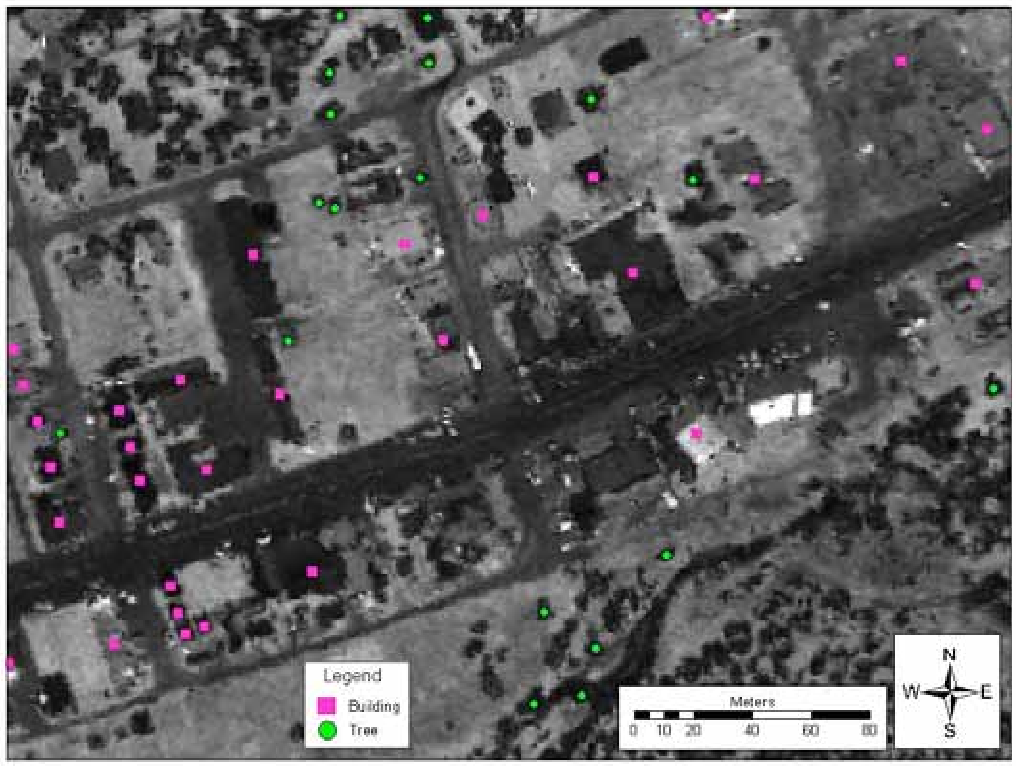


Figure 8. Feature centroids on the BEM.

7) The point shapefiles were then overlaid onto the LiDAR imagery to check the accuracy of the shapefile differentiation of the buildings and individual trees, and the locational accuracy of the features (Figure 9). We did not classify entire tree canopies, this task is left for the Phase II effort.



Location of Differnetiated Trees and Buildings on Extracted Features from Lidar Image

Figure 9. Tree and building centroid locations overlaid on LiDAR imagery.

8) The CAD templates of trees and buildings (and others in the future) are linked to the point shapefile from the type. The templates are then scaled to the feature values (length, width, and height from the three dimensional polygon shapefiles' tabular data) for correct sizing prior to insertion into the scene. The linking of these two files results in the accurate location and correctly scaled geometry of the virtual feature relative to the real feature as it exists on the surface of the Earth (Figure 10). To date, HyPerspectives has manually matched the templates to features. In the future, we may use a neural classification algorithm to perform this operation in three or more dimensions. Extending these algorithms from two dimensions to three or more did not fit within the scope of a Phase I feasibility effort, but will greatly enhance the number of classes of feature types and the accuracy of the classification process.

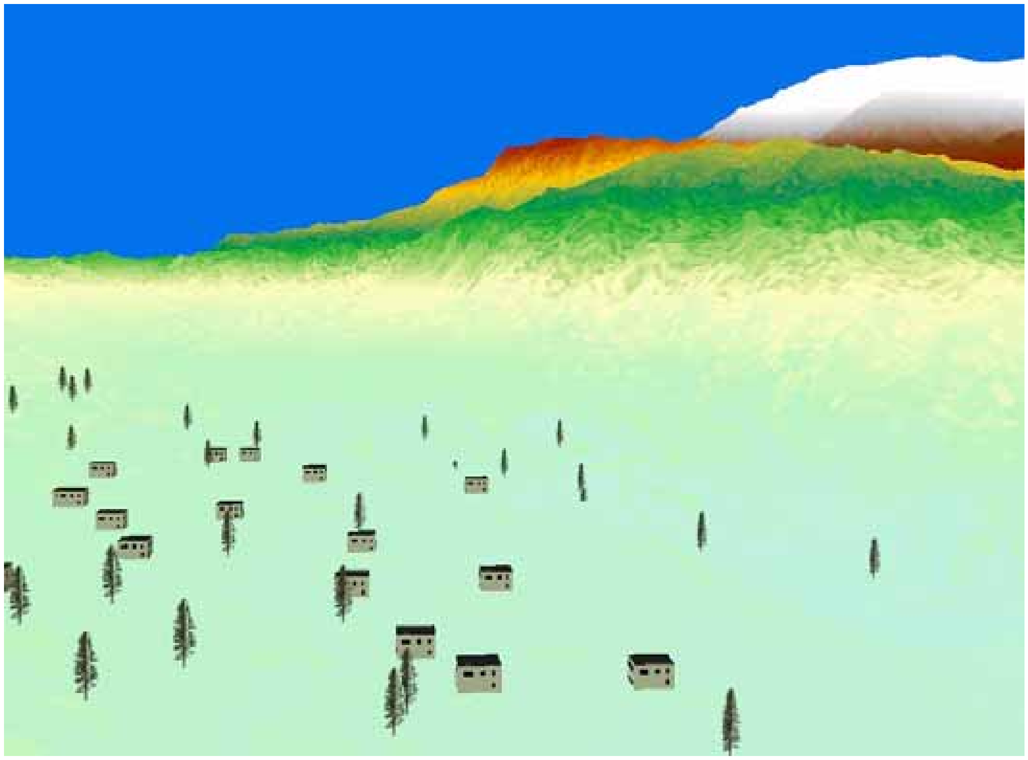


Figure 10. Partially reconstructed three-dimensional scene based on the BEM and extracted features. Features are accurately centered and are in correct proportion and scale.

9) The final step in the process is to export the visual database from the ESRI three-dimensional shapefile to the OpenFlight format commonly used by high-end flight simulation systems. Rather than reinvent the wheel and code this translation utility in-house, we have identified commercial-off-the-shelf (COTS) translation tools that can be purchased for several hundred dollars. Two of these are MultiGen–Paradigm SiteBuilder three-dimensional ($1995) and TerraSim TerraTools (price quoted on request).

As can be seen in Figure 11, the visual database in its current state is appropriate to a Phase I feasibility effort quite simplistic. This simplicity results from incomplete feature classification and a limited template set. Total feature classification (e.g., ground cover, multiple tree species, roads, rivers) was outside of the scope of the Phase I effort, but will be a focus area for Phase II work. During Phase II, HyPerspectives will acquire and/or develop a much more realistic set of templates, as well as work on the photorealism of the scene in general. The focus to date has been on the accuracy of the scene, not visual realism.

One glaring omission from the scene, especially from a flight simulator perspective is that there are no utility lines present. This is due to the nature of the LiDAR data as received by HyPerspectives from the military collectors of the data. We did not receive the raw point-cloud data, but rather a once-filtered data set that had bee preprocessed to remove pits and spikes. We feel that this step removed the elevated line data.

Additionally, the realistic three-dimensional modeling of power lines involves the catenary curving (line sag) of the lines, which is fairly complex. We have been able to identify the major power transmission lines from the fused hyperspectral data, but have left the template modeling of utility lines as an exercise for Phase II.

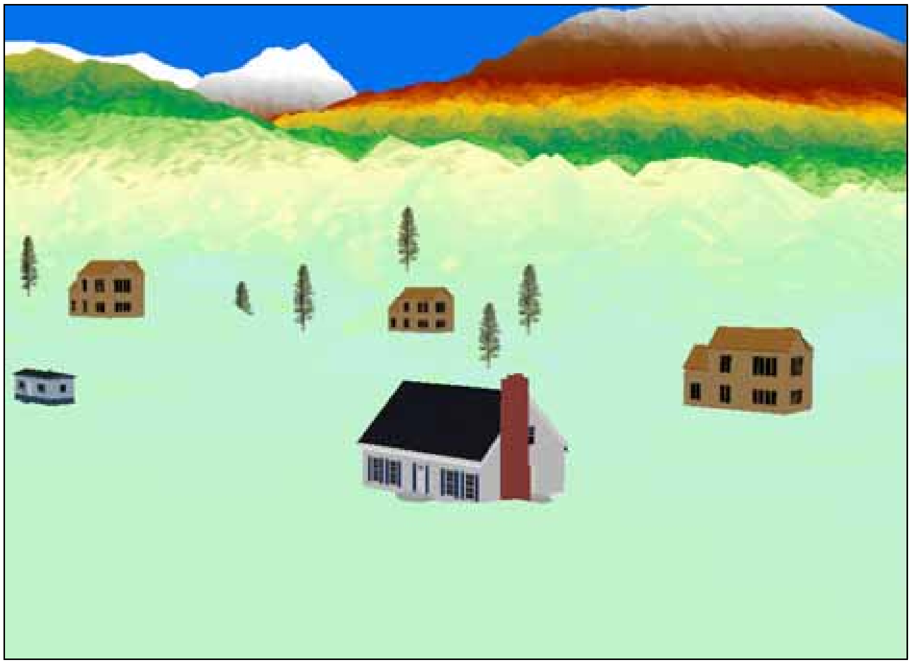


Figure 11. Different classifications of buildings with resulting templates.

Conclusion

We have successfully demonstrated and proved the concept of the "A to Z" process of constructing an accurate three-dimensional scene from LiDAR data. We have also identified some potential problems with the way the data is delivered, such as the prefiltering for spikes and pits, that may be removing important features *a priori*. We have successfully identified and extracted features from the LiDAR data. We have examined and experimented with several feature classification techniques that will prove useful in Phase II. We have successfully used the ESRI products to incorporate our extracted feature set into a reconstructed three-dimensional scene. We are looking forward to Phase II when we will be able to automate the process and add more realism to the completed scenes.

Acknowledgments

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