PRODUCTION SYSTEM FOR AUTONOMOUS 3-DIMENSIONAL MODELING WITH LIDAR, IFSAR, AND PHOTOGRAMMETRIC DSM DATA

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ABSTRACT

We describe an autonomous production system that utilizes Computational Fluid Dynamics (CFD) techniques and Partial Differential Equations (PDEs) to create accurate textured 3D site models with LiDAR, IFSAR, and stereo imagery. LiDAR is the data set of choice for specific urban scenes. IFSAR or stereo imagery is used for broad areas to mitigate cost. A high resolution Digital Surface Model (DSM) from any of these sources is input into the Harris' LiteSite™ toolkit. A DSM and high resolution imagery are all that are required to create an autonomously textured site model. Initially a DSM is input and an inpainting algorithm is used to autonomously repair voids due to low returns, system malfunctions, and coverage issues, for a DSM derived from IFSAR, LiDAR or optical data. PDE inpainting is derived from the Geometric Heat Equation (GHE) and the Navier-Stokes' equation. Once system errors and coverage issues in the DSM are repaired, a surface based anisotropic diffusion algorithm is applied to remove system noise from the DSM. The anisotropic diffusion algorithm has its origins in the isotropic heat equation. The LiteSite™ toolkit uses an autonomous PDE inpainting algorithm to fill voids in a bare-earth product where vegetation and building features have been extracted. The sides of the buildings are autonomously textured with oblique imagery while filling obscured areas with a 3D PDE or exemplar inpainting algorithm. A high quality textured urban 3D model derived from LiDAR is produced for specific areas merged with a broad area site model derived from correlated imagery or IFSAR DSM.

Keywords: LiDAR, IFSAR, DSM, Computational Fluid Dynamics, Partial Differential Equation

INTRODUCTION

This paper describes a complete production system for automated 3D site model creation. This system is unique due to its novel combination and application to several exciting research topics. Harris has developed algorithms to apply both a PDE-based and an exemplar driven method of void filling to DSM (Digital Surface Model) space and these key technologies are applied in several separate ways during the course of the automated site model generation process. One of the components of the PDE-based approach, anisotropic diffusion, is also used on its own as a preprocessing step. The major advantage of the production system is that it is completely automated. Each of the autonomous components (Autonomous Bare-Earth Extraction, Building & Vegetation Extraction, Building Geometry Generation and Model Texturing for buildings and ground) are discussed.

This paper begins with an overview of each of the novel DSM void fill methods that are an important part of the overall process and then proceeds to discuss LiteSite™ process and the remaining components. Evaluation and results of sample models are provided.

PRODUCTION SYSTEM OVERVIEW (LiteSite™ Process)

Figure 1 illustrates the LiteSite™ production system. Also shown in this figure is its relationship to the semi-automated production system RealSite™.
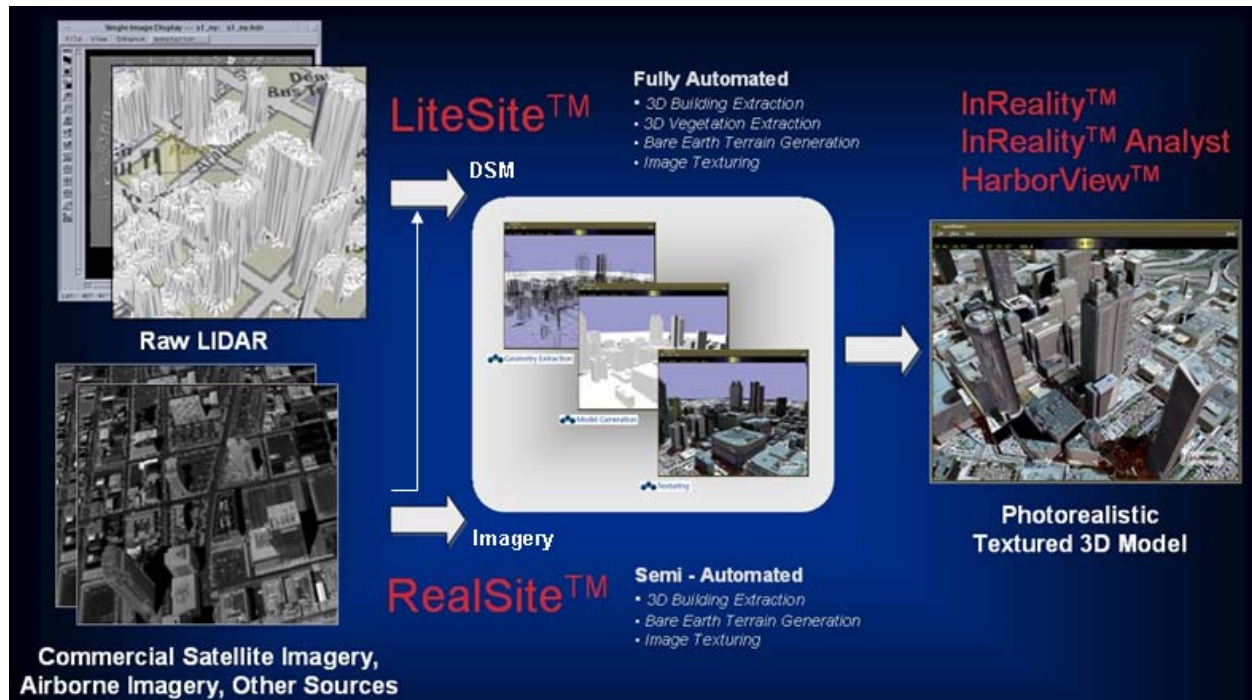

Figure 1. LiteSite™ Fully Autonomous Production System.

LiteSite™ is a production system for autonomous 3D site model creation from a wide variety of input DSM sources. Model generation begins with a preprocessing step such as boundary sharpening or edge enhancement. Voids in the input data sets are filled and a bare earth data set is generated. Cultural features are then separated from vegetation features. The accuracy of key stages in our process is highly dependent on the accuracy of void filling of the DSM inpainting algorithm. A discussion of our system for assessing data accuracy for various fill methods has been presented (Rahmes et al., 2007). The vertices from the building roofs and sides as well as the ground surface are mapped into polygons and projected into geo-spatial coordinates. Textures may then be automatically applied to their corresponding polygons.

Each component of the core process (shown in Figure 2 below) will now be discussed in further detail.
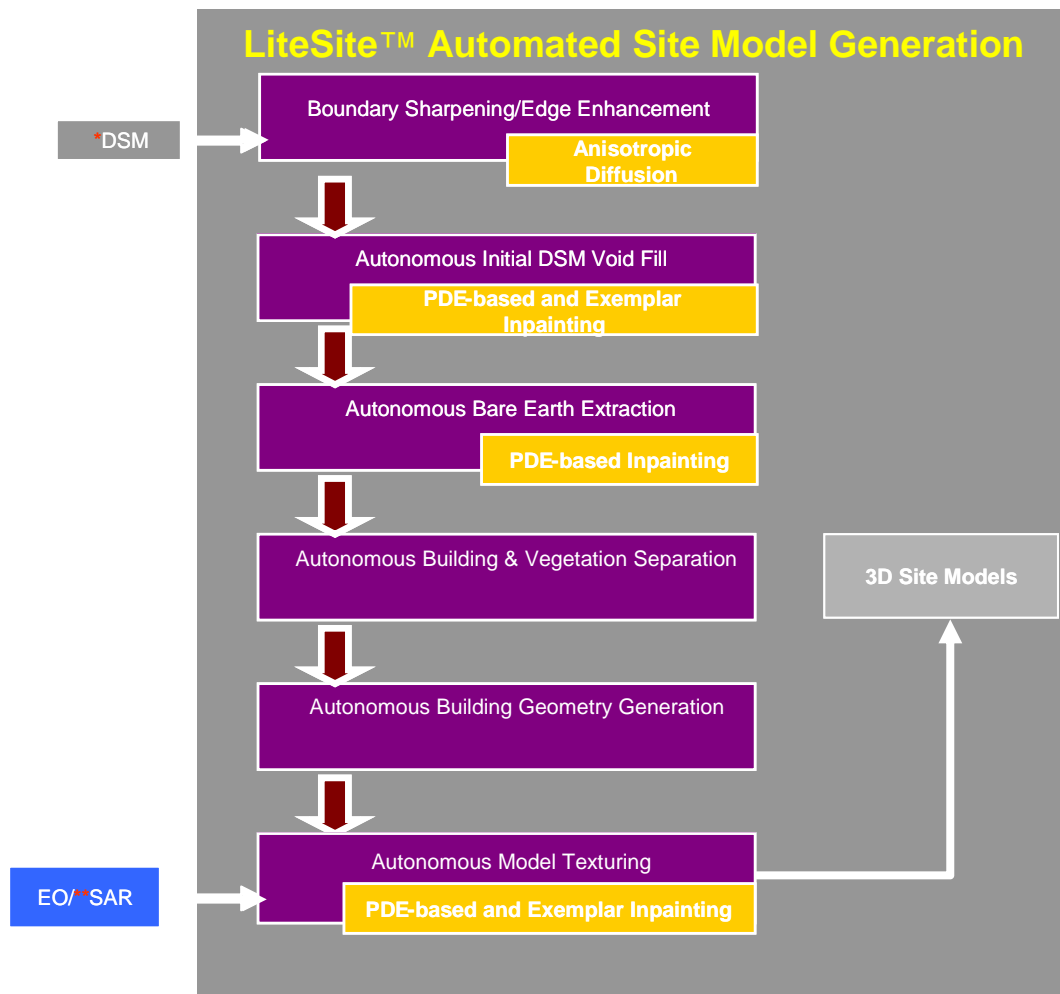

Figure 2. LiteSite™ Process Overview.

BOUNDARY SHARPENING/EDGE ENHANCEMENT
(ANISOTROPIC DIFFUSION)

The term anisotropic implies that the diffusion is not applied uniformly. Specifically, the data is diffused across the DSM in such a way as to smooth out all homogeneous areas while at the same time attempting to maintain valid edges by careful consideration of the local gradients. This allows noise removal while mitigating the side effects of blurring natural edge content which would be detrimental to further automated processing. The application of a small number of passes of this algorithm can be an effective preprocessing step for cleaning up data for the remaining portion of the process.

AUTONOMOUS INITIAL DSM VOID FILL
(PDE-BASED AND EXEMPLAR INPAINTING)

The first step in the overall process is to fill in void regions introduced during the data collection and processing. This is actually quite common for a variety of reasons. The voids shown in the example below (Figure 3a) resulted from inadequate stereo pair coverage in these areas for a DEM correlation procedure.

One characteristic of this type of void region that makes it particularly difficult to fill is the broad range of data that needs to be restored. Each void may contain a mix of fragments of buildings, trees, bare earth, and countless other types of culture that appear throughout the scene. Many different types of both high and low frequency data appear merged together in nearly all of these regions.

As discussed in our previous work (Rahmes et al., 2007), we have developed a unique way to combine the two fill algorithms discussed above, PDE-based and exemplar inpainting, to overcome this difficulty and exploit the benefits of each method. We use this here to complete the input DEM, providing us better results with the remaining automated processing. The result of this step is shown below in Figure 3.
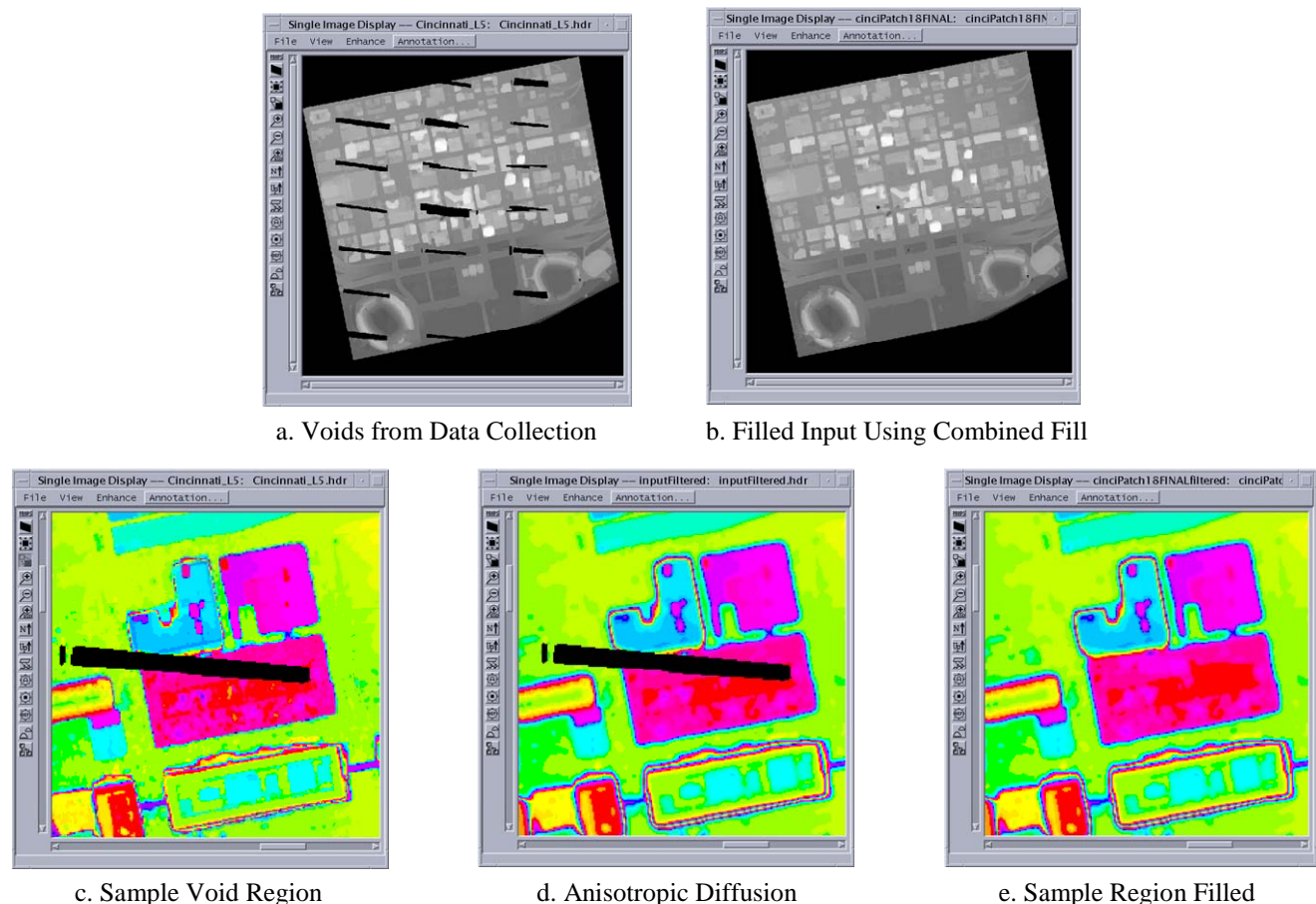

a. Voids from Data Collection   b. Filled Input Using Combined Fill

c. Sample Void Region   d. Anisotropic Diffusion   e. Sample Region Filled

Figure 3. Autonomous Initial DSM Void Fill.

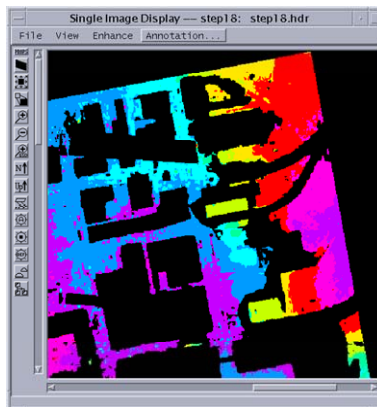# AUTONOMOUS BARE EARTH EXTRACTION
(PDE-BASED INPAINTING)

The PDE inpainting algorithm propagates information from extracted building and vegetation boundaries as shown in Figure 4 below. The input data is iteratively evolved until a steady state is achieved. We control the speed of propagation. However, there is a tradeoff between accuracy and the speed depending on data resolution and number of iterations.
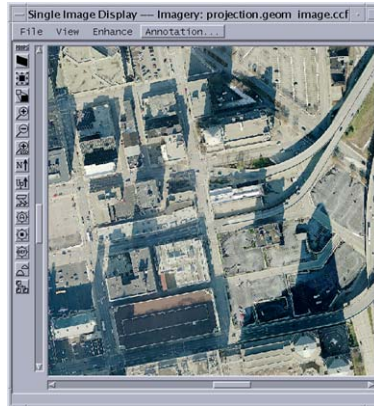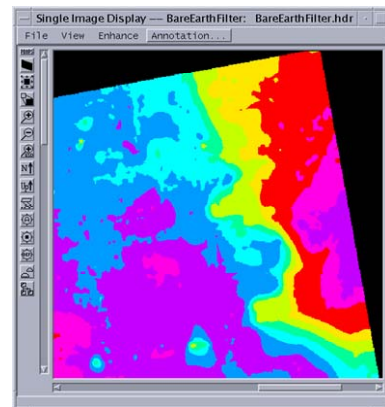
a. Image of Input
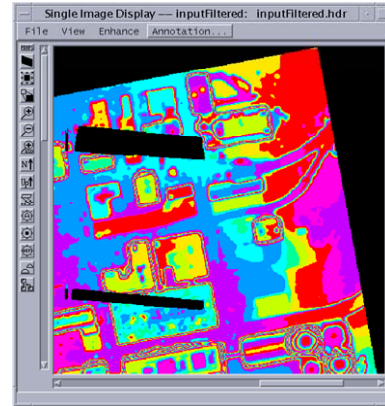
b. Input DEM

c. Bare Earth Extraction

d. PDE-based Inpainting

Figure 4. Bare Earth Extraction and Fill Using PDE-based Inpainting.

An example of DSM inpainting using IFSAR data is also shown below in Figure 5.

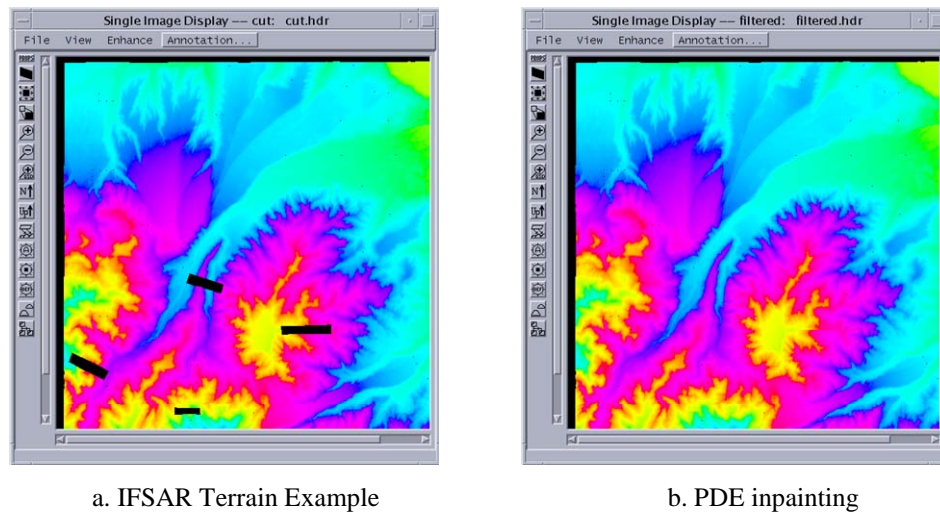a. IFSAR Terrain Example   b. PDE inpainting

Figure 5. IFSAR Data and Fill Using PDE Inpainting.

The ability to extract a bare earth terrain model from a DSM is critical to the success of the site model creation process. The ability to do this autonomously provides significant time and labor savings.

At this point in the process a multi-resolution data pyramid (Figure 6) is constructed using a modified re-sampling algorithm (similar to the common practice in image processing). At the lowest data level of the pyramid the void regions are filled, creating a lower resolution estimate of the true bare earth. Next, the level directly above this region in the pyramid is filled. Each post at this level is then examined and retained only if it is found to be within a threshold of this second level directly below it. The overall effect is the removal of culture and vegetation while minimizing the loss of valid terrain posts. This process is repeated until only the final level remains, at the original resolution level, with voids corresponding to the previous location of building and tree posts. Figure 4 shows results of this process on an urban area.

These voids must be resolved if the output of this step is going to be useful in further processing and as an optional output product. This is an interpolation problem that is extremely well suited for our PDE-based DSM inpainting process. With the absence of extremely high frequency data, as it has all now been removed, the diffusing characteristic is well suited for this approach and the smooth terrain contours are allowed to diffuse into the void region. The result is a fully populated bare earth Digital Terrain Model (DTM).
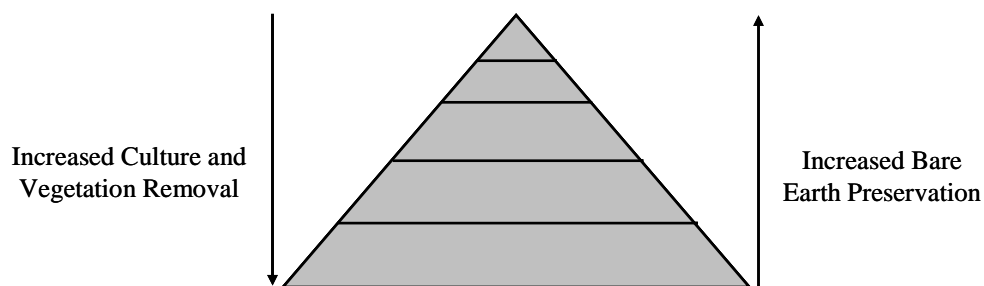

Increased Culture and Vegetation Removal

Increased Bare Earth Preservation

Figure 6. Bare Earth Resolution Level Data Pyramid.

AUTONOMOUS BUILDING AND VEGETATION SEPARATION

Our algorithms perform autonomous cultural feature and vegetation extraction. These features are automatically detected and voids are created and inpainted in the DSM. The process is initiated by identifying the areas of interest where cultural and vegetation features have been extracted. It is important to represent the height

contours in the interior of identified inpainted regions as accurately as possible. In the previous step, Autonomous Bare Earth Extraction, the sections removed from the input file to create the intermediate bare earth containing voids are actually saved as an intermediate output. The contents are the full set of culture and vegetation located in the original input DSM. The goal of this step in the process flow is to separate these two components from each other. For applications where multiple LiDAR returns are available this is more straightforward. However, some sources may only provide a single DSM, such as a photogrammetrically derived DSM created from an imagery stereo pair. Our algorithms are optimized to this more general case and require only a single first return DSM.

AUTONOMOUS BUILDING GEOMETRY GENERATION

Once the building posts have been isolated from the original input, they are further processed and converted into a polygonal representation. Each contiguous block of posts is processed individually. A circle detection algorithm indicates whether a particular building may be a cylinder or similar shape. Similarly, other common building and roof type detection are applied initially. If the building is determined not to match one of these common types, then its dominant directions (2 orthogonal directions) are detected, and a clustering-based algorithm is used to generate the perpendicular building edges.

Each building component polygon is assigned a height and these polygons are used to represent the buildings in the original DEM. An example output of this process is shown below in Figure 7.
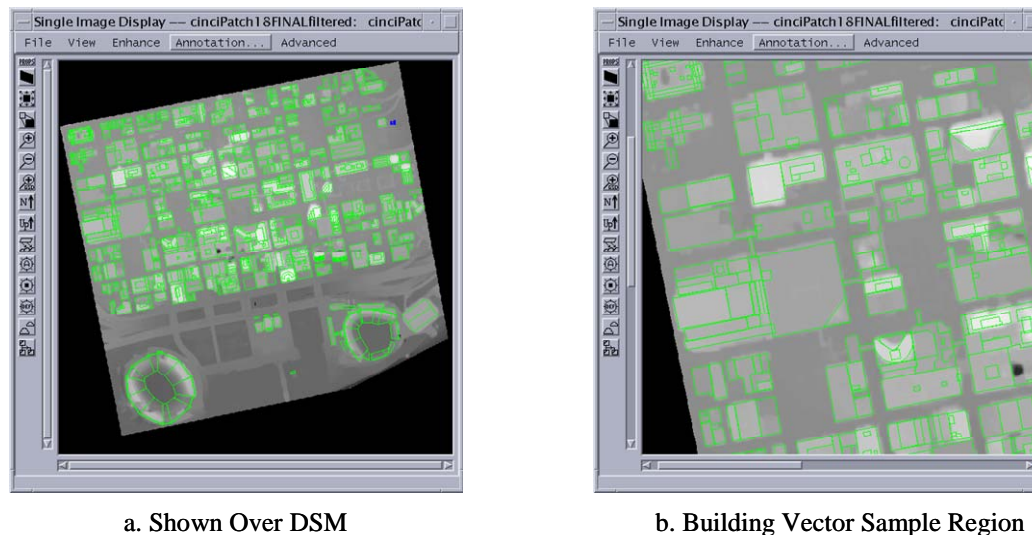

a. Shown Over DSM   b. Building Vector Sample Region

Figure 7. Building Vectors.

AUTONOMOUS MODEL TEXTURING
(PDE-BASED AND EXEMPLAR INPAINTING)

During conversion of the building objects into 3D visualization models or 2D shapes, imagery is mapped onto building surfaces. Common formats can be textured such as: IV, VRML, GeoVRML, KML, 3DF, etc. Image priority is used to specify which images have the best image quality for the current area. The image that has the best look angle relative to the surface to be textured is selected, which determines what should provide the best textures.

Obscuration detection removes building layover of modeled buildings onto other modeled buildings. It leaves the texture blank unless another image has coverage in the area and is available to take its place. Due to this and basic lack of coverage in certain areas, void regions may appear in the texture that is used for the buildings. To resolve these null regions, LiteSiteTM provides the capability for autonomous image inpainting of null regions in the texture image using the PDE or exemplar approach. Sample output from this process illustrating autonomous model texturing is shown in the next section in Figure 8.

3D SITE MODELS

The data set demonstrated in Figure 8 is a suburban area of Cincinnati, Ohio, with area of 1.5 square kilometers and 0.3 m DEM post spacing points derived from our image correlation process. Source imagery is provided courtesy of Pictometry for purposes of illustrating Harris automated processing results. This high resolution DSM and imagery are used for automated terrain, building, and vegetation extraction as well as automated building and ground texturing.
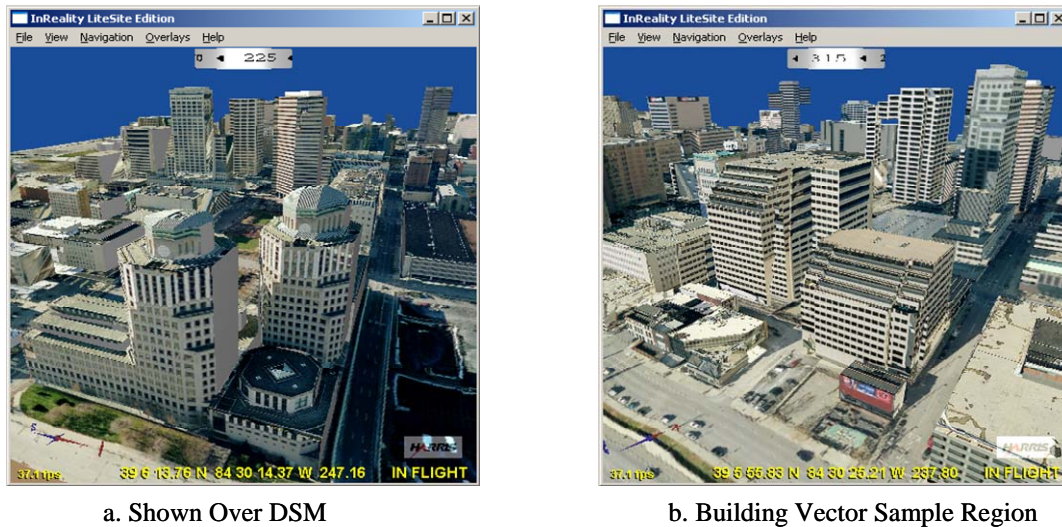

a. Shown Over DSM   b. Building Vector Sample Region

Figure 8. 3D Model Presented Using InReality.

InReality™ is a viewer application used to display (as shown in Figure 8) and navigate LiteSite™ and RealSite™ 3D models. Using sophisticated resource management algorithms, InReality™ permits viewing of 3D models on a variety of PC platforms from laptops to high-end desktops. InReality™ is designed to permit a user to easily navigate the virtual scene and provides powerful tools that permit the 3D models to be used in a variety of fields.

Figure 9 shows an example of high resolution X-Band, 3m post resolution IFSAR data. This data was collected by EarthData International, Inc. over Colombia, South America. Shown on the right side of the figure is a triangulated irregular network (TIN) of an area of approximately 750 square kilometers.
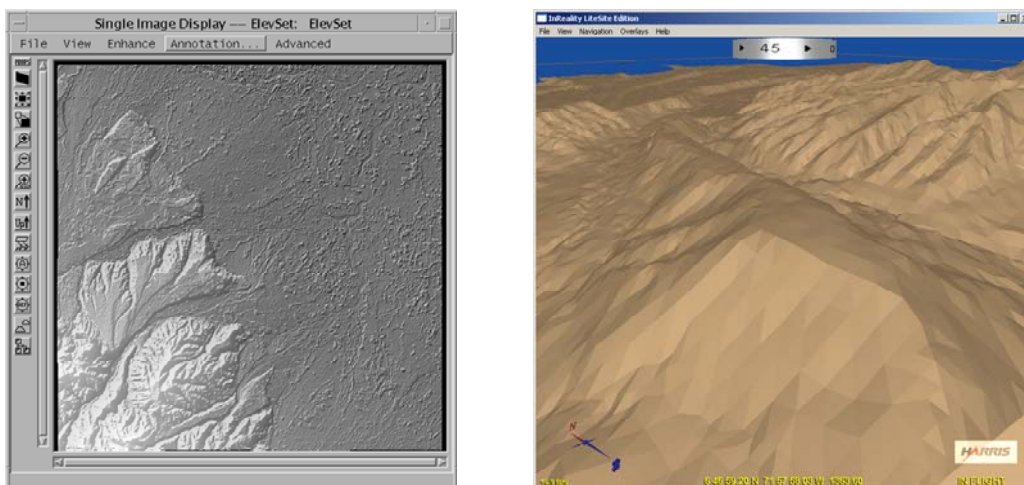

Figure 9. IFSAR LiteSite™ / InReality™ Data Set.

SUMMARY

This paper described an autonomous production system that utilizes Computational Fluid Dynamics (CFD) techniques and Partial Differential Equations (PDEs) to create accurate textured 3D site models with LiDAR, IFSAR, and stereo imagery. The combination of components makes up a full suite that allows end-to-end automated site model creation that is accurate, efficient, and cost effective by using DSM input (typically LIDAR, IFSAR, or photogrammetrically derived) from the initial preprocessing of anisotropic diffusion and data collection void filling through automated 3D texturing.

ACKNOWLEDGEMENTS

REFERENCES

Rahmes, M., Yates, J. H., Allen, J., Kelley, P. (April 2007) Autonomous Selection of PDE Inpainting Techniques vs. Exemplar Inpainting Techniques for High Resolution Digital Surface Models. *Society Of Photo-Optical Instrumentation Engineers (SPIE)*