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OPERATIONAL PROCEDURE FOR AUTOMATIC TRUE ORTHOPHOTO GENERATION

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ABSTRACT

Orthophoto imagery is a valuable layer in a GIS because it provides a generic, inexpensive, and accurate base map. However, in cities with tall buildings it is difficult to create a seamless database of orthophoto imagery. Traditional methods for orthophoto rectification disregard buildings. In this paper, we describe a fully automated process, developed by ASI, that creates true orthophotography," i.e. seamless imagery without building lean. In particular, we present a new mosaicking method, which automatically chooses the "best" imagery. We also present an automatic method for optimal seaming, which reduces the visibility of the seam line. Examples from Lower Manhattan, New York City, are presented.

Keywords: True Orthophotography, Automatic Optimal Seaming, Automated Mosaicking.

1 INTRODUCTION

In traditional digital orthophotography production, objects like buildings and bridges are not modeled in the digital terrain model (DTM). Therefore, these features are distorted from their true location in the final digital orthophoto image (DOI). This distortion shows up in the form of leaning buildings and warped bridges. In severe cases, the impact of this distortion can affect the usefulness of the DOI. For example, a tall building may "lean" over a street, and hide information such as manholes, fire hydrants, and utility poles. Complex, multi-level freeway interchanges may appear badly deformed. When a vector GIS layer is superimposed with the imagery, building outlines fail to match with the imagery representing the tops of buildings, and vector road edges appear as though passing through buildings.

Based on a three-dimensional or a two-and-a-half-dimensional description of the buildings and bridge structures (a DTM that includes the buildings and bridges) the rectification process for removing the building lean is straightforward. However, wherever a building or bridge is repositioned correctly, blind spots occur. These hidden areas necessitate filling from other imagery and require an intelligent mosaicking procedure.

1.1 Motivation

In 1997, the New York Department of Environmental Protection contracted with the author's company to create digital orthophotography for New York City. Moreover, because of extremely tall and closely spaced buildings in Manhattan, ASI developed an innovative and operational approach for increasing the usability of the orthophotography in these areas.

Figure 1 shows a traditional digital orthophoto of the Lower Manhattan area. Note that the sides of the buildings are visible, and that the buildings lean over and obscure streets and other features.

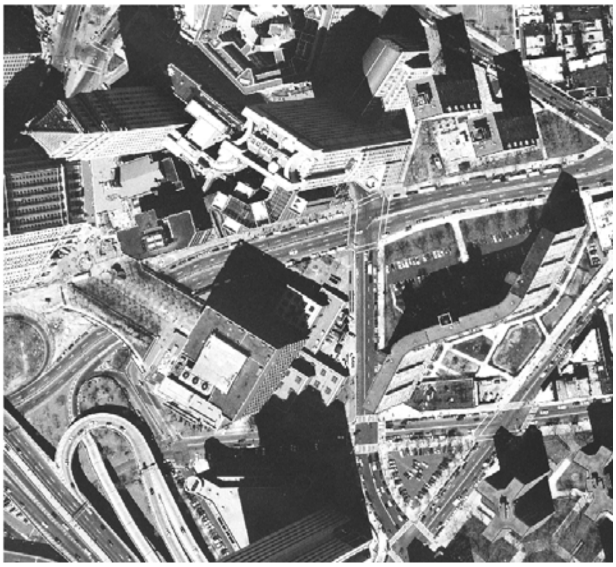

Figure 1 Conventional DOI from Lower Manhattan

2 OVERVIEW

The entire process is divided into two steps: the first step (orthophoto rectification) is done individually for each image, and the second step (mosaicking) merges the individual images into a seamless image database.

A) **Orthophoto Rectification** removes the effects of relief displacement and camera tilt.

   1) This step creates an intermediate DOI based on a TIN representation of the city surface. The resulting DOI contains buildings and bridges in their correct positions. Areas obscured by other objects like buildings and bridges are filled with blank image contents.

   2) This step creates a blind spot image by back-projecting the buildings into the image. This step

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identifies image areas that contain blank image contents and which will need filling with other imagery.

3) This step creates a weight image that defines for each orthophoto pixel a quality measure for the particular perspective. To define the quality measure we use the slope of individual surfaces relative to the viewing angle, the distance from the nadir point and the distance from a blind spot.

B) **Mosaicking** merges all of the individual images into a seamless image database.

1) The process creates initial seam lines based on the weight image and the blind spot image.

2) The process uses the initial seam lines as seed lines for an automated optimal seaming process. The optimal seaming process uses a “similarity measure” between images to seam along a path where the images are the most similar. This prevents the seam line from running through objects that are not modeled in the DTM and can be different in adjacent images: for example, cars, trees or shadows.

3 THE TRUE ORTHOPHOTO PROCESS

3.1 Modeling the City Surface

A digital orthophoto is only as accurate as the surface description. Therefore, if we want to rectify a building or bridge to its correct, upright position, we must capture buildings and bridges as part of the surface to be rectified. We call the surface description that is used to create true orthophotography a Digital City Model (DCM), which is analogous to the Digital Terrain Model (DTM).

3.1.1 The Digital City Model

Capturing the DCM is the most expensive aspect of the process because it is accomplished using either analytical stereo plotters or soft-copy plotters. It is extremely manually intensive. Lower Manhattan is an area with many tall buildings that reflect elaborate architecture from different eras. They exhibit multi-layers, and a variety of complex surfaces such as flat roofs, sloped roofs, terraces, housings for elevator shafts and air conditioners, domes, pyramids, spires, and ornamental outlines. Depending on the accuracy requirements of the final orthophoto, we need to capture each of these features in detail so that each one is rectified to its proper position. Figure 2 shows the level of detail we used for representing the buildings in Lower Manhattan.

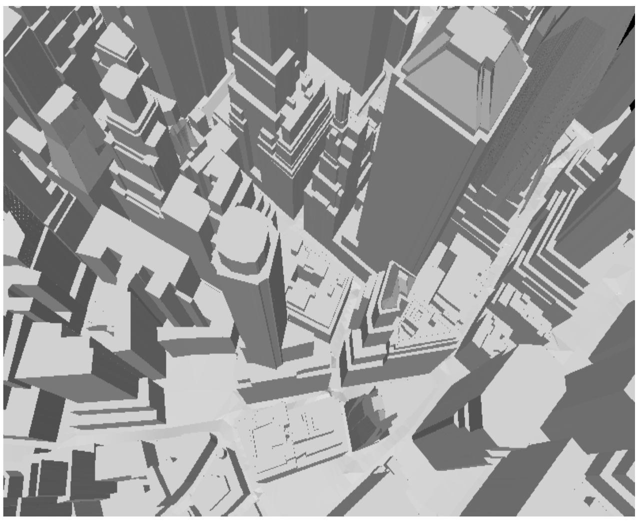

Figure 2 Digital City Model of Lower Manhattan

3.1.1 Representation of the Digital City Model

In traditional orthophoto production, a regular grid DTM is used to represent the ground surface. This representation is insufficient for producing "true orthophotography," because the point spacing is too large. The resulting interpolation errors manifest themselves in the DOI as *wavy effects* around sharp discontinuities in the terrain. This effect is even worse in built-up areas.

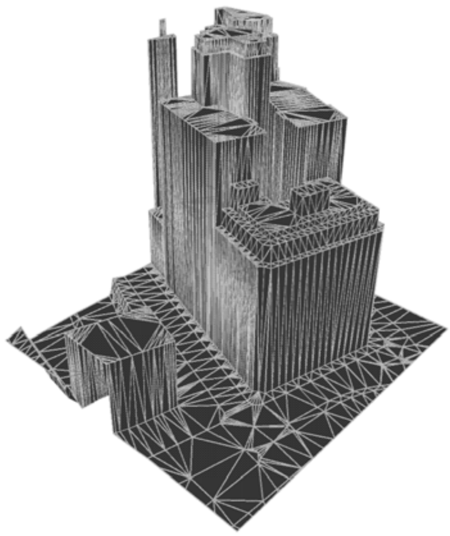

Figure 3 Digital City Model represented by a TIN

The preferred method for rectification is based on a triangular irregular network or TIN. A TIN can model the ground surface, buildings, and bridges with a series of flat, triangular surfaces. Where there is a lot of height variation in the model, the triangles are small, and visa versa. The drawback of using a TIN is that it is computationally more expensive than a regular grid. Figure 3 shows the TIN representation of parts of Lower Manhattan.

3.2 Orthophoto Rectification Based on the City Model

Based on the TIN representation of the city model, the rectification process for removing the building lean in the individual images is straightforward. The process ‘moves’ buildings and bridges into their proper locations, but also leaves holes or blind spots in the place from which they came. To address this problem, we identify these areas and compute a *blind spot image*, by simply back-projecting the city model into the individual image and marking obscured areas as black. Figure 5 shows the blind spot image for one of the aerial perspectives in the area of figure 1.

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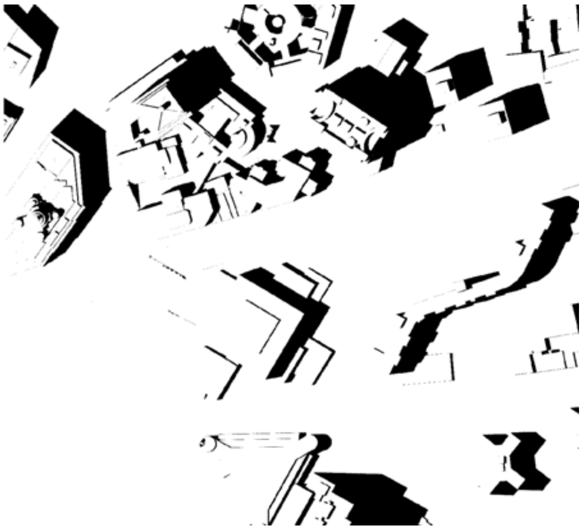

Figure 4 Blind Spot Image

3.3 Mosaicking

The most technically challenging part of this process is the mosaicking of imagery. The rectification process moves buildings and bridges into their proper locations, but also leaves blind spots. In order to create an image with the most complete coverage possible, a considerable overlap between aerial photographs is necessary. This way, what is hidden in one aerial photograph will often be visible in another, and we use this information to fill in the blind spots.

3.3.1 Which pixel to choose and from which image

To resolve the redundancy in the available image information, and to "pick the best " imagery for every final orthophoto pixel, we calculate a quality measure for each pixel in the individual DOI's. The quality measure is defined as a combination of the following three different factors:

1) Close proximity to the nadir point.
   The closer a pixel is to the nadir point - the higher the weight. This minimizes distortion of all features not modeled: for example, trees and cars.

2) The relative orientation of the ground surface to each image plane.
   The smaller the angle between the viewing direction and the normal vector of a TIN facet - the higher the weight. In this manner, we choose pixels from imagery that have the best view of each triangular facet in the TIN. This avoids smearing problems that result from severe over-sampling.

3) The distance from a blind spot.
   The closer a pixel is to a blind spot - the lower the weight. As blind spots are void of content in the DOI, choosing a pixel close to a blind spot will result in a "disharmonious" image.

These three quality measures are combined in a so-called weight image, which is computed for each individual DOI. Based on these weight images, the quality measure reduces the decision on choosing pixels to simply picking the pixel with the highest weight.

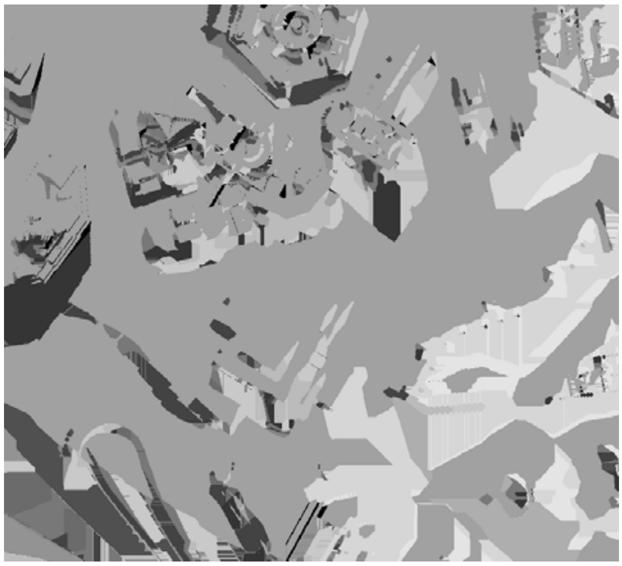

Figure 5 Mosaic pattern for the image shown in Figure 1

Figure 5 shows the mosaic pattern for the same area shown in figure 1. Areas of the same color indicate which aerial image we used to fill the DOI. The pattern is very complex and would be extremely time consuming to duplicate manually. The mosaicking depicted here is fully automated.

The results of this process are *initial* seam lines. We have two possibilities as this point. We can either feather image patches along these seam lines to construct a final DOI or we can further optimize the seam lines by a process described in the next section.

3.3.2 Finding optimal seam lines

The seam lines identified in the previous mosaicking step are used as the initial seam lines for the optimal seam line process. These initial seam lines are in effect based on the geometry of the image and the ground surface, and not on image radiometry. The initial seam lines might fall on ground features not modeled in the digital city model such as trees, cars or shadows, which can be different in the individual DOI's. ASI developed an optimal seaming process for this reason.

We use the correlation coefficient to compute the similarity of the image contents from two different DOI's. Based on this measure, a weighted graph search algorithm finds the optimal seam line along a path where the images are the most similar. The search area is bounded by a distance function from the initial seam line. The distance between points on the graph is defined by the size of the objects that the optimal seam line should avoid.

Shown in figure 6 are the results of the process when applied to two DOI's. Figure 7 shows the similarity measure for the same area. The brighter the grey value in this image - the higher the similarity.

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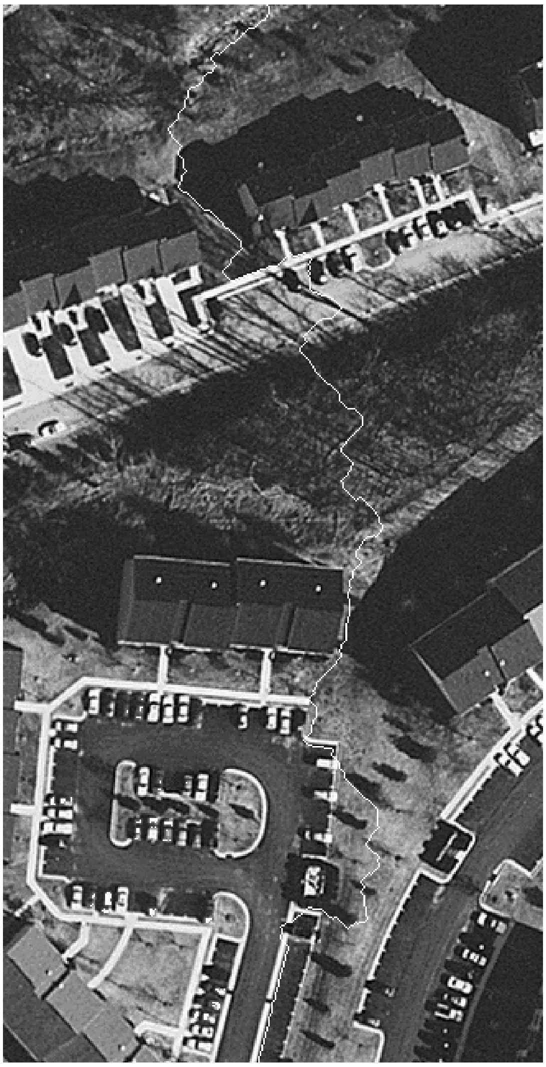

Figure 6 Conventional DOI with an optimal seam line

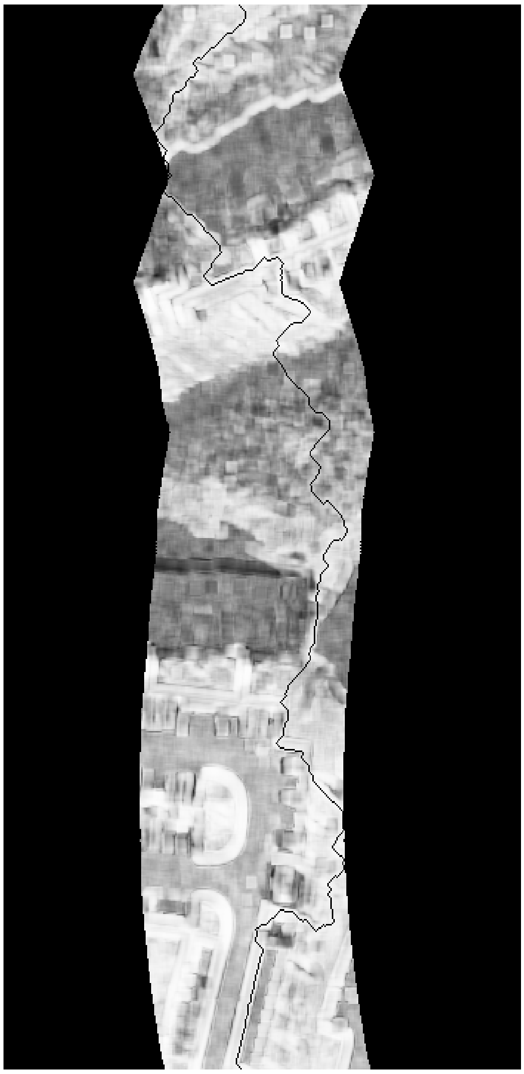

Figure 7 Similarity map for scene in figure 6

Note that, in this case, we applied the optimal seaming conventional DOI's. The buildings lean in different directions in the different DOI's. This causes a low similarity measure (dark values) in these areas. This forces the seam line to run between and not through the buildings.

The automatic optimal seaming is not yet part of our true orthophoto process. The true orthophoto examples depicted in this presentation were mosaicked along the initial seam lines and locally feathered.

4 EXAMPLE

Our goal was to implement an operational procedure for the creation of true orthophotography. Our test site was a half-mile square area in the vicinity of the Wall Street district of Lower Manhattan in New York City. In this particular project, we used three sets of photography: two sets at a scale of 1"=800' (1:9600), and one at a scale of 1"=1000' (1:12000). The 1"=800' imagery was flown with a 6 inch (153mm) lens, and the 1"=1000' scale (1:12000) with a 12 inch (306mm) lens. One set of the 1"=800' was flown north-south, and the other along the streets, both with a 80% forward-lap and 30% side-lap.

We used five aerial photographs for creating the true orthophoto shown in Figure 8. Note the absence of walls after the buildings are placed in their proper location. The bridges in the lower left corner are also correctly positioned.

5 CONCLUSIONS

We presented a new automated process for producing true orthophotography. The process involves three key factors. First, a DTM is captured that accurately models the terrain, buildings, and bridges.

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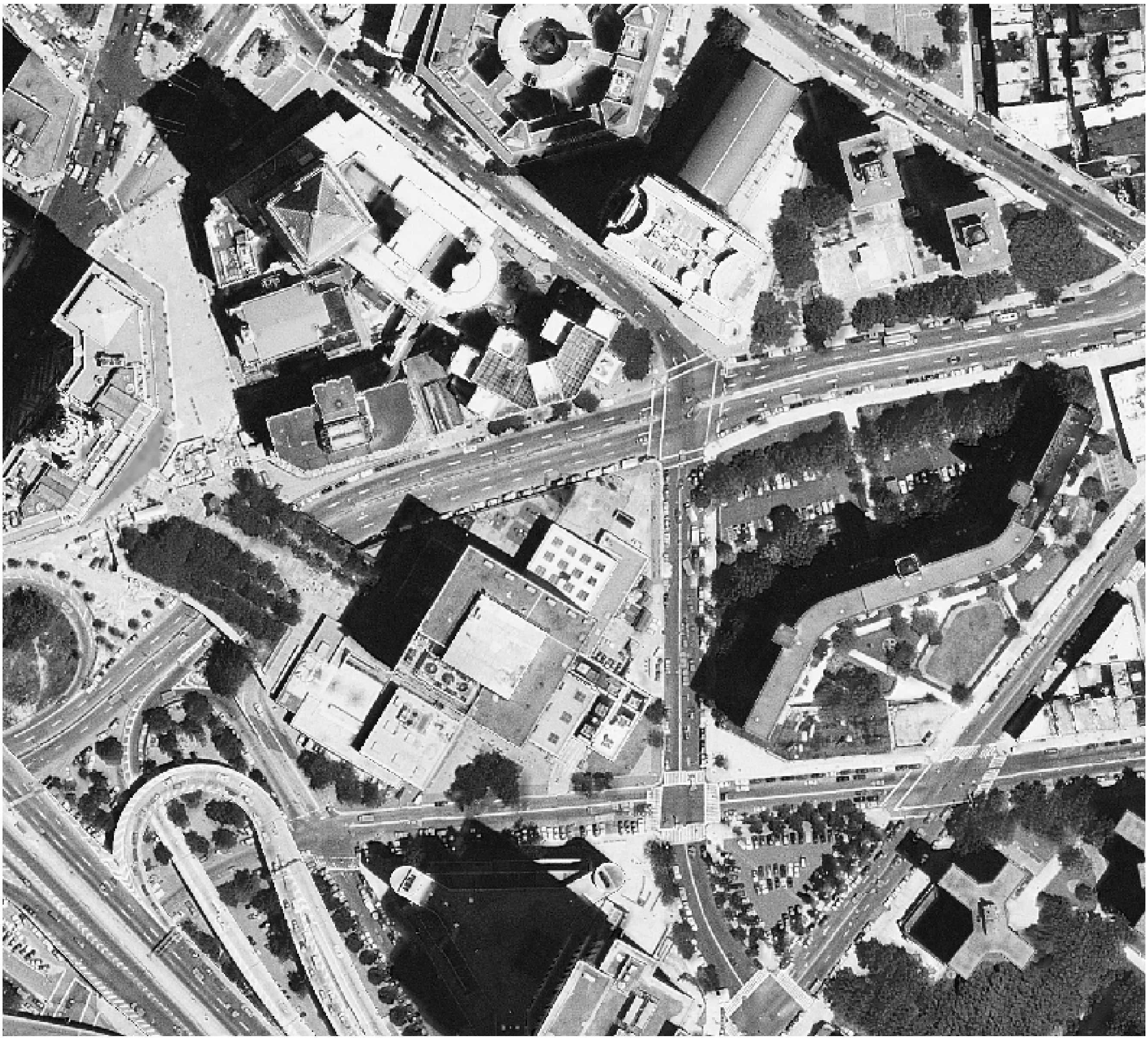

Figure 8 True Orthophoto of area in Lower Manhattan

Second, our rectification algorithm uses a TIN to position the buildings and bridges in their true location. Third, we use a sophisticated and automated mosaicking process to combine imagery from many perspectives. The result is an aesthetically pleasing, seamless orthophoto that contains buildings without lean, and sidewalks and roads that are completely visible. Most of these new developments, especially the mosaicking and seaming procedures, can also be used in conventional orthophoto production to increase the quality of the resulting seamless image database.

True orthophotography has a few disadvantages. Since building lean is removed, the DOI holds fewer visual cues about the building heights. In other words, a person will have difficulty telling the difference between a concrete slab at ground level and a flat building top that is ten stories high. Interpretation problems and confusion may result depending upon the intended use of the orthophoto.

Another disadvantage is the cost of capturing the DCM. However, for most cities, the downtown area is a small percentage of the total area, which means the costs of creating "true orthophotography" are relatively small as well. Also, downtown areas are usually well established. Therefore, the DTM will remain static, retaining its value and usefulness over a long period.

6 OUTLOOK

An important residual benefit to this process is the highly accurate digital city model. The model can also be used for other purposes such as for RF propagation for cellular network planning. Combining 3D city models with imagery to create virtual reality models is a next logical step.

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Figure 9 Virtual Reality Model using the digital city model and the true orthophotography

Depicted in Figure 9 is a rendered view from ESRI's 3D Analyst extension to ARC/VIEW. We have draped the "true orthophoto" onto the DTM to produce the perspective view. In future developments we will incorporate terrestrial imagery from a video.

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