PHOTOGRAMMETRY USING 3D GRAPHICS AND PROJECTIVE TEXTURES

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ABSTRACT

We present a process that enables mensuration in a 3D-visualization environment using multiple overlapping images. A Virtual Projector with accurate camera information allows imagery to be projected onto terrain and feature surfaces. This method encourages the use of multiple overlapping images in VR. We present results that demonstrate the ability of this process to efficiently produce photospecific VR and accomplish accurate mensuration in a multi-image environment.

Current photospecific visualization tools lack native support for precise camera models. The system being developed is called Visualization Environment Supporting Photogrammetry and Exploitation Research (VESPER). The basic elements of photogrammetry are integrated with 3D-visualization technology. These are precise camera calibration, position and orientation, overlapping images, and image to ground transformation. Methods will be presented that enable the understanding of multiple overlapping images. Image to ground transformation is accomplished through careful application of projective textures.

The fusion of multiple image sources in an interactive visualization environment demonstrates the benefits of bringing the rigors of photogrammetry to computer graphics. The methods presented show promise in allowing the development of faster tools for model verification, change detection, damage assessment, and photospecific modeling of feature data. The use of virtual projectors can simplify the data preparation process for virtual reality applications while adding greater realism.

1 INTRODUCTION

1.1 Problem Statement

Photospecific visualization products[1] can provide high quality interactive flythrough capabilities for precisely correlated 3D databases[2]. These databases are generated by a digital photogrammetric workstation [1] (DPW).

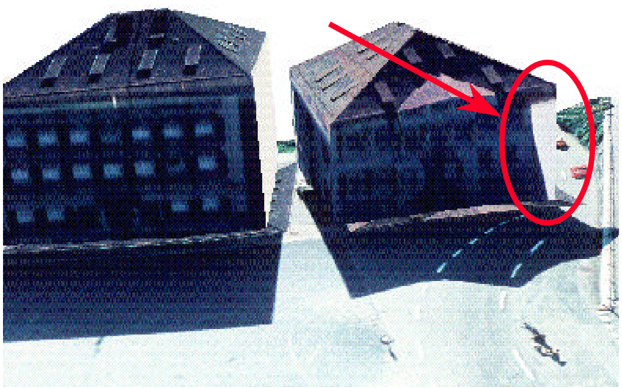


Figure 1: The identification of significant modeling errors when viewing in a 3D environment. This defect is not readily identified from an overhead stereo view.

When viewing photospecific data in a 3D environment it is common to discover modeling errors that require going back to the photogrammetric workstation for defect correction and generation of a new 3D database. This is because current photospecific visualization products lack the ability to perform precise mensuration from the source imagery that a digital photogrammetric workstation possesses. However, the defects are more readily identified using 3D visualization tools than in the stereo viewing environment of a photogrammetric workstation.

[1] RapidScene® & TOPScene® are examples of photospecific visualization products.
[2] OpenFlight and AFX are popular database formats.

1.2 Goals

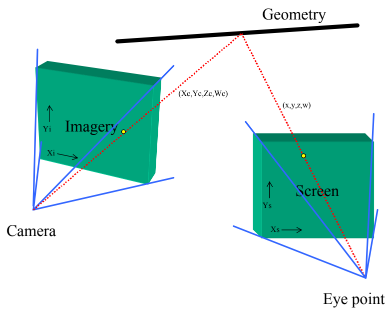
Our research objective is to develop an interactive 3D visualization environment which can be used to coherently display multiple images projected on terrain and feature data, and to better understand the terrain and features utilizing the information provided by the projected images.

Photogrammetry provides the basis for rigorously relating imagery to the ground coordinate system [2]. Image understanding deals with automated and semi-automated approaches to the extraction of spatial features directly from single and multiple images. Three-dimensional visualization provides the environment for editing and verification of the resulting data bases and simulation for various user applications. The approach in this research is based at the outset on the interaction between these disciplines at all stages involved in the extraction of spatial feature data from imagery.

The system being developed is called Visualization Environment Supporting Photogrammetry and Exploitation Research (VESPER). With VESPER the basic elements of photogrammetry are integrated with 3D-visualization technology producing a “Virtual Projector”. Methods will be presented that enable the understanding of multiple overlapping images. Image to ground transformation is accomplished through the application of projective textures.

1.3 Projective textures

Projective texture mapping [3][4] allows the camera to be treated as a projector for efficient application of imagery to surface models. Texture coordinates are assigned to polygon vertices as the result of a projection in real time. This allows the texture image to be associated with a camera positioned within the scene.



2 TEXTURE MAPPED VS. VIRTUAL PROJECTOR DATABASES

2.1 Texture Mapped Databases

Most scene visualization software systems currently support texture mapping. Photogrammetric software products like the DPW can output photospecific texture mapped databases compatible with these real-time scene visualization systems. The databases comprise terrain and feature models and imagery (textures) tied together. The imagery is cut into thousands of small patches where each patch contains the best piece of imagery selected from all available images for a given facet. These patches may even be warped for rendering efficiency.

A facet is generally described by vertices with (x,y,z,s,t) values where s,t are normalized indices into a specific texture patch. This type of DPW output, a virtual reality (VR) database, no longer contains the sensor information necessary to perform mensuration.

Figure 1 shows the easy identification of significant modeling errors when viewing in a 3D environment. This defect is not readily identified from the DPW’s overhead stereo view. This texture mapped database method requires returning to the DPW to correct the model if possible, outputting a new 3D database, and reevaluating the result in a 3D modeling environment. This iterative process is labor intensive. A 3D-visualization environment that can provide for both identification and correction of errors can improve this process.

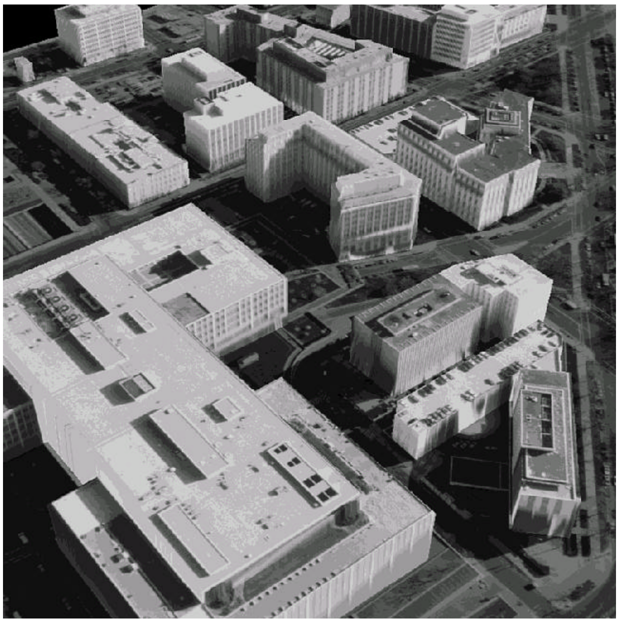


Figure 2: A frame image projected onto a terrain surface and features creates this VR scene in real-time.

2.2 Virtual Projector Databases

The application of a projective texture can be seen in Figure 2 where a single frame image taken at 3000 feet is projected onto terrain and feature surfaces. The surface contains a digital terrain map generated using the Automated Terrain Extraction (ATE) algorithms developed by Bingcai Zhang [5] with features extracted using semi-automated feature editing tools.

The terrain is output by ATE as an OpenFlight database containing only (x,y,z) values and no imagery. The DPW provides the camera calibration and position information required for projecting the source image onto the terrain and feature surface. This method provides a smaller more versatile database. With additional overlapping images projected onto the surface mensuration is possible.

3 VISUALIZATION ENVIRONMENT

3.1 Requirements

We present a process that enables *mensuration* in a 3D-visualization environment using multiple overlapping images (Fig. 3). A Visualization Environment Supporting Photogrammetry and Exploitation Research (VESPER) was developed that provides:

- *A.* Support for DPW produced terrain and features
- *B.* The ability to position projection cameras
- *C.* Support for multiple projective textures
- *D.* Mechanisms to display and differentiate overlapping images
- *E.* Methods to accomplish mensuration
- *F.* Edits of terrain and feature models
- *G.* Ability to translate, rotate, and scale models

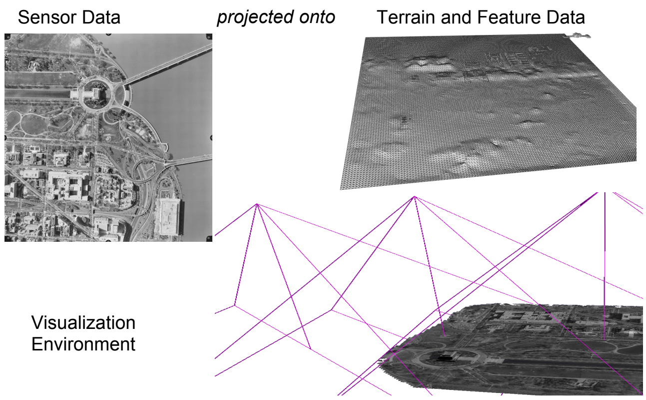


Figure 3: The image projection process is the reverse of the sensor data collection process.

3.2 Import terrain and features

Terrain and feature data can be imported from the DPW. The data is encoded using the OpenFlight data format with faces colored white. This provides an initial high quality surface model for application of our virtual projector techniques. USGS Digital Elevation Model (DEM) data may also be ingested. This terrain type can be loaded using an Adaptive Surface Definition (ASD) representation (Fig. 3 upper right).

3.3 Position Projection Cameras

The DPW image support files contain the camera calibration, location and orientation data. This data is used to precisely position the cameras for projecting the imagery onto the surface model of the terrain and features. The projection frustum is determined and interior orientation parameters applied.

3.4 Image Projection Process

The image projection process was implemented in VESPER using the methods described by Korobkin [6]. The image is resampled, placing the camera centerline in the center of the frame and making the image power of 2 rectangular, to accommodate real-time hardware requirements [7]. This resampling uses the camera calibration and interior orientation data contained in the DPW image support file. The use of cliptexture mapping [8] within our projectors enables us to project many very large images simultaneously. Aerial frame images are typically 9k x 9k pixels and space based imagery can be much larger.

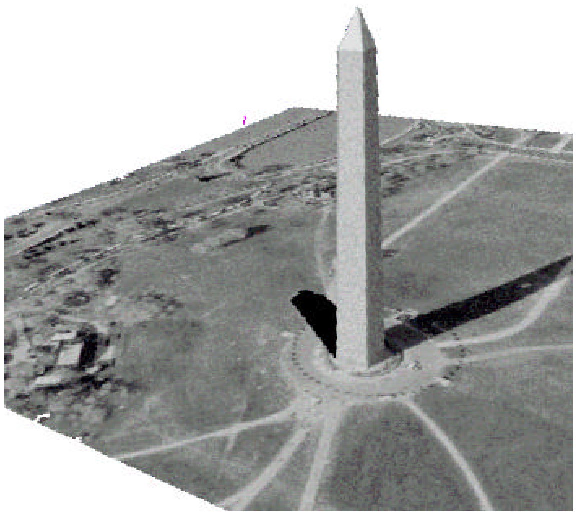


Figure 4: Depth map shadows accurately identify the camera's occluded areas.

3.5 Depth Map Shadows

Occluded areas need to be properly identified. The application of "depth map shadows" [9][10] gives satisfactory results while still maintaining real-time frame rates. The accurate projection of imagery on the Washington monument demonstrates the precision of the projected image process. Notice the correct masking of the sensor's occluded area (Fig. 4). Identification of the sun's position and application of the same processes should enable efficient shadow removal. (The shadow is to the right.)

3.6 Mechanisms to display and differentiate overlapping images

The simultaneous projection of multiple images onto an imperfect terrain and feature surface results in a messy and difficult to interpret blend of overlapping images. Wherever the surface is correct the images align properly. Visual display mechanisms to help understand the multiple overlapping images must be developed. We identified several mechanisms to try.

- Flicker through the images
- Color (red/green, blue/yellow etc.)
- Positive/negative
- Stereo display

Flickering through the projected images results in a motion effect wherever there are terrain and feature model imperfections. This technique makes it easy to identify model defects but it is difficult to make model edits. Moving objects and changes are also easily identified.

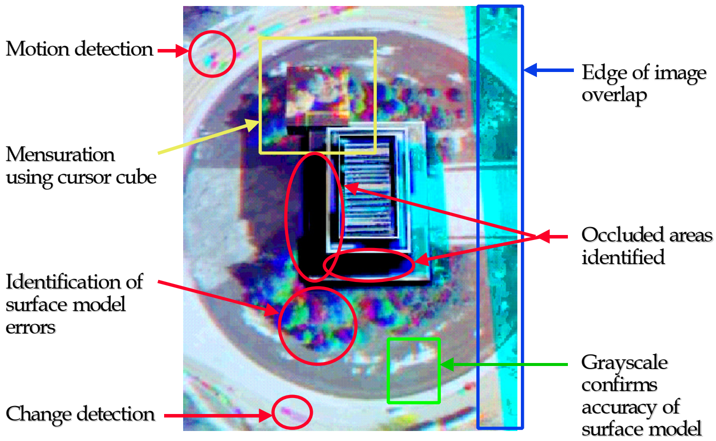


Figure 5: When the colored images blend on a correct surface model they provide a gray scale result.

A method has been developed which separates the images using spokes of the color wheel. Each image is assigned a different color and a blend of the colors gives white. Two overlapping images use red - cyan, three images red - green - blue, etc. When the images blend on a correct surface model they provide a gray scale result. Wherever there are imperfections in the surface model the colors separate (Fig. 5). This technique not only makes the identification of defects, change, and motion possible, it can capture all that in a single composite frame.

The positive/negative display mechanism is a variation of the color separation approach that can be useful for radiometric analysis. Stereo displays are still effective but of course impose all of the constraints for stereopsis.

3.7 Mensuration

Mensuration can be accomplished by accurately identifying where the overlapping projection images align. This requires an easily repositioned projection surface. A cursor cube for capturing imagery as it moves through space was developed. It is basically a six-sided projection screen. Face centered crosshairs and the cube's corners provide single pixel measuring points. A ground position is identified when all the overlapping images align on the cube (Fig. 6). Digital readouts display the geolocation of the cursor as it is moved about. This cursor works with all of the image display methods.

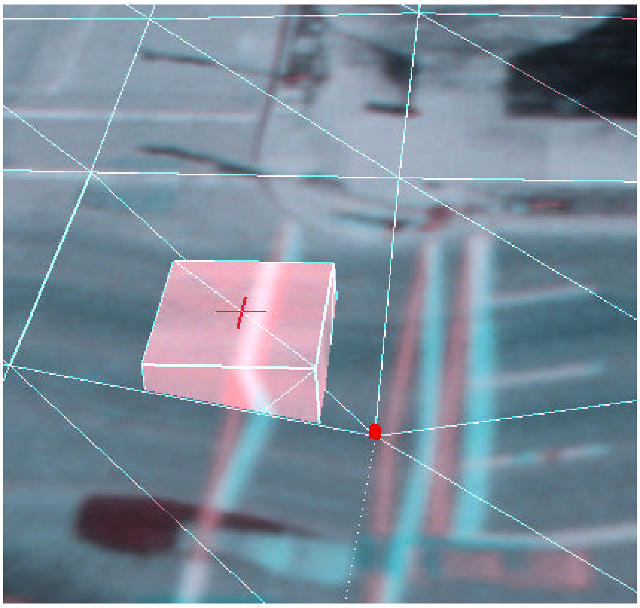


Figure 6: The cursor cube was used to identify a 6.2 foot elevation error in the Digital Terrain Model (DTM).

3.8 Edits of terrain and feature models

Conventional graphics programming techniques are used to implement vertex selection and edits. Vertices can be interactively edited in VESPER allowing precise correction of model errors. Notice the red - cyan color separations that occur when the vertex in the crosswalk is pulled out of position (Fig. 6). This demonstrates the positive visual cues achieved by the color blending technique when editing a surface model.

3.9 Translate, rotate, and scale object models

Functions for translate, rotate, and scale are required to support the placement of generic feature objects and architectural CAD models. Detailed models of famous landmarks are readily available over the Internet. Models of the Lincoln Memorial and the capitol building have been successfully incorporated into VESPER scenes. VESPER revealed significant modeling errors in these purchased datasets.

4 RESULTS

4.1 Measurement Accuracy

Mensuration accuracy was evaluated by comparisons of VESPER measurements with SOCET SET® 4.1 measurements. The SOCET SET® reference measurements were made using a conventional stereo display and 3D cursor. For the purposes of this analysis these measurements are considered ground truth. The VESPER measurements were made using the cursor cube described in section 3.7. The 30-foot DTM data is included to present the inaccuracy inherent in DTM surfaces. The measurements were performed using three overlapping images from a sequence of controlled images gathered over Washington D.C. The footprint of the sequence is outlined in blue in (Fig. 8). The images have a ground sample distance of 0.5 feet. A plot of the measurement deltas shows that subpixel measurement accuracy is achieved (Fig. 9).

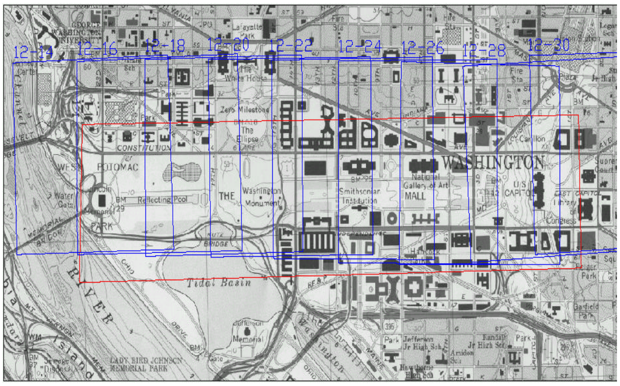


Figure 8: A sequence of images was used for the mensuration tests. The red outline identifies the footprint of hyperspectral data utilized in (Fig. 11, 12).

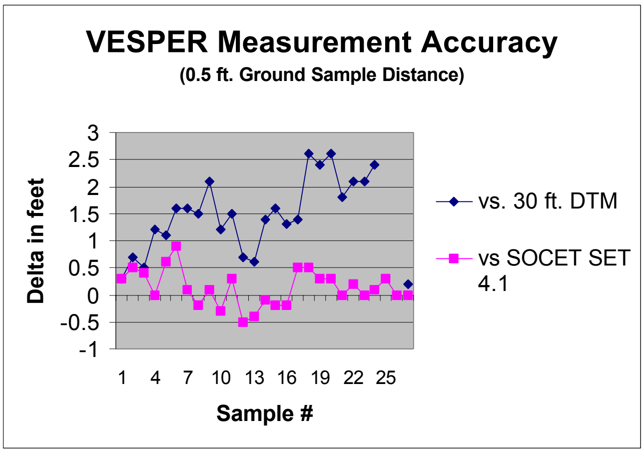


Figure 9: The elevation measurements collected with VESPER compare well with those from SOCET SET®.

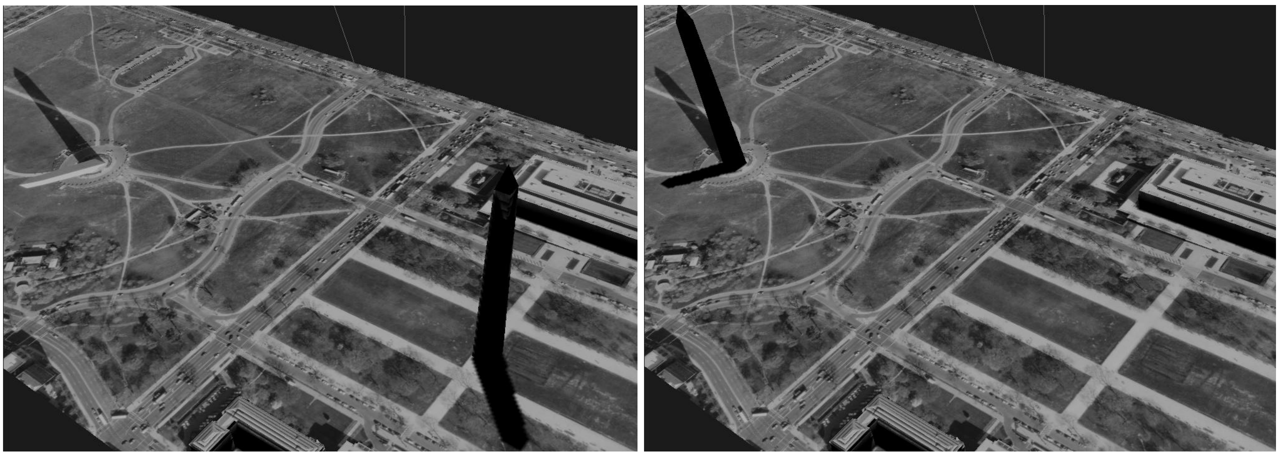


Figure 10: A feature model is precisely placed with VESPER using terrain data and a single image with the feature occluding some portion of the terrain.

4.2 Precise Model Placement Using a Single Image

Placement of building features using a single image can be accomplished if the underlying terrain is known, the feature occludes some portion of the terrain, and an assumption of verticality is reasonable. A model of the Washington monument was precisely positioned using a single image (Fig. 10). This was accomplished by placing the model on the ground and translating and rotating the model until it fits the image. The model is scaled to the correct height by correctly matching the depth shadow to the monument's image on the ground. This method successfully exploits the occlusion information that is usually a hindrance to stereoscopic methods.

4.3 Exploitation Applications

The virtual projector methods used for VESPER provide a convenient mechanism for rapidly bringing together image and model data collected and produced by diverse means. This capability has proven useful for data exploitation applications. David Landgrebe at Purdue University has produced a thematic map [11] of the DC mall from hyperspectral imagery (Fig. 11). C. Lee also at Purdue has developed methods to produce an ortho-rectified image of this thematic map [12]. When projected and blended with frame images the quality of the ortho-rectification and the thematic map can be evaluated (Fig.12). Virtual projectors also enable the fusion of hand held imagery with overhead, Figure 13, and real-time true ortho mosaics, Figure 14.

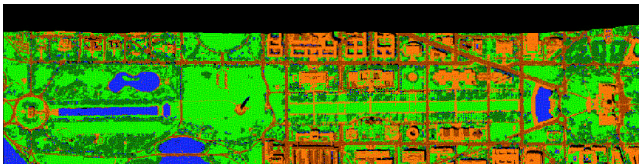


Figure 11: Data from diverse collection sources can be easily brought together with VESPER.

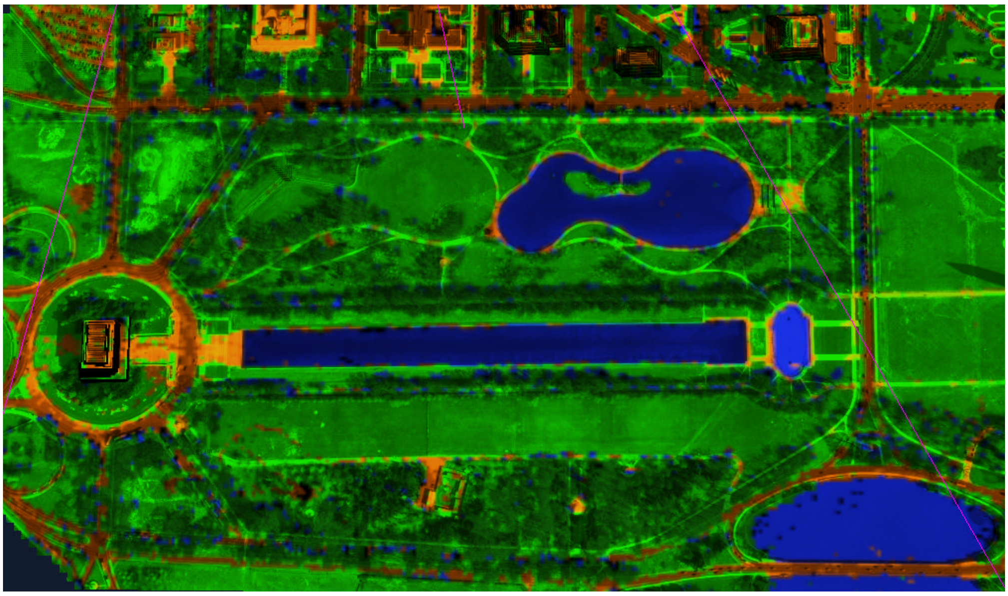


Figure 12: A hyperspectral thematic map (Fig. 11) and a frame image (Fig. 3) are projected and blended.

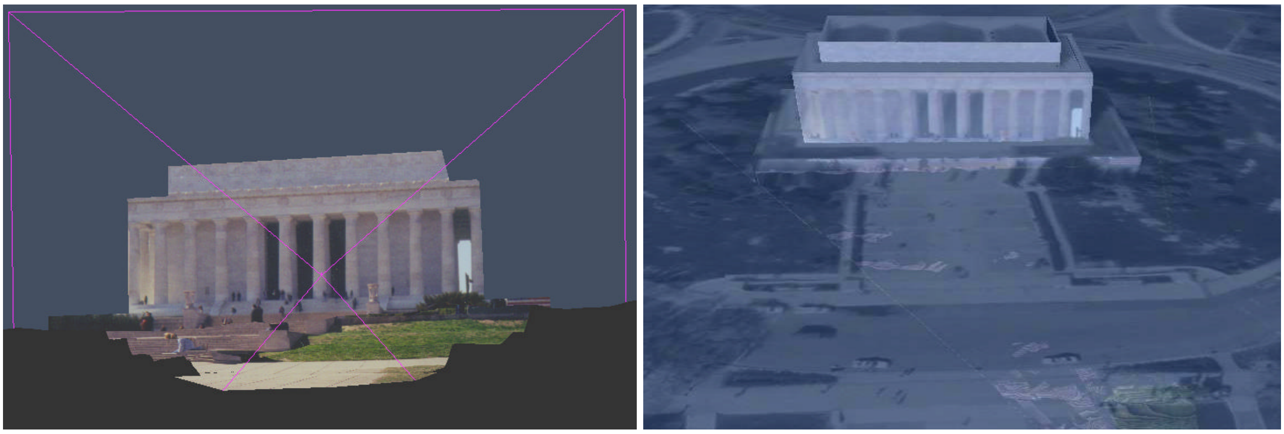


Figure 13: The fusion of imagery taken with a hand held camera together with aerial imagery enables exciting new capabilities for immersive VR, line of sight analysis, and real-time data fusion.

5 CONCLUSION

The methods presented show promise in allowing the development of faster tools for model verification, change detection, damage assessment, and photospecific modeling of feature data. They enable improved data understanding and 3D model defect detection. Application of the virtual projector concept has proven effective in photogrammetric applications using frame and orthographic cameras. Further research is underway to utilize virtual projector techniques with other sensor models. Current research shows that non-frame sensors may be modeled as a collection of many small frame cameras (piecewise frame). VESPER has successfully demonstrated the production and presentation of true ortho mosaics, contour lines, line of sight analysis, and of course perspective scenes all in real-time. The introduction of sensor models to VR enables the imagery to be decoupled from the geometry thereby enabling the update or modification of either one independent of the other. This decoupling simplifies many real-time rendering issues including textured ASD. The use of virtual projectors also simplifies the image data preparation process for generating conventional virtual reality databases.

Figure 14: True orthographic mosaics can be generated on the fly in real time by simply taking an orthographic overhead view of a scene that uses virtual projectors. This ortho view of the scene from Figure 2 also highlights the occlusions caused by the buildings.

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