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ADP023085

TITLE: Process for Generation of Polygonal Target Models for Infrared Sensor Simulation

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TITLE: Proceedings of the Ground Target Modeling and Validation Conference [13th] Held in Houghton, MI on 5-8 August 2002

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Process for Generation of Polygonal Target Models for Infrared Sensor Simulation

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I. Abstract

US Army Night Vision and Electronic Sensors Directorate (NVESD) has recently developed a process for generating polygonal target models with attributions suitable for integration with thermal modeling code for use with its infrared sensor simulation Paint the Night (PTN). This paper will describe the process for generating those models from high-resolution Combinatorial Solid Geometry (CSG) models and close-up infrared sensor imagery. It will discuss the method of encoding material attributions into the polygonal data format, SGI Performer™ binary format. It will describe the commercial and custom software tools used in this process. Finally, it will show sample synthetic imagery of targets in scenes generated by PTN with integrated one-dimensional steady-state thermal modeling code.

II. Introduction

In support of its imaging sensor simulation program, the U. S. Army's Communication and Electronics Command (CECOM) Night Vision and Electronic Sensors Directorate (NVESD) has developed a process for generating polygonal vehicle models (henceforth referred to as targets) with attributions suitable for integration with signature modeling codes. The process was developed for use with NVESD's Paint the Night (PTN) Forward Looking Infrared (FLIR) scene simulation software, but the same process can easily be applied to create targets in other wavebands and for other simulations. In fact, with sufficient care in the modeling process, the same models may be developed for use in multiple wavebands.

In the past, NVESD has modeled infrared targets by applying an image of the target's thermal signature, called a texture, directly to a 3-D polygonal model of that target. The target signature is typically a thermal image of the real target collected digitally at close range with a thermal imaging camera. This image is radiometrically calibrated and the image mean is adjusted so that reference points in the image and synthetic scene match. The result is a target with a "real" thermal signature. Signatures are collected at night to minimize the effects of solar loading, heating of the target due to the sun.

In order to generate both day and nighttime scenes with the same targets, a method was developed to add solar loading effects to the target. The brightness of a particular part of the target was increased by a predetermined solar loading factor, based on the location of the sun in the scene as determined by the simulation. This allowed the night target signatures to be extrapolated to day scenes. While effective, this method makes some compromises in accuracy. Since a uniform solar loading factor is applied to an entire model, it does not take into account the differences in materials within the target and the effects of solar loading on internal heat sources.

Two key limitations existed in the previous target models. First is an inability to change model signature based on environmental changes other than sun position, such as ambient temperature. Second is the inability to vary thermal signatures based on the operational state of the target. For example, a tank that has been moving has tracks with a brighter thermal signature while a tank that has been stationary has track signatures closer to that of the armor. Or when the tank has been firing its main gun, the signature of the gun barrel is brighter than when it has been inactive.

One solution to these two limitations would be to collect target signatures for each environmental condition, operational state of interest, and all their permutations. This results in problems. First, collection of all the real imagery for target signatures would be prohibitively time consuming and costly. Second, even if all the required target signatures were collected, dynamic management of the textures within the simulation would provide significant technical challenges, perhaps beyond the capacity of today's hardware.

To reduce the need for data collection, a thermal signature model can calculate the target signature. To get the detail of target signature required for PTN, a very detailed finite element model would be necessary to produce the high fidelity signature images required for a texture. While this solution satisfies our desire to have target signatures at multiple operational states and under varied environmental conditions, both the fidelity requirement of the model and the processing time required to run the model would make this solution practically unworkable for real-time applications.

In order to get the benefits of the calculated model with a manageable level of computer resources we have developed a hybrid solution. This solution utilizes low-resolution thermal modeling and textures based on "real" imagery. A target polygonal model is broken up into thermally similar regions, such as wheels, and attributed with that information. The thermal model can calculate the bulk temperature and radiance characteristics of that region and pass that information on to the simulation that assigns the appropriate color. To achieve greater detail, the image is textured with real imagery, but in this case the imagery is modified to provide only fine scale detail and not the main signature.

This paper will discuss in detail the process of generating target models from high-resolution source geometry and target imagery. It will show some sample synthetic imagery generated by PTN using targets created by this process. This paper will not give details on any specific thermal modeling method or software or discuss the additional information required to implement such a model.

III. Methods

Source Geometry

Most target models used in the PTN simulation originate from high fidelity combinatorial solid geometry models produced by the Survivability Lethality Analysis Directorate (SLAD) at Army Research Labs (ARL). These models were created using ARL's 3-D computer aided drawing package called BRL-CAD™. This package uses a combinatorial solid geometry approach that involves modeling complex 3-D shapes by combining various primitive solid shapes (spheres, cones, cylinders, cubes, etc.) using Boolean operators (union, intersection, difference). In order to use these models in a PTN simulation, the BRL-CAD™ models must be converted into a polygonal format. To address the run-time performance of PTN, the number of polygons in each model must also be drastically reduced.

The BRL-CAD™ model is first converted into the 3-D polygonal geometry format, OBJ, developed by Alias|Wavefront™. This is a popular 3-D polygonal geometry format that organizes the vertex and material data in an easy to follow ASCII file. The conversion is carried out using a command-line executable program distributed with the BRL-CAD™ modeling package. This process retains the hierarchical information of the original BRL-CAD™ model inside the newly created OBJ file. Using a tool developed by NVESD, the OBJ model file is then converted into a SGI Performer™ binary format (PFB), the PTN native format. The resulting PFB target model retains the high fidelity characteristics of the original BRL-CAD™ model. This results in a polygonal model with an excessive number of polygons. At this point, the target models contain on the order of 150,000 polygons

Internal Polygon Removal

A major culprit to the high number of polygons is the detailed interior representation of the target models. PTN is only concerned with the parts of the target that can be seen from the outside. Any interior polygons that cannot be seen by a sensor can be removed. NVESD has developed a tool that effectively removes all internal polygons of the target model leaving only the external shell of polygons. There is usually a 10-fold reduction in the number of polygons once the interior polygons are removed.

Geometry Manipulation with Maya

At this point, the target models still contain an excess number of polygons. A typical target model can be represented by less than 5000 polygons, without significant loss of fidelity from the BRL-CAD™ original. In order to further process the target models and reduce the number of polygons, a software package called Maya is used. Maya is an industry leading, comprehensive 3-D modeling package developed by Alias|Wavefront™. Maya version 3.0 was used for this effort, but subsequently version 4.0 has been released. It has many powerful features and tools for manipulating geometry and applying textures. The most compelling feature of Maya is the accessibility of its core application programming interface (API). Using the Maya API, developers can create customized tools that can be used within Maya via plug-ins. This feature was immediately put into use to add the capability of importing and exporting PFB geometry files into Maya. A plug-in was developed by NVESD that can bring PFB geometry into Maya along with the hierarchical information and then export a PFB file that retains the hierarchical, texture, and material properties information.

Polygon Reduction in Maya 3.0

Once the target model is brought into Maya, an array of polygon manipulation tools are used to further reduce the number of polygons. There are two main approaches for reducing the polygon count. The first approach is to completely remove objects from the target model that are deemed unnecessary for the proper representation of the models in PTN. These objects are those that do not significantly add to the profile of the target or those that can be represented by the application of textures. The second approach for reducing the number of polygons is to replace complex objects with similar and less polygonal intensive objects. For application in the PTN simulation, it is unnecessary for many objects on the target models to be so highly detailed and represented with so many polygons. These objects include the wheels, headlamps, gun barrels, and hatches. A much simpler model of these objects can usually be created in Maya and used to replace the originals. Figure 1 shows a BMP1 model with the drive, idle, and guide wheel highlighted in black. Combined, these wheels contain over 3,000 polygons. After these wheels are replaced with simpler, polygonal cylinders the number of polygons drops to under 1,000. The overall physical appearance remains the same.

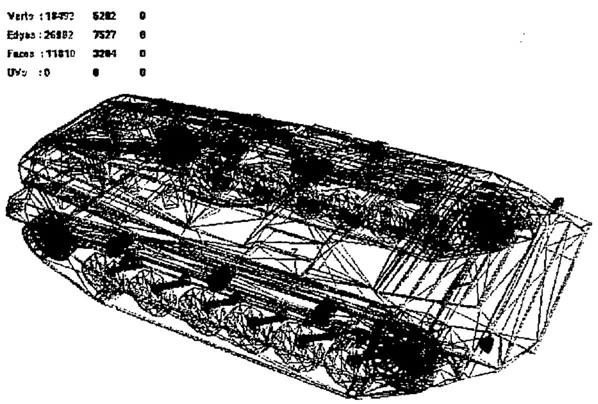

Figure 1 – The drive, idle, and guide wheels contain a combined 3,284 polygons.

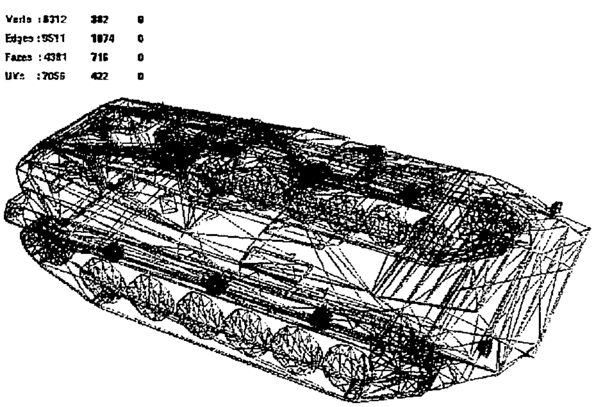

Figure 2 – By replacing the original wheels with simpler polygonal objects the number of polygons goes down to 716.

Because the original source models came from a combinatorial solid geometry format and were not optimized for polygonal representation, even simple objects can consist of an excess number of polygons. For example, one side of a simple rectangular armor plate does not need to be represented by more than two triangles. However, after converting the original source models into a polygonal format, that armor plate may be represented with several times more triangles than necessary. Removing the extraneous polygons and replacing it with fewer triangles provide another way for reducing the number of polygons. Most target models can be represented with fewer than 5000 polygons without significantly impacting the visual characteristics of the models.

Identifying and Regrouping Thermal Regions

The next major step in the PTN target build process is to identify the thermal regions of the target, and to regroup the regions within the target model accordingly. The thermal regions are identified using infrared sensor images taken at various target viewpoints. These infrared sensor images will also serve as textures for the target models. In some cases, the thermal regions closely correlate with a group of physical objects within the model. For example the grouping of wheels may have the same thermal characteristics and therefore represent a single thermal region. In other cases, the thermal regions do not correlate to any single physical object and may be irregular in shape. An example would be the thermal hotspot on the hull of a tank that corresponds to the area over the engine compartment. This thermal region must be carved out of the target model geometry and regrouped as a separate physical region. Figure 3 shows how the thermal regions of the BMP1 were broken out. Each different grayscale region in the Figure 3 represents a distinct thermal region. The hierarchy of the BMP1 target model is shown in Figure 4. Each thermal region is broken out into separate groups. In the case of the BMP1, the geometry was broken out to 12 distinct thermal regions: main hull, front hull, turret, guns, deflector, tracks, glacis, hatches, intake grill, exhaust grill, wheels, and side skirts.

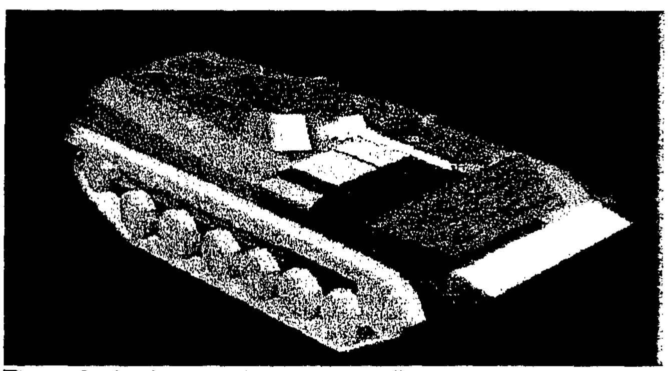

Figure 3 – Each grayscale represents a distinct thermal region.

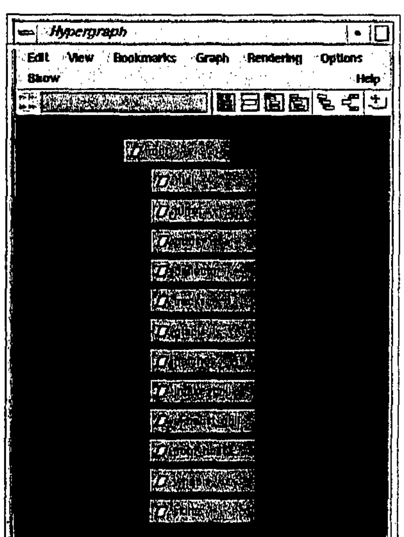

Figure 4 – Each group in the hierarchy represents a distinct thermal region.

Application of Texture and Assignment of Material Shaders

Once the geometry manipulation steps are completed, the target model must be textured with the appropriate infrared sensor imagery. The process of creating textures from source imagery is detailed in another section. When modeling with Maya 3.0, the texture images must have pixel values that are no greater than 8-bits per channel. The latest release of Maya (version 4.0) does provide support for up to 12-bit image files. Using the tools available in Maya 3.0, the target models are textured with the prepared texture image. Special care must be taken to ensure that the thermal regions in the imagery are in alignment with the corresponding physical regions within the target model. Figure 5 demonstrates how the polygons in the target model are mapped to the texture image.

Once texturing is complete, each corresponding thermal region is assigned to a separate material shader that has been given a unique name that identifies the thermal region. The Phong shader must be used in each case because the export plug-in only supports this particular shader. The exporter will insert the unique name given to each shader into the user data field of the material node of the corresponding Performer group node. This is important because the user data field is what the PTN simulation will use to identify each thermal region of the target models so that the material properties for those can be properly modulated.

Figure 5 – This image shows the mapping of polygonal regions of the target model on the texture image.

Exporting to PFB

The completed Maya target model (see Figure 6) is then exported to a Performer binary format (PFB) using the import/export plug-in. Because of the dynamic range requirements of the PTN simulation, it is important to produce target models that are textured with 12-bit image files. A tool was developed at NVESD that creates 12-bit textured models from the directly exported 8-bit textured models by swapping the internal 8-bit texture reference with a reference to an exactly corresponding 12-bit image reference. The end result is the creation of two different versions of the target model in PFB – an 8-bit textured version and a 12-bit textured version.

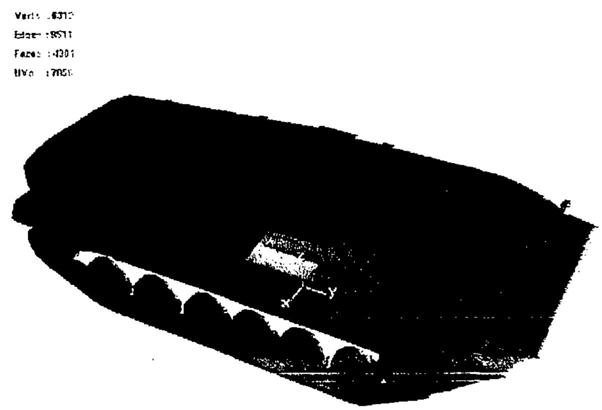

Figure 6 – A finished target model.

Texture Averaging and Thermal Modeling

The thermal regions within each target model will be modulated by using a thermal model that computes and modifies the OpenGL emissivity value of each thermal region during real-time PTN simulations. For this method to work properly, the texture image file must be modified so that the mean value for all pixels within the texture image that are mapped to a particular thermal region must be shifted to some specified mean value. This process must be repeated for each thermal region so that the resulting texture image has corresponding regions that each have the same average pixel values. A tool was developed at NVESD to achieve this goal. This tool iterates through each group corresponding to a thermal region within the target model, averages the pixel values in the texture image mapped to that group, determines the multiplicative factor that the average pixel value is off by (from the specified mean value), and then multiplies each pixel within that region by that factor. This effectively shifts the mean pixel value of each region to the specified value. Figure 7 displays a BMP1 target modeled that has been textured with an averaged texture image.

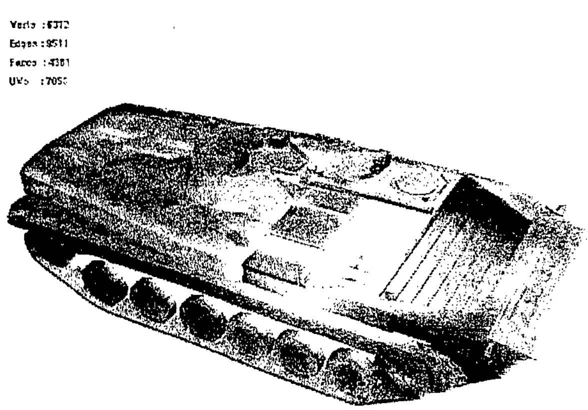

Figure 7 – A target model whose texture has been averaged.

Creation of IR Textures

Textures are created from real imagery of targets taken at night of vehicles in a fully operational state. The imagery has been collected using a calibrated thermal imager. A texture consists of the four principal orthogonal ground views of the target and a top view if available. The processing of the texture imagery is done using ImageJ, a Java based freeware image processing package developed by the National Institutes of Health. The views are read into ImageJ from IMG files using an ImageJ plug-in developed by NVESD. The imagery is then calibrated based on the imager's internal calibration information stored in the IMG file header. Then the means of the images are adjusted so that a reference value in the image matches the same reference value in the simulation. This reference may be a thermal reference source or, if none is available, the temperature of the ground in the image. This ensures that imagery taken under different conditions matches, and that the imagery matches across targets. The images are then cropped and pasted together into a single image. This image is then resized to make a texture image where the image extents are a power of two.

IV. Sample Imagery

Figure 8 shows multiple synthetic advanced FLIR images generated by Paint the Night (PTN) using an integrated 1-D thermal model, and targets generated using this process. The scene contains a BMP1 and a T72 in day (Figure 8A), night (Figure 8B). and crossover scenes (Figure 8C).

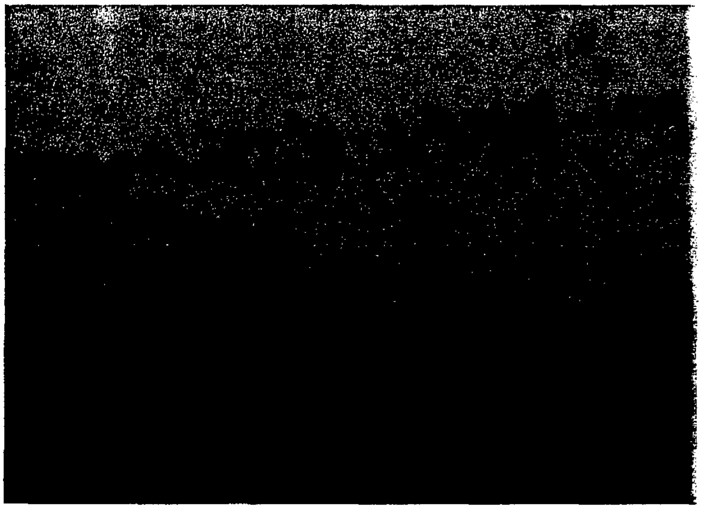

Figure 8A – PTN Scene Daytime (1500 hours)

Figure 8B – PTN Scene Nighttime (2300 hours)

Figure 8C – PTN Scene Morning (0700 hours)

V. Conclusions

This paper described a process for the generation of polygonal targets suitable for use with thermal signature modeling codes. While some coding was required particularly in the area of geometry format conversions and image manipulation, the bulk of the operations were performed on commercial, government owned, or free software. While these models were developed for PTN, the process is not limited to a particular thermal model or type of simulation. In fact, the same process can easily be applied to create targets in other wavebands and for other simulations, and with sufficient care in the modeling process the same models may be developed for use in multiple wavebands.