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HPC Enhancement of Plume Modeling for Use by Military Simulators

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1. Introduction and Background

CT-Analyst® is a high fidelity, fast, accurate, model for the transport and dispersion of contaminants. These capabilities arise from the use of Dispersion Nomografs™, which are pre-computed from detailed high-resolution three-dimensional (3D) computational fluid dynamics (CFD) calculations from FAST3D-CT. These calculations are run ahead of time and currently take a week or more to run on a moderate sized high performance computing (HPC) machine. CT-Analyst runs on a variety of platforms that include Windows, Mac OS X and various flavors of UNIX and Linux.

An application programming interface (API) was developed to make CT-Analyst's high fidelity physics based plume predictions available to modeling and simulation (M&S) tools. This plume API was used with the M&S application One Semi-Automated Forces (OneSAF). OneSAF is a next generation entity level simulation[1]. For a 10 by 5 km region of Baghdad, OneSAF made use of CT-Analyst through the application programming interface (API) to determine the plume locations, the plume concentration at points within the simulation, and to determine the attenuation of visibility along a line. Figure 1 shows the overall process required to generate these plumes for OneSAF. Before the simulation is run, FAST3D-CT generates a Pre-Computed Nomograf database. During the simulation, OneSAF calls a CT-Analyst process that in turn interprets the Nomograf database to generate plumes.

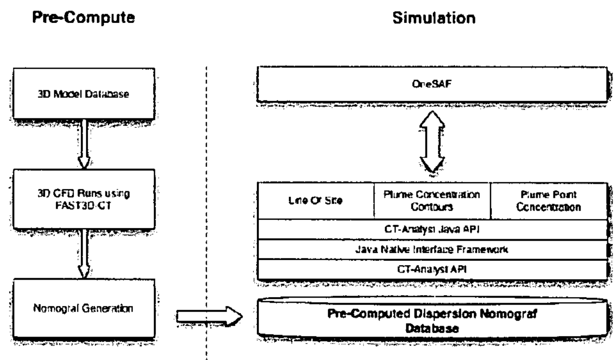

Figure 1

FAST3D-CT, a detailed physics-based numerical model[2], was developed at the Naval Research Laboratory (NRL) to accurately predict plume evolution and the contamination footprints resulting from these releases. FAST3D-CT is a general-purpose fully 3D computational fluid dynamics model for contaminant transport in complex urban geometries. It is based on the high-resolution, time accurate Flux-Corrected Transport algorithms invented at NRL. A wide range of contaminant physics and physical environment models are employed in FAST3D-CT. FAST3D-CT is used to perform the time-accurate, high-resolution 3D CFD as an offline, high-fidelity urban contaminant transport scenario generator.

The salient data and statistical features from the FAST3D-CT CFD calculations are summarized and distilled into memory efficient, time-independent Dispersion Nomograf™ data sets. These are interpreted and evaluated by CT-Analyst. There are no time-dependent integrations performed explicitly by CT-Analyst. Instead, all predictions produced by CT-Analyst are simply the result of applying an interpolation procedure utilizing the appropriate Nomograf data set based upon the high-resolution CFD results. This same interpolation procedure can be used in both upwind and downwind directions with equal effectiveness. These simple geometric operations are used to determine the probable source zone upwind of each sensor. CT-Analyst provides the unique capability to immediately backtrack and simultaneously determine the location of multiple unknown sources simply based on sensor readings and meteorological parameters.

2. CT-Analyst API

Since CT-Analyst 3.0, CT-Analyst has developed a mature, stable API that allows its functionality to be extended to a variety of software platforms and protocols. This was accomplished by adding a middle layer (Figure 2) to the software that can be easily mapped to other interfaces. The CT-Analyst API and graphical user interface are written in C++ using Trolltech's QT Framework. This API then calls the Dispersion Nomograf Library functions that query the Dispersion Nomograf Database. The Dispersion Nomograf Libraries are primarily written in FORTRAN. Using the CT-Analyst API, CT-Analyst has exported its functionality to other protocols such as Google Earth's KML file format and Microsoft Component Object Model (COM)[3]. The COM implementation has been used in successfully in other software packages including the Missile Defense Agency's PEGEM and Defense Group, Inc.'s CoBRA®.

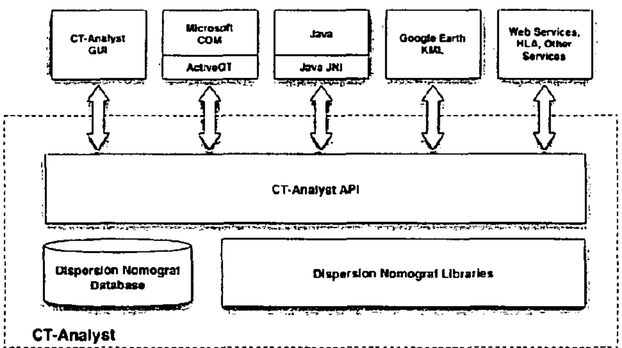

Figure 2. CT-Analyst design and component breakdown

3. Implementation

There were two main components to this project: generating the Dispersion Nomografs for the area of interest and developing an API for communication between CT-Analyst and OneSAF.

To generate the Dispersion Nomografs for the area of interest, in this case Baghdad, the typical process is: 1) acquire the geometry data for the area as well as other data such as satellite imagery, 2) process the data into a model compatible with FAST3DCT, 3) run the relevant cases with this model, and 4) generate the Nomograf database.

The original input data for the Baghdad geometry was a 3D OpenFlight model of a 10 by 5 kilometer area centered on the US 'Green Zone'. This OpenFlight model contained complete renderings of the Baghdad landscape, including terrain, buildings, roads and water. This OpenFlight model was then converted into an AutoCAD DXF file, which expressed the scene as a two-dimensional (2D) collection of building outline polygons, with a height attribute value attached to each. The DXF information was then translated into an ESRI shapefile, a format similar to DXF that is our preferred format for preparing geometry information for use in the Nomograf generation process.

Once the building height information was collected, it was exported from the polygon format into a raster format using MF Works, a geographic information system raster program that allows for the direct manipulation of cell values. Two terrain models were generated, one with an average ground height (flat earth) and one with the actual terrain values from the OpenFlight model. A water model was created using previously generated information. Each of these datasets was then georeferenced using the Universal Transverse Mercator coordinate system and exported to a format compatible with FAST3D-CT.

Two Dispersion Nomograf databases were generated, one for each of the terrain models. Both of the databases used building and water models. Eighteen separate FAST3D-CT simulations were run for each database. The area computed was a 10 by 5 km area at a resolution of 6 meters. This was by far the largest area attempted at this resolution. At this resolution, any areas above 25 sq kilometers require HPC resources to run within a reasonable amount of time. For the Nomograf database with flat earth, a 256 processor SGI Altix at NRL was used to generate the database. For the Nomograf database with terrain, the 256 processor SGI Altix at NRL was used as well as a 32 processor, 64 core SGI Altix obtained through the High Performance Computing Modernization Program (HPCMP) Dedicated High Performance Computing Investment program.

To communicate with OneSAF, it was decided with a group at SAIC who are implementing Physics-based Environment for Urban Operations enhancements to OneSAF to develop a Java API for CT-Analyst. This approach was taken because Java was a common language known by both development teams. As can be seen from Figure 3, when OneSAF requests plume information, a separate process developed by SAIC would call the CT-Analyst Java API. The CT-Analyst Java API would then call CT-Analyst interface via the Java Native Interface (JNI) framework. The communication between OneSAF and this process was via sockets. The API implemented for OneSAF included generating plume density contours, concentrations at various points in the domain, and the attenuation of visibility due to source releases between two locations in the domain.

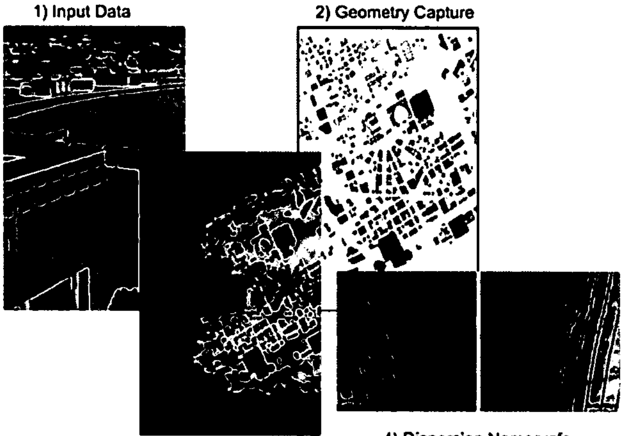

Figure 3. The Nomograf generation process

OneSAF displays plumes as polygons, however, CT-Analyst computes plume displays using a raster format. A function was developed to handle this translation from a CT-Analyst 2D concentration array to polygons representing concentration contours. The first version utilized a basic horizontal and vertical raster scan that would simply detect contour points by searching along each row in the concentration array for the concentration threshold. The second version improved on this algorithm by searching only for the first value where the contour threshold was reached, and then performing a neighbor-to-neighbor search until the contour line was complete. This dramatically improved the accuracy of the generated contours, and allowed for the depiction of concentration gradients within them. The second version also allowed multiple sources to be processed at once allowing for overlapping plumes.

The point concentration commands were implemented by first calculating the plume concentration for the sources in the domain. The point concentration was then read from the calculated concentration array. In a similar manner, the attenuation calculation was implemented by integrating the concentration from the calculated concentration array along the line passed in by two points.

4. Ongoing Work

Work to process thousands of source releases per second for OneSAF is currently underway. The most computationally expensive operation, calculating the plume concentration can now be calculated in parallel using Message Passing Interface (MPI). This operation only requires each node to be passed the location of the source in UTM coordinates and additional properties such as mass.

For the concentration and visibility attenuation calls, this parallel implementation should be very efficient because the only additional information that needs to be passed to each node is the location of points to be sampled for the point concentration function and two points per line for the attenuation calculation. With the concentration calculated on each node, the single processor implementation can be used to calculate the point concentration and visibility attenuation. These values can then be gathered using a MPI_REDUCE command. At this time the generation of contour plots is still an expensive operation due to a serial implementation of the raster to contour generation.

There were some complications with using Sun's Java Runtime Environment with MPI. On several MPI implementations such as Myrinet's MPICH-GM, the function malloc is overloaded with MPICH-GM's own implementation of malloc to reduce the number of memory copies per operation. This conflicts with the version of malloc supplied by Sun's Java Runtime Environment. However, this was worked around by disabling the overriding of malloc by the MPI implementation or using another variant of MPI like the standard MPICH framework that does not override malloc.

5. Results

This version of the API has been tested on several different HPC platforms including The Army Research Laboratory's x86 cluster *powell* and an SGI Altix at NRL. A third HPC platform will be tested in the near future. As can be seen in the Figure 4, OneSAF original plumes approximate a plume as a circle (Figure 4a) while the OneSAF using CT-Analyst display plumes that are affected by the meteorological conditions, terrain and buildings in the domain (Figure 4b). Depending on the types of contaminant in the plume, this can have a great affect on how entities within the domain will react. For example, when combined with the visibility attenuation command, an entity within OneSAF might choose to go around a plume if the visibility was too poor.

6. Future Work

The benefit of accurate plumes can be seen quite clearly with the CT-Analyst plume displays. Additional functions such as CT-Analyst's unique backtrack functionality could also be added to the API to simulate unknown source detection by entities. As the speed of HPC hardware increases, this API could potentially be used with 3D CFD codes such FAST3D-CT instead of CT-Analyst.

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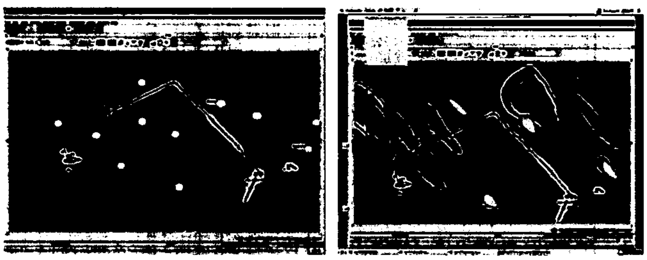

Figure 4. OneSAF depiction of plumes using their standard plume model (4a) vs. CT-Analyst plumes (4b)

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