Tonatiuh: An object oriented, distributed computing, Monte-Carlo ray tracer for the design and simulation of solar concentrating systems

Manuel J. Blanco[1]
[1]The University of Texas at Brownsville, Brownsville, Texas, manuel.blanco@utb.edu

ABSTRACT

The objective of the work that is underway at the Department of Engineering of The University of Texas at Brownsville, under a DOE-NREL Minority Research Associate (MURA) subcontract, is the design, development, implementation, verification and validation of Tonatiuh, an open-source advanced object-oriented Monte Carlo ray tracing program to assist in the design and analysis of solar concentrating systems.

After thirty four months of software development, Tonatiuh is well underway not only to fulfill but to exceed all of its promises. Some of the most relevant features already incorporated into Tonatiuh are:

- Robust theoretical foundation and computational scheme
- Clean and flexible software architecture
- Operating system independence
- Advanced User Interface

1. Objectives

As stated in the Concentrating Solar Power section of the *"Solar Program Multiyear Technical Plan 2003-2007 and beyond"*, many of the existing models used for the technical and economic analysis of parabolic-trough and solar tower systems need to be updated and validated. This includes models for collector optics and thermal performance, among others.

The Tonatiuh software development project is intended to improve the cost-effectiveness of solar energy technologies by advancing the state-of-the-art of the simulation tools available for the design and analysis of solar concentrating systems.

When completed, it is expected that Tonatiuh, will:

- Provide a unifying computational paradigm for the simulation and analysis of virtually any type of solar concentrating system that may be envisioned;
- Be extremely user-friendly, easy to adapt, expand and maintain; and
- Be able to take advantage and efficiently handle any computer power available to it.

An additional objective of the Tonatiuh software development project is to provide education and training on solar energy to undergraduate minority students through project-related research and educational activities.

2. Technical Approach

Underlying the software development of Tonatiuh is a computational scheme that provides (1) a model of the concentrating system, (2) a model of the incoming solar radiation, (3) a model of the basic interactions between the radiation and the elements of the concentrating system, and (4) a flexible way of specifying the results that the program should produce.

The concentrating system is modeled by an input aperture, a bounding volume, and a set of surfaces; both real and virtual.

The input aperture is located on the surface of the bounding volume. It is defined in such a way that only the solar radiation passing through it is relevant for the energy balances of the system under study. The geometry of this surface is selected to facilitate calculations. The input aperture changes both in shape and orientation to accommodate the changes of the incident solar radiation with time.

The bounding volume is defined, at every instant, so that it always encloses the region of space under study. Furthermore, it is defined in such a way that once the solar radiation exits the bounding volume, it does not further interact with the system under consideration. Thus, among other things, the bounding volume provides a criterion to stop calculations.

The surfaces used to specify the concentrating system can be both virtual and real. The virtual surfaces are used to specify locations at which the user wants the program to compute radiation data, such as the incident flux or the total incident power.

The incoming solar radiation field is represented by specifying at every point of the input aperture the value of the radiance from any incoming direction (i.e., the energy per unit time, unit solid angle and unit projected surface in the direction of propagation).

The modeling of the interactions between the incident solar radiation and the real surfaces of the solar concentrating system is addressed within the domain of geometrical optics, i.e., neglecting the finiteness of the wave length. This is a simplification often used in radiation heat transfer. It is based upon the fact that almost all of the solar energy that reaches the Earth arrives in the form of electromagnetic radiation of small wavelengths, compared to the dimensions of the system under consideration.

During the first two years of the project, the Iterative Software Lifecycle was the software development methodology used to develop Tonatiuh. It is a risk-

oriented methodology, which seeks to identify and address the main risks involved in the software development effort as early as possible. This is achieved by structuring the software development effort in releases. From one release to another a whole software lifecycle is completed, new functionality added, errors identified and corrected, and improvements implemented.

By the end of the second year, however, it was decided to make a move towards the Extreme Programming methodology, which is the software development methodology currently in use within the project. This software development methodology is a "extreme" form of the Software Lifecycle methodology, in which every few days a complete software lifecycle is finished, and new, incremental, versions of the program are released at least once per day.

The basic design criterion for the development of Tonatiuh is always trying to use and leverage available technologies and resources. Thus, a substantial amount of effort is continuously being devoted to identifying and efficiently using and integrating existing technologies and tools.

3. Results and Accomplishments

During the last twelve months, the following software development tasks were accomplished:

- The underlying program's computational paradigm was refined and further developed.
- The design of the program's first ray tracing engine was completed.

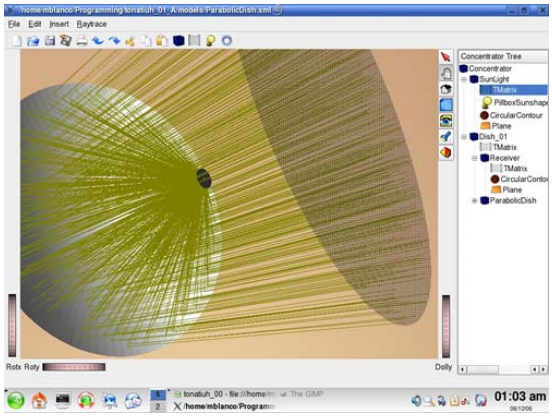

Fig. 1. Tonatiuh's simulation of a Parabolic Dish – Circular Receiver ensemble

- Extreme Programming[1] was adopted as the formal software development methodology of the project.
- Eclipse[2] was adopted as the Integrated Development Environment (IDE) for all the Operating Systems at which Tonatiuh is targeted (i.e., Windows XP, Linux, and Max OS X).
- SouceForge Enterprise was adopted as the collaborative software development tool for the project.
- All 3D math-related classes were modified to improve efficiency, memory management, and easy of use.
- The hierarchies of the shape, object, and material related classes were expanded and simplified.
- Their base classes were made fully abstract, and their interfaces cleaned-up, in order to facilitate the expansion of the program's functionality via plug-ins.
- A random number generator hierarchy was created to allow the user to select at run-time the actual generator to use, and also to allow the addition of random number generators to the program via plug-ins.
- A much more complex, but flexible scheme was devised to specify the properties of the solar light models used in the program.

As a consequence of the work carried out, Tonatiuh is being built upon very solid foundations. These foundations will facilitate the emergence of Tonatiuh as the reference program to simulate the energy behavior of solar concentrating systems.

4. Conclusions

Tonatiuh is well underway not only to fulfill but to exceed all of its promises. It is expected that, when finished, it will become a very valuable tool to assist solar researchers in the design and analysis of solar concentrating systems. Some of the most relevant features already incorporated into the program are:

- Robust theoretical foundation and computational scheme
- Clean and flexible software architecture
- Operating system independence
- Advanced User Interface.

During 2007, two major releases of the program are expected. By the end of June, the first industrial-grade desktop version of the program will be released, while by year's end a parallel and grid-enable beta-version of the program will be delivered. Versions of these two releases will be available for Windows XP, Suse Linux 10.X and Mac OS X.

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