VIMS'99, IEEE Workshop on Virtual and Intelligent Measurement Systems, Venice, Italy, May 21, 1999.

# Modelling Issues in Virtual Prototyping Environments

Emil M. Petriu (1), Marius D. Cordea (1), Dorina C. Petriu (2), Lou McNamee (1)

(1) SITE - School of Information Technology and Engineering
University of Ottawa, Ottawa, Ont., K1N 6N5 Canada
petriu@site.uottawa.ca
(2) Department of Systems and Computer Engineering,
Carleton University, Ottawa, Ont., K1S 5B6 Canada

*Abstract: The paper discusses model development aspects for electronic design automation using Virtual Prototyping Environments (VPEs) . Examples illustrate the real-time NN implementation and the experimental calibration of 3D electromagnetic field models for a VPE.*

## 1. Introduction

The traditional approach to any product development is based on two-phase iterations consisting of a Computer Aided Design (CAD) phase followed by a physical prototype-testing phase. This approach becomes increasingly inefficient as the complexity of the systems is ever increasing and the design is moving from the usual mono-domain optimization problem to a multi-domain concurrent design exercise.

Modelling of the physical systems becomes increasingly attractive as the continuos progress in computer technology and real time algorithms allows to simulate the behavior of these systems for a wide variety of initial conditions, excitations and systems configurations - often in a much shorter time than would be required to physically build and test a prototype experimentally.

CAD is evolving toward a new generation of Virtual Prototyping Environment (VPE) that allow designers to conduct interactive what-if experiments on a multi-domain virtual workbench that provides an *augmented reality* (AR) perception of phenomena that usually a human cannot naturally feel, [1]. AR prototyping results in shorter product development process than the classical approach, which requires for a series of physical prototypes to be built and tested.

The whole idea of virtual prototyping relies on the ability to develop conformable models of the physical objects and phenomena, which are representing very closely the reality. Advanced computation techniques are needed to reduce the execution time of the models used in the interactive VPE applications when analysis is coupled with optimization, which may require hundreds of iterations. Model development problems are compounded by the fact that the physical systems often manifest behaviors that cannot be completely modeled by well-defined analytic techniques. Non-analytical representations obtained by experimental measurements have to be used to complete the description of these systems.

## 2. Virtual Prototyping Environment for Electronic Design Applications

A virtual VPE for interactive Electronic Design Automation (EDA) is currently under development in our laboratory. It provides interactive object specification, manipulation and visualization functions: (i) 3D manipulation of the position, shape, and size of the circuit components and layout; (ii) update electrical and material specifications of circuit components, (iii) accounting for the 3D EM and thermal field effects in different regions of the complex electronic circuit.

A virtual EDA scene is composed of multiple 3D objects: printed circuit boards (PCBs), electronic components, and connectors. Multiple PCBs can be assembled to define a complete electronic system, including the mechanical parts. Any object in the virtual environment is characterized by its usual 3D geometric shape, material property and *safety-envelopes* defining the 3D geometric space points where the intensity of a given field radiated by that object becomes smaller than a user-specified threshold value. Each type of field (EM, thermal, etc.) will have its own safety-envelope, whereas the geometric safety-envelope is the object shape itself.

Any object can be selected by attaching a *manipulator dragger* to it, allowing the user to apply translation, rotation or scaling to the selected object, as illustrated in Figure 1 and Figure 2. Menu style editing functions are available to update electrical and material specifications of the selected circuit components as shown in Figure 3. For each transformation of the selected/active object, the program updates the 3D geometric parameters and the safety-envelope of the object.

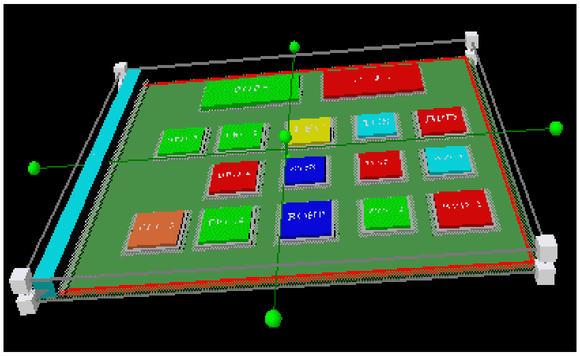
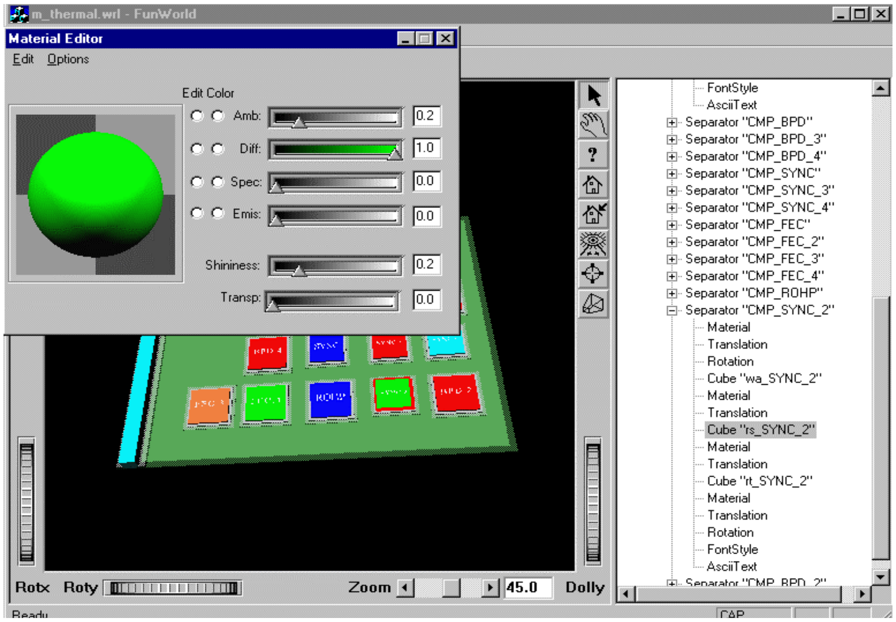


Figure 1. Universal manipulator dragger



Amb: 0.2
Diff: 1.0
Spec: 0.0
Emis: 0.0
Shininess: 0.2
Transp: 0.0
Zoom 45.0

Figure 3. Editing material properties

The main outcome of the what-if experiments conducted in this virtual environment is the detection of the collisions between the safety-envelope of the selected object moving under the control of the manipulator dragger and the safety-envelopes of the other objects in the scene. When a collision is detected, the active object returns to its last position just before the collision

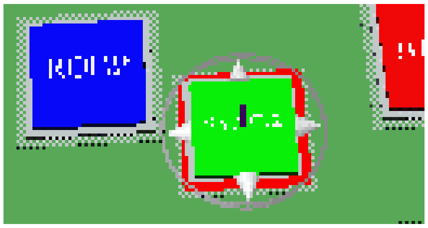


Figure 2. Rotation-translation manipulator dragger

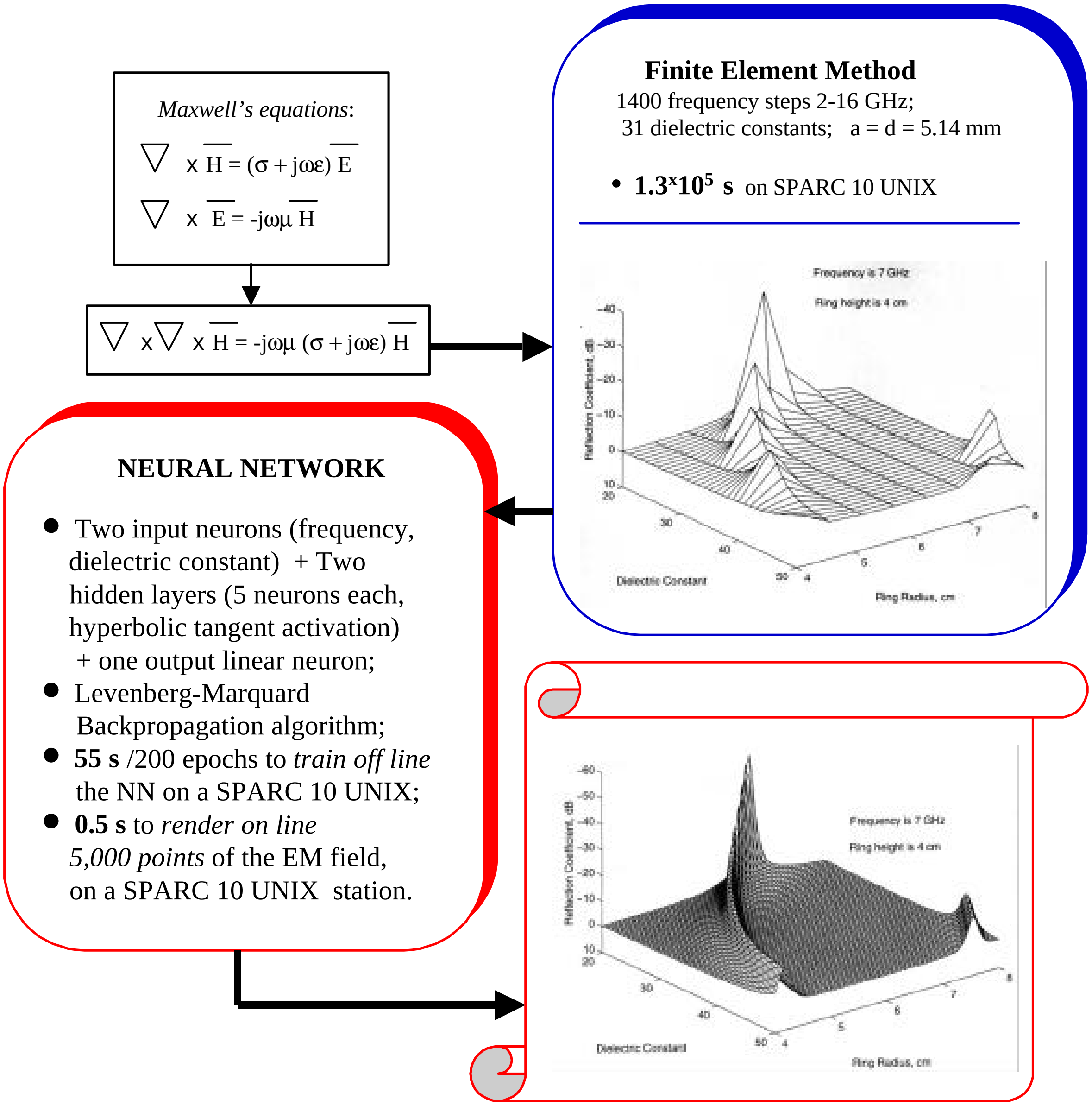
## 3. Neural Network Modelling of EM Fields

Advanced computation techniques are needed to reduce the execution time especially for the 3D field (EM and thermal) models used in interactive VPE applications.

Efficient modeling solutions could be implemented using NNs that can learn nonlinear behaviors from a limited set of measurement data. NNs, which consists of a collection of simple, processing elements provide the massive parallelism requested for this type of real-time modeling problems.

NN modeling requires an initial training phase when a learning algorithm iteratively adjusts the weights of neurons until the NN arrives to closely reproduce the finite set of training data. The NN may take a relatively long time to learn the system behaviour we want to model, but this is acceptable as this phase is done off-line. On the other hand, the recall phase, which is actually of interest for any VPE application, is done in real-time.

Despite the fact that the training set is finite, the resulting NN model has a continuous behavior. This allows a NN model to provide instantaneously an estimation of the output value for input values that were not part of the initial training set. An alternate approach based on a look-up table would have required not only a considerable higher amount of memory but also the use of interpolation formulas in order to provide such continuous output estimations.



*Maxwell's equations*:

$$\nabla \times \overline{H} = (\sigma + j\omega\varepsilon)\,\overline{E}$$

$$\nabla \times \overline{E} = -j\omega\mu\,\overline{H}$$

$$\nabla \times \nabla \times \overline{H} = -j\omega\mu\,(\sigma + j\omega\varepsilon)\,\overline{H}$$

**Finite Element Method**

1400 frequency steps 2-16 GHz;
31 dielectric constants; a = d = 5.14 mm

- **$1.3^{x}10^{5}$ s** on SPARC 10 UNIX

**NEURAL NETWORK**

- Two input neurons (frequency, dielectric constant) + Two hidden layers (5 neurons each, hyperbolic tangent activation) + one output linear neuron;
- Levenberg-Marquard Backpropagation algorithm;
- **55 s** /200 epochs to *train off line* the NN on a SPARC 10 UNIX;
- **0.5 s** to *render on line* *5,000 points* of the EM field, on a SPARC 10 UNIX station.

Figure 4. NN modelling of the 3D electromagnetic field radiated by a dielectric-ring resonator antenna

Figure 4 illustrates the NN modeling the 3D EM field radiated by a dielectric-ring resonator antenna with a ring radius *a* and a ring height *d* both with values from 4 to 8 mm in steps of 1 mm, and the dielectric constant of the ring $\varepsilon_r$ with values from 20 to 50 in steps of 1. The EM field training data are obtained as analytical estimations of far-field values in 3D space and frequency from near-field data using the finite element method combined with the method of integral absorbing boundary conditions, [2].

Each geometrical configuration was solved using the Finite Element Method (FEM) for each of the 31 dielectric constants and for 1400 frequency steps from 2 to 16 GHz, [3].

It is a backpropagation NN consisting of two input neurons, two hidden layers having 5 neurons with hyperbolic tangent activation function on each layer, and one output linear neuron. The training took 200 iterations/epochs using the Levenberg –Marquard algorithm.

While this training took 55 s on a SPARC 10 UNIX workstation, it took only 0.5 s to render 5,000 points of the 3D EM field surface. It is interesting to note that the EM field model rendered by NN has a higher resolution than the data set used for NN training. This is possible because the NN models have continuous/analog behaviour even when trained with a finite set of data.

## 4. Model Validation

While the VPE idea is gaining wider acceptance, it also becomes apparent the need for calibration techniques able to validate the conformance with reality of the models incorporated in these new prototyping tools.

Better experimental test-beds and validation methodologies are needed to check the performance of the computer models against the ultimate standard, which is the physical reality.

Such a venture will have to face many challenges : (i) the development of an experimental setup which should allow the desired manipulation of multi-domain (geometric, mechanical, electric, thermal, and material) design parameters, (ii) the identification and measurement of multi-domain phenomena which are considered to be behavioral characteristics for a given circuit design, (iii) finding the minimum set of experimental setups, cause-effect analytical/correlation methods, and calibration methodologies which provides a guaranty by interpolation (within acceptable error margins) the performance of the VPE computer models over wide ranges of multi-domain design parameters.

Several approaches, depending on the configuration and the nature of the Device Under Test (DUT) have been reported in the literature for the prediction of "far field" (FF) EM values form "near field" (NF) measurements. The analysis in homogeneous space simplifies greatly the problem of deriving an NF/FF transform algorithm.

The 3D EM field developed in our laboratory at the University of Ottawa is based on the NF/FF transform proposed in [2]. The radiating DUT is modeled by an array of short dipoles sitting on top of a table. The equation to solve for the electromagnetic fields is Helmholtz' wave equation:

$$\nabla^2 \vec{H} + k^2 \vec{H} = 0$$

in a homogeneous volume V bounded on one side by a surface where the magnetic field values of *H* are known through measurements and on the other side by the ground plane. Another surface at infinity, completes the definition of the volume V.

An explicit solution allowing to evaluate the magnetic field *H* anywhere in the volume *V* from its field values and its derivatives on a surface $S_1$ as proposed in [4]**:**

$$H(r') = \frac{1}{4\pi}\int_{S_1}\left[G(r,r')\frac{\partial H(r)}{\partial n} - H(r)\frac{\partial G(r,r')}{\partial n}\right]dS_1$$

where $S_1$ is the closed surface on which measurements are made, *n* is the normal to $S_1$, and *G(r,r')* is the free space Green's function.

This algorithm is independent of the type of radiation. While it shares some sources of error with other transform algorithms, the integral transform employed here is more immune to aliasing errors than the FFT-based algorithms. Another advantage over conventional FFT transforms is that the far-field results are available everywhere and not only at discrete points.

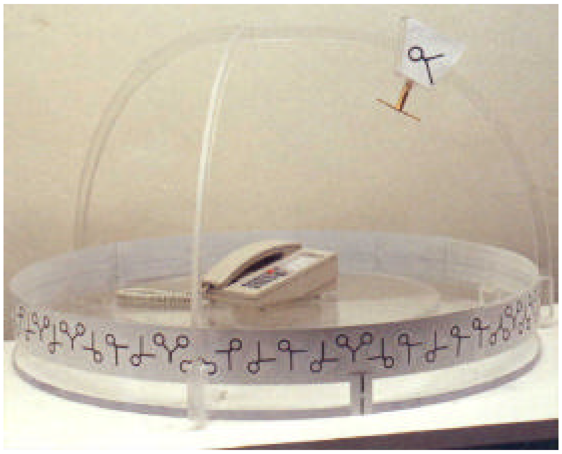


Figure 5. The experimental setup for the measurement of the 3D near field radiated by a DUT.

The EM field measurement system, [5], is shown in Figure 5. It consists of a turning table with a highly conducting grounded surface on which the DUT is resting. The EM field probe can be positioned anywhere on a 90° arc of circle above the turning table.

A special interface was developed for the control of the probe positioning and the collection of the measurement data via a spectrum analyzer.

The turning table and the probe can be positioned as desired by steering them with position-served cables driven by motors placed outside an anechoic enclosure. The probe positioning system and the steering cables are made out of non-magnetic and non-conductive material in order to minimize disturbance of the DUT's fields.

EM field measurements are taken on the two hemispherical surfaces for use in the interpolation algorithm to obtain the derivative's variation on the surface $S_1$ needed for the evaluation of EM field equation. The surfaces are closed with their symmetric image halves. This is possible due to the presence of the ground plane.

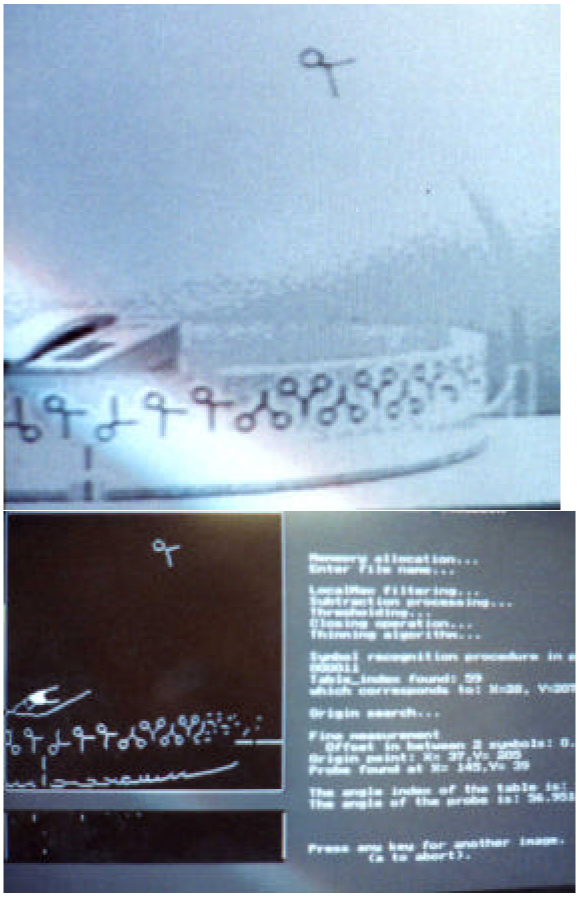


Figure 6. Visual recovery of the EM probe's azimuth and elevation.

The actual angular positions of the table and that of the probe are measured using a video camera placed outside the enclosure. The azimuth angle j is recovered, as shown in Figure 6, by encoding the periphery of the turning table with the terms of a 63-bit pseudorandom binary sequence, [6]. This arrangement allows to completely identify the 3D position parameters of the EM probe while it scans the NF around the DUT.

## Conclusions

Virtual prototyping environments emerge currently as a new generation of EDA tools. Such a tool will allow the designer to test interactively complex electronic systems on an augmented reality virtual workbench, by running concurrently what-if multi-domain (mechanical, electrical, thermal, etc ) experiments. Virtual prototyping will shorten the design cycle, will improve the product quality, and will reduce the time to market.

Advanced computation techniques are needed to reduce the execution time especially for the field (EM and thermal) models used in these virtual prototyping environments. Neural network models have much better real time performance than classical numerical EM field modeling methods, which is particularly important when the field analysis is coupled with system optimization.

Experimental calibration techniques (setup and methodology) are needed to validate the conformance with reality of the models incorporated in the new VPE tools.

## Acknowledgement

This work was funded in part by CITO - Communications and Information Technology Ontario. The authors wish to acknowledge earlier contributions of H.O. Ali and I. Ratner as reported in [3].

## References

[1] D. P. Mahoney, "Better than Real," *Computer Graphics World*, pp. 32-40, Feb. 1999.

[2] R. Laroussi, G.I. Costache, "Far-Field Predictions from Near-Field Measurements," *IEEE Tr. Electromagnetic Compatibility*, Vol. 36, No.3, pp. 189-195, 1994.

[3] I. Ratner, H.O. Ali, E. Petriu, "Neural Network Simulation of a Dielectric Ring Resonator Antenna," *J. Systems Architecture*, vol. 44, pp. 569-581, 1998.

[4] A.J. Poggio, and E.K. Miller, "Integral equation solutions of three dimensional scattering problems", in *Computer Techniques for Electro-magnetics*, Mittra R., ed., Pergamon Press, Oxford, 1973.

[5] A. Roczniak, E. Petriu, G.I. Costache, "3-D Electromagnetic Field Modeling Based on Near Field Measurements," *Proc. IMTC/96, IEEE Instrum. Meas. Technol. Conf.*, pp.1124-1127, Brussels, Belgium, 1996.

[6] E. Petriu, W.S. McMath, S.K. Yeung, N. Trif, T. Bieseman "Two-Dimensional Position Recovery for a Free-Ranging Automated Guided Vehicle," *IEEE Trans. Instrum. Meas.*, Vol. 42, No. 3, pp.701-706, 1993.