High Performance Computation and Interactive Visualization of Electromagnetics for Engineering Education Program

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Abstract —This paper introduces a newly developed High Performance Computation and Interactive Visualization (HPCIV) techniques for engineering education. This HPCIV system can be used to investigate the effectiveness of multi-physics or coupled domain and time domain problems, such as a comb-drive MEMS problem associated with a Pyramid type data structure obtained from a FEM, and the planar waveguide problem solved by Lattice data type based FD-TD method. The system combines HPCIV techniques to analyze the engineering problems with multiple users through networks concurrently, but at different locations. The case study problems, present the computational models with different aspects and results analyzed by a group of engineering students across a network or the Internet.

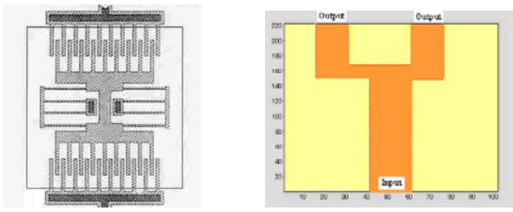
I. Introduction

Computational electromagnetic (CEM) modelling and interactive visualization techniques have moved from analysis to design in engineering practice. These techniques can be used to solve real life EM problems and help industry to provide better products. The application of computational electromagnetics (CEMs) can comprise computer simulations, database access, and interactive visualization. Interactive visualization is closely related to high performance computation which utilizes visualization techniques to deal with the high complexity of CEM problems. To achieve the best result from a practical coupled-domain application and a time domain wave propagation problem, the design engineers from different disciplines work together collaboratively to optimize the solution using interactive and collaborative visualization (CV) techniques. The computational results will be transformed and manipulated in the multi-user environment of the CV system and engineering students can view each individual image obtained from the post-processing stage across a network or the global Internet.

II. Computation Model for CEM

A. Model Attribute for Engineering Problems

Two application problems are used for the case study that are MEMS device (multi-physics or coupled domain) and waveguide (time domain wave propagation) problems. Design of a comb-drive micro-electro-mechanical system (MEMS) as shown in Fig.1 (a) is a typical electromechanical coupled-domain problem, where the MEMS device requires multidisciplinary optimization of Finite Element Method (FEM)-based computational solutions of mechanical stress and electrical field. The second application problem is the wave propagation along a planar waveguide can be computed by Finite Difference – Time Domain (FD-TD) computation method as shown in Fig. 1 (b). The Y shape is planar waveguide. The topside of two ports are output ports with the absorbing boundary condition applied to. The bottom terminal is input port where the Gaussian excitation is located at bottom side of planar waveguide.



(a) (b)

Fig. 1. (a) Comb-drive MEMS micro-resonator as a coupled-problem, (b) planar waveguide model

B. CEM for Coupled-Domain Problem

In the coupled-domain problem, Laplace's equation is used as a governing equation (1) for the electrostatic potential V, while the mechanical forces can be expressed by equation (2),

$$-\nabla \cdot (\varepsilon \nabla V) = 0 \,. \qquad (1)$$

$$-\nabla \cdot \sigma = F \qquad (2)$$

where σ is stress tensor and ***F*** denotes the volume forces.

The electrostatic force density is applied to each of the combs as a perpendicular boundary load. The force density is given by $F_{es} = \varepsilon E^2/2$, and the electric field ***E*** can be obtained from potential *V*. using the equation of $E = -\nabla V$.

C. CEM for Time-Domain Problem

The wave propagation along a planar waveguide can be computed by Finite Difference – Time Domain (FD-TD) computation method. The Y shape is planar waveguide and the topside of two ports are output ports with the absorbing boundary condition applied to. The bottom terminal is input port where the Gaussian excitation ($E = E * exp(-\alpha\,((\tau - \beta\Delta t)^2))$) is located at bottom side of planar waveguide, where τ = absolute time, $\alpha = (4/(\beta\Delta t))^2$, β = number of time steps from peak to truncation. In this case study, the Maxwell's equations for 2 dimensional TE mode are used.

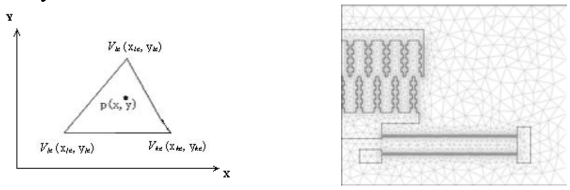
III. Implementation Of HPCIV System

The HPCIV system integrated the advances of computing technologies and collaborative visualization (CV) techniques to solve the practical application problems.

The data transformation and manipulation of computation results plays an important roll in CV system, as computer simulation results always have many different data type and a large number of data with variables (static or time dependent) at each node. Each node also consists of the value and coordinates. The data type should be taken into account when it is applied to CV system.

A. Pyramid Data Conversion for FEM Environment

Multi-physics or coupled-domain problems can be solved by using FEM easily, as the same nodes and elements of FEM mash structure can be used for different problem domains. However the computational results cannot be directly used for the CV system, additional effort has been made in this work to develop a data conversion strategy. As shown in Fig. 2, the FEM output data file should be loaded into memory; split into three individual data files, namely coordinate, element, and data respectively, and then count the number of data in the data file and transfer those data along with the coordinate values to a lattice file; obtain the number of elements from the element file, compute the corresponding number of connections, and set up the element array and connection array.

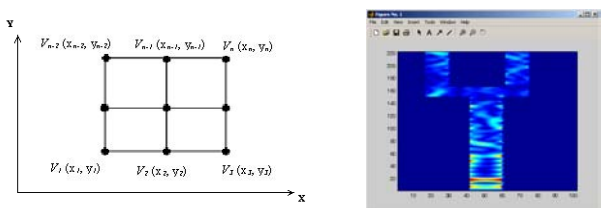


(a) (b)

Fig. 2. (a) A triangular element-based Pyramid data structure used for CV system, and (b) the common FEM mesh used for the computation of coupled-domain problem.

B. Lattice Data Conversion for FD-TD Environment

The wave propagation along a planar waveguide is a time domain problem, which can be computed by FD-TD computation method. The data type obtained from FD-TD based simulation has Lattice data type which can be transformed and manipulated to CV with sequential computing results at each time step. Lattice data structure normally has two parts; one holds data value and other holds node coordinates. A node is a point in a lattice defined by a unique coordinate or set of coordinates in Cartesian space, usually indicating the position of data value or values, as shown in Fig. 3.



(a) (b)

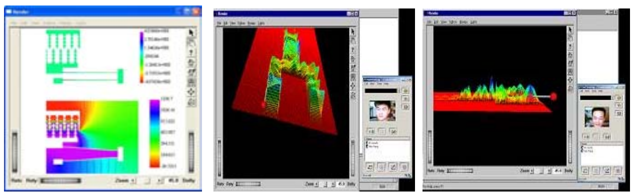
Fig. 3 (a) FD-TD method provides the perimeter lattice in the regular nodes distribution format, and (b) Time dependent wave propagation.

The MUR first order absorbing boundary conditions are used for E_y at the topside of two ports to absorb the wave reflection. The equation used here has the form of:

$$E_y^{n+1}(i,nx+1) = E_y(2,i) + \frac{c_0\Delta t - \Delta x}{c_0\Delta t + \Delta x}\left[E_y^{n+1}(1,i) - E_y^{n}(2,i)\right] \quad (3)$$

C. Collaborative Visualization for Post-Processing

The performance of most micro-machined devices depends critically on the interaction between forces generated by a variety of motions and electrical fields; the dynamic performance is due to the coupling between electrostatic and mechanical forces. To achieve the best performance of a MEMS device, the final structure has to satisfy each field property required for multi-disciplinary optimization [4]. Figure 4(a) illustrates the electric filed and mechanical force distributions of comb-drive MEMS micro-resonator, where the computation results were collaboratively presented in the CV system. Figure 4(b) and (c) present the wave propagation problems which analyzed by two engineering students through network in CV system.



(a) (b) (c)

Fig. 4 (a) Collaboratively view computation results of a comb-drive MEMS in coupled-domain, (b) and (c) are two engineering students worked together through network for the wave propagation problem.

IV. CONCLUSION

The paper introduced the high performance computation and interactive visualization technology for CEMs. Collaborative visualization technique for computational electromagnetics promise to radically change the way research group analyse their results. It is no longer necessary for the members of the team to come together at a single location: they can work independently; exchange the ideas over the network or Internet in a collaborative session as they please. The detailed computation and interactive visualization results will be presented in full paper.

V. REFERENCES

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