Elastic Wave Propagation Simulation System Based On Parallel Processing Architecture

Paweł Paćko and Tadeusz Uhl

Department of Robotics and Mechatronics, AGH – University of Science Technology
al. Mickiewicza 30, 30-059 Cracow, Poland
e-mail: tuhl@agh.edu.pl

Abstract

The authors developed numerical methods based on Local Interaction Simulation Approach (LISA) and Elastodynamic Finite Integration Technique (EFIT) for simulation of elastic wave propagation in structures. The methods have been implemented in the simulation framework using parallel processing architecture - Computer Unified Device Architecture (CUDA) offered by graphical processing units (GPUs). The proposed approach enables calculation of large models (approx. 35-40 mln DOFs) and reduces calculation time hundreds times comparing to the same algorithms implemented using standard processors. Developed numerical methods have been coupled with FE modelling of piezoelectric transducers. Simulation environment has been integrated with the measurement hardware and allows for using simulation-based settings directly in measurement. Obtained experimental data can be correlated with simulation-based one.

Keywords: parallel computing, waves, numerical analysis, structural monitoring

1. Introduction

Elastic waves are widely used in Structural Health Monitoring (SHM) systems and Non Destructive Testing (NDT) applications due to their sensitivity to structural defects, transferring information over long distances and other properties. However, due to the short time scale (high-frequency) phenomena involved, requiring investigation of structure with high spatial resolution, the simulation of wave propagation in structures is a rather time-consuming task. All available numerical methods have their advantages and disadvantages, e.g. long computation times, poor accuracy, low time and spatial resolution, differentiation errors etc. Continuous development of processing units allows more complex phenomena and larger models to be simulated. Since the cost of such powerful computers is still high, other solutions are searched for. Recent evolution of graphical processing units (GPUs) has shown that new architecture available in low-cost graphical cards can be efficiently used for numerical simulation. Therefore it is possible to calculate large models on standard PCs.

2. Numerical methods for wave propagation

Considering capabilities and limitations of various numerical methods used for simulation of elastic wave propagation in structures, two methods: LISA and EFIT have been investigated and modified.

2.1. Local Interaction Simulation Approach (LISA)

LISA [1] belongs to finite difference group of methods, although the governing equations are derived in very specific way. In implementation presented here wave equation for homogenous, isotropic and linearly elastic material is considered. Following [1], the equilibrium equation for isotropic solid is discretized in time and space using well known central difference approximations. Therefore LISA inherits most features of FD methods and, as many others, is well suited for parallel processing.

2.2. Elastodynamic Finite Integration Technique (EFIT)

Second method which has been employed for the simulation of elastic wave propagation is Elastodynamic Finite Integration Technique [2, 3]. The EFIT is based on Finite Integration Technique (FIT) method. In the EFIT method set of equations, i.e. Newton-Cauchy equation of motion and deformation rate equation, are discretized using staggered spatial grids and staggered time scheme which allows for very efficient parallel implementation of the algorithm.

3. Piezoelectric transducer modelling

For modelling of piezoelectric transducers the finite element method has been used. Once the transducer dimensions and excitation signal parameters are set, the FE model is built and calculated. Various transducer/structure coupling conditions can be considered here (e.g. wax or glue). The results are then postprocessed and used as an input for wave propagation in structure. Since only the influence of the transducer on the plate is to be considered, only a part of the structure is modelled. This is necessary for reproducing boundary conditions which are imposed by the structure on the transducer. The boundary conditions can be alternatively matched by concurrent modelling of the transducer (FE) and the structure (LISA/EFIT). In order to reduce the model size the part of the structure modelled by FE should be chosen as small as possible. On the other hand the wave reflections, distorting the wave field imposed by the transducer on the plate, should be avoided. To achieve this, additional absorbing boundary layers are applied to the model.

4. Simulation framework

The above methods have been parallelized and implemented using GPU equipped with CUDA technology. The software has been divided into modules dedicated for particular applications:

- Phased arrays
- Time reversal techniques
- Pre and postprocessing
- Correlation of experimental/numerical data

The system for simulation of elastic wave propagation in structures has been integrated with measurement equipment allowing for using simulation-based settings in physical experiment. The measured structure responses can be automatically correlated with the signals obtained in numerical experiment providing additional information about the structure and the measurement equipment. The structure of the developed system is presented in Fig. 1.

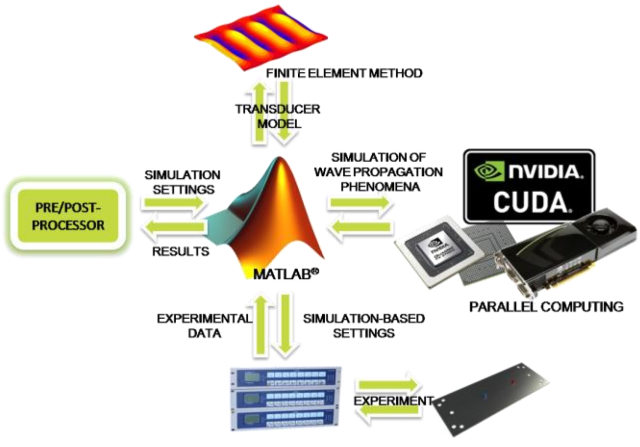

Figure 1: The schema of the developed system

5. Simulation results and discussion

Simulation results obtained by using the developed system have been compared with experimental ones. The considered setup consisted of a plate, a linear array of eight piezoelectric transducers and a laser vibrometer. The delays for particular array elements have been calculated using the module for simulation of phased arrays. Subsequently, they have been applied to the hardware. The signals generated by the array members formed a beam along specified angle. As the result the out of plane component of plate surface velocity have been recorded using laser vibrometer. The experimental setup and the obtained results are shown in Fig. 2.

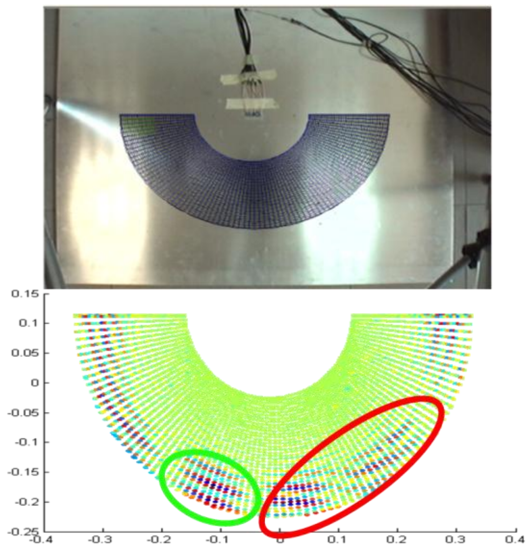

Figure 2: Experimental setup and the results obtained by using laser vibrometer

The simulation results obtained prior to the measurement shown poor correlation with the experiment. In order to determine the source of discrepancies, each of the transducers in the array has been investigated separately and it turned out that one of them has been damaged. The simulation of the array in current state has been repeated. The results are shown in Fig. 3.

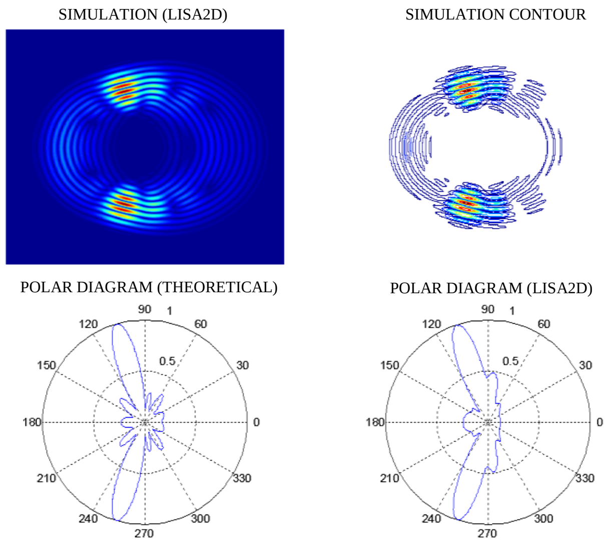

Figure 3: Simulation results for damaged array of transducers

Very good agreement of the simulation and experimental results was obtained proving the presented simulation system capabilities.

References

[1] Delsanto, P.P., Schechter R.S., Mignogna R.B.. Connection machine simulation of ultrasonic wave propagation in materials. III: The three-dimensional case. *Wave Motion* 26 pp. 329–339, 1994.

[2] Fellinger, P., Langenberg, K. J., Numerical Techniques for Elastic Wave Propagation and Scattering. *Elastic Waves and Ultrasonic Nondestructive Evaluation*, pp. 81-86.

[3] Fellinger, P., Marklein, R., Langenberg, K. J., Klaholz S., Numerical modelling of elastic wave propagation and scattering with EFIT – elastodynamic finite integration technique. *Wave Motion* 21, pp. 47-66, 1995.