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HIGH PERFORMANCE COMPUTING NETWORK TECHNIQUES FOR VIBROACOUSTIC ANALYSIS

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1. INTRODUCTION

Some loudspeakers are based on models which have evolved over many decades and been extensively tested. However the consumer market is very competitive and new designs have to evolve more rapidly nowadays. Analytical techniques offer a tool which can be used to assist in the design process and which can potentially permit the consideration of very radical changes using non-standard components which would be expensive to construct on a one-off basis, thus accelerating the design cycle. They also have a role to play in helping the engineer to comprehend the phenomena and hence make more efficient design changes, see ref [1]. This paper considers vibroacoustic analysis techniques using the finite element (FE) and boundary element (BE) methods and whether parallel computation techniques can be used for FE/BE analysis. Examples of this are included in refs [2], [3] and [4]. Finite and boundary element methods are also used in the loudspeaker industry for magnetic field analysis. Thus the parallel computation techniques considered perhaps may also be of benefit to the design of the internal magnets. The type of analyses considered here can be used more generally to analyse "small acoustic systems", which are small numbers of acoustic wavelengths in extent. This would apply to design of loudspeakers, small rooms, vehicle interiors for part of the frequency range, arrays of sonar transducers, radiation/scattering by submarines and many other application areas.

Vibroacoustic analysis using FE and BE were originally used by large organizations, such as government agencies, and very large companies, e.g. automotive manufacturers, because software was not readily available and the computational requirement was very great. However with the continuing trend of increase in computer power, decrease in computer cost, the refinement of numerical techniques and the evolution of commercial software based on these techniques, vibroacoustic analysis is much more accessible to small organizations. Despite these beneficial changes there is still a need to analyse situations which require greater computation than that available at easily-affordable prices. Using the BE method the mesh density required is generally related to the acoustic wavelength. Thus if the frequency is doubled then the surface mesh required will need 4 X as many patches. The storage in memory/disk and the time needed to form these will increase by a factor of 16 and the time needed to solve the resulting set of equations will go up by a factor of 64. Parallel computing techniques, considered by this paper, enable processors to "add" their computational speed, memory and disk to address higher frequencies/larger problems. However there is a communication overhead in splitting the computation between the processors.

2. PARALLEL COMPUTING

A high performance computing network (HPCN) is a collection of processors linked by a network. They can be viewed as a single computer with the computational task split between the processors. Some calculations on a processor depend on results from the other processors which are communicated through the network. The early supercomputers, such as the Cray X/MP in 1986, had this structure. Lower cost HPCN computers based on the transputer technology subsequently became available. However programming these multiprocessing systems was an order of magnitude harder than writing code for conventional serial processors. Sometimes the sequential nature of an algorithm makes it quite unsuitable for parallel processing. Furthermore communication between processors was non-standard, and software writers were reluctant to invest effort creating a parallel version on one particular platform if it would not port onto another systems.

The use of workstation clusters to run parallel applications is becoming an increasingly popular alternative to using specialised, typically expensive, parallel computing platforms such as the Cray T3E or the IBM SP2. Traditionally a workstation referred to some sort of UNIX platform and the dominant function of PC based machines was for administrative work such as word processing. There has, however, been a rapid convergence in processor performance of UNIX workstations and PC based machines in the last three years. This can be associated with the introduction of high performance Pentium based machines and the Window NT operating system. This convergence coupled with the comparatively low cost of PCs and their widespread availability has led to the utilisation of PC based systems as some form of computational resource for parallel computing.

The Message Passing Interface (MPI) [5,6] is a portable message-passing standard that facilitates the development of parallel applications and libraries. MPI makes it feasible to transfer code written in high level languages between different types of parallel computer ranging from tightly coupled, massively parallel machines, through to networks of workstations. MPI has a range of features including point-to-point, with synchronous and asynchronous communication modes; and collective communication (ie barrier, broadcast, reduction operations). One of the attractions of MPI is it availability for various platforms. MPICH [7] is a version of MPI build on top of Chameleon [8], which was developed by Argonne National Laboratory and Mississippi State University. This is probably the most popular implementation of MPI being used on UNIX platforms. For Microsoft Windows NT platforms there has recently been developed a number of MPI implementations though until very recently the only one enabling both C and FORTRAN environments was WMPI [9]. WMPI from the Instituto supererior de Engenharia de Coimbra, Portugal is a full implementation of the MPI standard.

3. PARALLEL VIBROACOUSTIC SOLUTION

The algorithm described in this paper for parallel vibroacoustic analysis is a parallelization of the PAFEC VibroAcoustics code created by PACAN-D, an EU funded project.

Traditionally a parallel system consists of a master processor and a large number of slave processors. The master shares out the work to the slaves and collects the results at the end of the computational phase of the analysis. As we were dealing with a small cluster of NT workstations the parallel algorithm was written such that the master acted as a slave process during the numerical intensive sections of the code. Due to the complexity of the data storage with the PAFEC-FE code it was decided to concentrate on the numerically intensive sections of the code. This means the master processor follows the original, serial, route through the analysis. When a numerically intensive section is reached all of the slave processors as well as the master processor work on a similar amount of work. This means that the system is load balanced within the parallel sections of the code whilst all of the IO is dealt with by the master processor only.

For a fully coupled vibroacoustic solution, using an acoustic BE mesh coupled to a mesh of structural FE the set of equations to be solved can be written as [1]

$$\begin{bmatrix} [S]+i\omega[C]-\omega^2[M] & [T]^T \\ -\omega^2\rho[G][E]^T & [H] \end{bmatrix} \begin{Bmatrix} \{u\} \\ \{p\} \end{Bmatrix} = \begin{Bmatrix} \{F\} \\ \{p_I\} \end{Bmatrix} \tag{1}$$

where {u} is a vector of displacements on the structural mesh, {p} is a vector of pressures on the BE. [S], [C] and [M] are the structural stiffness, damping and mass matrices and are large and sparse. [H] and [G] are small dense matrices derived from the BE formulation. [T] and [E] are coupling matrices. Sometimes the structural representation is simplified using a smaller modal model of the structure, but this does not permit variation of properties with frequency, which occurs for the surround and cone on a loudspeaker. The current work was based on a full solution of equation (1), using the 4 stages below.

Stage 1 - FE merging/reduction

The dynamic stiffness matrix and coupling matrix [T] are formed by merging contributions from individual finite elements. The equations are simultaneously solved. Degrees of freedom are eliminated as early as possible. The matrices are shared between processors and the elimination is done in parallel.

Stage 2 - forming the BE matrices

For each collocation point on the BE surface it is necessary to integrate over the surface to form a row in the BE matrices. Parallelization is achieved by sharing these collocation points between the processors. Distributed BE matrices are formed.

Stage 3 - reducing the BE matrices

The matrix $-\omega^2\rho[G][E]^T$ is formed and reduced using resolution with the structural elimination equations from stage 1. As above the matrices are distributed between processors.

Stage 4 - Gaussian elimination of final equations

The resulting compact dense set of equations is solved using a parallelized form of Gaussian elimination on the distributed matrix.

4. RESULTS

A test case was supplied by Celestion International using 140 quadratic shell elements and a mass element (1917 degrees of freedom, with a frontsize of 112) to model a dustcap, surround, cone and box. Internal and external fluid regions modelled with two acoustic BE, each comprising of 140 quadratic patches and 457 acoustic degrees of freedom.The mesh is shown in figure 1.

The test problem was run on two HPCN's, an NT cluster and a Silicon Graphics workstation. The NT cluster of machines to be used consisted of 266MHz Pentium machines linked with standard 10 Mbit ethernet. To reduce traffic conflicts over the ethernet the cluster of machines were liked via a switch effectively isolating the cluster from the rest of the network. The shared memory SGI machine consisting of eight 75 MHz processors.

The solution times for each frequency for the NT cluster are given below

	1 processor	2 processors	3 processors
stage 1	49	57	66
stage 2	76	38	25
stage 3	508	256	176
stage 4	75	78	108

The number of FORTRAN words in the array used for most of the program data storage was 19085236, 11963350 and 9158554 in the 3 cases.

The solution times for each frequency for the workstation are given below

	1 processor	2 processors	3 processors	4 processors
stage 1	73	136	223	308
stage 2	165	86	58	41
stage 3	975	484	315	227
stage 4	132	95	85	104

5. CONCLUSIONS/FURTHER WORK

Stages 2 and 3 of the solution process are very efficiently parallelized. These stages involve little communication between processors. Stage 1 is slower when run on more than 1 processor. This is because there is a relatively high ratio of communication to computation. Stage 4 suffers from the same problem to a lesser extent. However as the problem size increases the ratio of communication to computation decreases for all stages. It is thus believed that the viability of parallel vibroacoustic analysis has been shown for large problems. Work is in progress on some larger problems which will hopefully confirm this conclusion.

6. REFERENCES

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Figure 1 external boundary element mesh for test case