A Benchmarking Framework for Wave-Based Computational Methods in Architectural Acoustics

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Abstract
In order to establish a common platform to make mutual comparison among numerical methods, a framework to arrange benchmark problems and to provide comparable results is being developed in the WG on Computational Methods for Environmental Acoustics, Architectural Institute of Japan (AIJ). A dozen of typical benchmark problems are selected for basic/practical examinations. To make clear comparison among calculated results with respect to computational accuracy and efficiency, regulations for calculation and data forms for contribution are specified in detail. At the first stage, on the same computing condition, calculations are carried out with several methods, such as commercial/self-programmed FEM, BEM, FDM and so on. Finally, this platform will be open to be public on the WWW, where one can freely contribute a new result and refer to other results.

2. Benchmarking Platform
In principle, the benchmarking platform of this project specializes in wave-based computational methods for architectural and environmental acoustics. It provides a set of benchmark problems, subsidiary data files for computing, and bulletin boards to contribute results on the web site [7]. At the beginning stage, computed results with several methods in common computing environment are also arranged for the first reference. In the future, anyone will be permitted access to the site to submit a new result and to refer to other results.

2.1. Setup on the platform
The benchmarking platform open to the WWW has the following contents:
- Top: preface/updated/contact
- Introduction: motivation/action/problems
- Directions: regulations/arrangements
- Benchmark Problems: properties/tasks
- Papers

in English and in Japanese. The main part is “Benchmark Problems”, where arranging properties of problems such as geometry and boundary condition, tasks of computing, bulletin boards for computed results, subsidiary data files and so on.

2.2. Selection of problems
Typical benchmark problems are selected regarding several aspects: categories (exterior/interior/structural-acoustic), types (basic/practical), domains (frequency/time), phenomena (radiation/scattering/diffraction/insulation), and objects. The basic type problems have perfectly reflecting surfaces of simple shapes, and some of which give theoretical solutions; the practical type have surfaces of realistic shape and with absorption.

Table 1 shows the classification of the benchmark problems currently provided, including candidates for the structural-acoustic category. Simple objects, such as a cube, a sphere and a flat panel, are arranged for the basic
Table 1: Classification of benchmark problems.

<table>
<thead>
<tr>
<th>category</th>
<th>type</th>
<th>index</th>
<th>domain</th>
<th>object</th>
<th>phenomenon</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. exterior</td>
<td>0. basic</td>
<td>A0-1F</td>
<td>freq</td>
<td>cube vibrating</td>
<td>radiation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A0-2F/T</td>
<td>freq/time</td>
<td>cube</td>
<td>radiation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A0-3F/T</td>
<td>freq/time</td>
<td>sphere</td>
<td>scattering</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A0-4F/T</td>
<td>freq/time</td>
<td>sphere</td>
<td>radiation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A0-5F/T</td>
<td>freq/time</td>
<td>flat panel</td>
<td>diffraction</td>
</tr>
<tr>
<td></td>
<td>1. practical</td>
<td>A1-1F/T</td>
<td>freq/time</td>
<td>loudspeaker</td>
<td>radiation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A1-2F/T</td>
<td>freq/time</td>
<td>diffuser</td>
<td>scattering</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A1-3F</td>
<td>freq</td>
<td>barrier on the ground</td>
<td>diffraction</td>
</tr>
<tr>
<td>B. interior</td>
<td>0. basic</td>
<td>B0-1F/T</td>
<td>freq/time</td>
<td>cube cavity</td>
<td>scattering</td>
</tr>
<tr>
<td></td>
<td>1. practical</td>
<td>B1-1F/T</td>
<td>freq/time</td>
<td>auditorium</td>
<td>scattering</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B1-2F/T</td>
<td>freq/time</td>
<td>auditorium with seats</td>
<td>scattering</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B1-3F/T</td>
<td>freq/time</td>
<td>reverberation room</td>
<td>scattering</td>
</tr>
<tr>
<td>C. structural-acoustical (to be planned)</td>
<td>0. basic</td>
<td>C0-1F</td>
<td>freq</td>
<td>plate in baffle</td>
<td>insulation</td>
</tr>
<tr>
<td></td>
<td>1. practical</td>
<td>C1-1F</td>
<td>freq</td>
<td>plate in room</td>
<td>radiation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C1-2F</td>
<td>freq</td>
<td>plate between rooms</td>
<td>insulation</td>
</tr>
</tbody>
</table>

Figure 1: Geometry of Problem A0-4F/T, a piston source (S) and receiving points (R1-4). Unit [m].

Figure 2: Geometry of Problem A1-2F/T, a point source (S) and receiving points (R1-4). Unit [m].

Figure 3: Geometry of Problem B0-1F/T, a point source (S) and receiving points (R1-4). Unit [m].

Figure 4: Geometry of Problem B1-1F/T, a point source (S) and receiving points (R1-4). Unit [m].
type; realistic objects such as a loudspeaker, a panel diffuser, a noise barrier on the ground, a middle-scale auditorium and a non-rectangular reverberation room, for the practical type. For example, Figures 1 to 4 illustrate the geometries of problems in A0, A1, B0 and B1.

2.3. Computing tasks

For evaluation of accuracy of computational methods, spatial distributions at specific frequencies and frequency responses at specific positions are assigned to be computed in the frequency domain tasks, and impulse responses or the similars with a filtered pulse at specific positions are assigned in the time domain tasks. Some of practical type problems require to calculate special acoustical values.

Furthermore, in order to evaluate computational efficiency, processing time and used memory are required to be simultaneously measured for each subdivided computing processes, except for mesh generation. In addition, condition on used mesh, such as element size and the number of nodes, are required to be specified.

2.4. Regulations for computing

Firstly, air conditions, time factor and units are determined as general regulations. In the frequency domain tasks, a stationary state with a single frequency is respectively considered, where octave-band mid-frequencies ranging from 31.5 Hz to 4 kHz are assigned. In the time domain tasks, the sampling frequency is fixed at 8 kHz, where each discrete-time sampled value corresponds to the integrated value ±0.5 time samples of the continuous-time signal. If a filtered pulse is used for the source, it must be supplied as complementary data.

2.5. Arrangements for data files

For contribution of computed results, a prescribed data form is provided as a downloadable file of MS Excel format, which has three kinds of entry sheets for face items, numerical output, and computing performance. Besides, as subsidiaries for the pre-process of computing, datasets of geometrical frame and mesh are arranged for problems of complicated shape as shown in Figure 9.

![Figure 5: Results for Problem A0-4F, indicating radiation directivity at R4 (See Figure 1), computed by multipole expansion.](image)

![Figure 6: Results for Problem A1-2F, indicating scattering directivity at R4 (See Figure 2), computed by FMBEM.](image)

![Figure 7: Results for Problem B0-1F, indicating frequency response at R2 (See Figure 3), computed by FEM, BEM, FMBEM and mode expansion.](image)

![Figure 8: Results for Problem B1-1T, indicating impulse responses at R1/ R2 (See Figure 4), computed by FDTD.](image)
5. Acknowledgements
This project is ongoing in collaboration with the members of the WG on Computational Methods for Environmental Acoustics, Architectural Institute of Japan (AIJ), and supported by Japan Society for the Promotion of Science, Grant-in-Aid for Scientific Research (A), No.15206064, 2003-2005.

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6. References

3. Computation for Reference
For every benchmark problem, the first reference results are being generated with several methods by using two types of common computers. Comparison among these results are also meaningful to clarify the merits of methods regarding the characteristics of problems.

3.1. Common computing environments
Considering the current two types of parallel processing, the following machines are set up for common use.
- SMP machine:
  HIT HPC-IA642 Quad Itanium2
  Itanium2 1.3GHz (3MB cache) *4, 16GB memory
- Cluster of 2 machines:
  VT64 Opteron Workstation (for each)
  Opteron 2GHz (1MB cache) *2, 16GB memory
When computing performance of a method is measured, a single job is exclusively processed by either parallel computer. At the next stage, the effect of the parallel processing will be examined for a variety of methods.

3.2. Numerical examples
Figures 5 to 8 give examples of computed results for the problems shown in Figures 1 to 4, respectively. These graphs are drawn using entry sheets contributed by the WG members, to which results of computing performance are also attached. Some detailed discussions about the results can be referred to [2-6].

4. Conclusion
At the first stage of this project, a benchmarking platform, providing a set of problems, regulations and subsidiaries, has been installed, and computation was done with common parallel computers to generate the first reference results. At the next stage, comparison among computed results with a variety of methods will be done regarding accuracy and efficiency. Finally, this platform will be open on the WWW for all interested persons.

Figure 9: Example of the mesh dataset with 24,514 boundary elements, provided for Problem B1-1F/T.