TLM research areas at University College Dublin.

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1 TLM acoustic device modelling: mechanical-acoustic interaction

In University College Dublin considerable progress has been made in using TLM to model acoustic devices which include regions with acoustically active boundaries. Passive acoustic boundaries are surfaces which absorb or reflect sound waves, partially or totally (and also "boundaries at infinity"). Active boundaries, on the other hand, are surfaces which can, in addition, allow acoustic energy to flow in both directions across them, thereby coupling the acoustic system to a separate mechanical system. Active surfaces are found in many important acoustic devices. Examples include loudspeaker cones, microphone membranes, musical instruments and vibrating probes in fluid sensors.

1.1 High acoustic impedance, stiff boundaries

As a first step to handling such situations, a very stiff, high impedance acoustic boundary (e.g. a vibrating heavy metal plate as sound source) was modelled. A given velocity boundary condition was imposed on the acoustic TLM pressure scheme by making the spatial derivative of the acoustic pressure wave at the boundary proportional to the time derivative of this given boundary velocity, both derivatives being approximated by finite differences. At each time increment the TLM boundary nodes were adjusted, relative to the corresponding nodes just inside the boundary, to give the correct derivative across the boundary. This "velocity boundary condition" scheme worked well.

1.2 Finite impedance, stiff boundaries

Then a stiff (non-flexing) but finite acoustic impedance boundary was modelled, where the dynamics of the mechanical and acoustic systems now interact in both directions. This interaction was modelled by having the acoustic pressure from the TLM as one of the forces driving the vibrating mechanical boundary (with its own inherent dynamics), and this moving boundary then "fed" the acoustic system , as a "velocity boundary" as before. Good agreement was obtained with a problem for which analytical results were available, namely a mass-spring-damper system (piston) at one end of an air-filled pipe closed at the far end. This work is at present in preparation for publication.

1.3 Flexible boundaries vibrating under tension

At present we are investigating an active boundary consisting of a flexible membrane, where membrane tension is the restoring (elastic) force inherent in the boundary. In this case we use two TLM schemes, one for the tension waves in the membrane, the other for the air-borne acoustic waves, with the two systems interacting. In one direction the membrane "drives" the air TLM much as in the velocity boundary described above. In the other direction the air pressure waves drive the membrane by adding to the curvature of the membrane at each point, using a finite difference approximation to this curvature. The wave velocities in the two systems can differ considerably, so that ideal time and space increments in the two TLM systems may not match each other. Interpolation is possible however, where necessary. Modelling the response of a condenser microphone with its thin membrane/electrode is one application of this technique.

1.4 Flexible boundaries vibrating under bending stiffness

To date only tension-driven membrane waves have been modelled. Flexural vibrations, where bending stiffness is the primary restoring elastic force within the boundary, can arise, for example, in head phone membranes and in musical instruments. Such surfaces are not governed by the wave equation, but by a partial differential equation with a fourth order spatial derivative term (as in the Euler-Bernoulli beam equation in 1-dimension). Initial work suggests that the basic TLM algorithm can be adapted to model such flexural vibrations, but the ideas have not yet been tested in numerical code.

The above work is being sponsored in part by a world leading manufacturer of professional microphones and headphones.

2 TLM on non-orthogonal meshes

Does TLM work on non-orthogonal meshes, such as a honeycomb (3 branches meet at each mesh node) or on a mesh of triangular shapes (6 branches per node)? It would appear that it does, although not surprisingly directional and frequency propagation properties are different. The interest in such questions is provoked by the idea of using a TLM type propagation and scattering to model the propagation of pressure signals through a moving fluid. The fluid is modelled by a "free Lagrangian" fluid particle model, developed in UCD, in which particles "flow" while deforming and rearranging. Pressure information propagates through liquids at acoustic speeds which are orders of magnitude higher than the fluid particle velocities, particularly with incompressible fluids. There are therefore significant advantages in using a different scheme for pressure and flow updates, with each scheme interacting with the other. The fluid particle model provides a "natural" network of interconnected points for a TLM-style algorithm for pressure propagation. This mesh however is neither rectangular nor uniform, but promises to provide a sufficiently good basis for a very flexible and dynamic fluid modelling scheme.