Superstable State-Space Representation for Large-Domain Wave Propagation

M. Q. Phan[1], **R. S. Darling**[2], **S. A. Ketcham**[3], **and H. H. Cudney**[4]

Abstract: Computer codes for high-fidelity acoustic simulations over a useful range in a realistic environment are available, but these codes run on massively parallel computers. For example, a 1.6-second 3-dimensional simulation of the propagation of a sound source in a city environment $(750m \times 750m \times 160m)$ with a bandwidth of the signals limited to 300 Hz takes 11.5 hours using 256 cores of a high-performance computer (HPC). In many applications such as determining source locations or to optimize sensor placement, such simulations must be repeated many times. One way to mitigate this computational burden is to find reduced-order representations of the essential dynamics of the original high-fidelity propagation problem, and exploit these reduced-order models for any required repeated simulations. For each source location, the supercomputer simulation needs to be done only once to create the input-output data from which the reduced-order models are derived. Simulations using these reduced-order models can be performed on a standard laptop computer and produce in minutes results that are comparable in accuracy to those obtained from a massively parallel high-performance computers in hours.

This paper describes a new state-space representation that is particularly suitable for modeling large-domain wave propagation dynamics. The new representation takes advantages of the special features of the wave propagation problem: (a) the number of states used to obtain a high-fidelity model of acoustic propagation is very large (in the billions for domains of interest) but the length of the available data records is relatively small (in the hundreds or thousands of time steps), (b) the number of output locations (in the tens-to-hundreds of thousands) is many orders of magnitude larger than the number of inputs (typically one for a single source), and (c) because of these relative dimensions, one can only realistically hope to find a model with prediction capability for the duration of the available data record, but not necessarily beyond. Termed "superstable", the representation is in state-space form, making it compatible with extensive state-space based computational and analysis tools for dynamic simulation, inversion for source recovery, model reduction, etc. Relationships between the new representation and the standard state-space and input-output representations are derived. The practical utility of the new representation is also demonstrated.

[1] Thayer School of Engineering, Dartmouth College, Hanover, NH 03755, USA
mqphan@dartmouth.edu

[2] Sound Innovations, Inc., White River Junction, VT 05001, USA
rdarling@sound-innovations.net

[3,4] Engineer Research and Development Center, Hanover, NH 03755, USA
stephen.a.ketcham@usace.army.mil, harley.h.cudney@us.army.mil