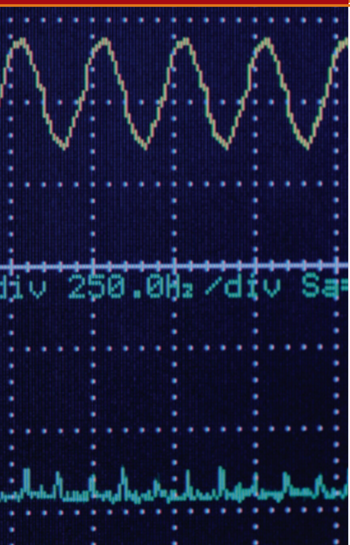
The Exploratory Advanced Research Program Fact Sheet

# Time-Frequency Analysis

## Mathematical Analysis of the Empirical Mode Decomposition

Exploratory Advanced Research . . . Next Generation Transportation Solutions




Invented over 10 years ago, empirical mode decomposition (EMD) provides a nonlinear time-frequency analysis with the ability to successfully analyze nonstationary signals. "Mathematical Analysis of the Empirical Mode Decomposition" is a 3-year Exploratory Advanced Research (EAR) Program study awarded to Princeton University by the Federal Highway Administration (FHWA), designed to ultimately develop and apply the extensive benefits of EMD to the transportation industry.

### The Origins of EMD

Over the past decade, EMD has been used in a wide range of fields, including biology, geophysics, ocean research, radar, and medicine. One such application of EMD has been as a tool for locating cracks or loss of rigidity in reinforced bridge columns. The algorithm has been fine-tuned and extended in a variety of different directions. Remarkably little is known about the mathematical properties, and very little mathematical research had been conducted on EMD, so it remains a remarkable empirical tool without theoretical foundations. Many other powerful mathematical techniques started this way, including the Fourier transform, one of the major disciplines within mathematics, which was initially viewed critically but now offers significant insight and solutions to a number of problems.

### The Key to Early Detection

EMD's ability to detect subtle changes in time-dependent signals makes it of particular importance and highly relevant to transportation requirements. In addition to assessing and monitoring bridges and structures, it serves as a vital tool in the detection of early signs of fatigue in vibrating metal components and can detect even the onset of irregularities in engine function that precede major breakdowns. Early detection of subtle changes makes it possible to diagnose serious mechanical problems in machinery before they are permitted to cause serious damage. Early diagnosis also allows for repairs that typically can be carried out much faster, and at much lower cost, than the more extensive repairs after a major, potentially dangerous, breakdown.

### Mathematical Challenges

Over the course of the project, the approach is to find not only connections with existing mathematical theory, but also make significant new developments. The innovative ideas developed for this project can currently be categorized into two classes: one part researching a "mathematical cleanup" of the sometimes very ad hoc components of the EMD algorithm, and the other part, a "mathematical reformulation," attempting to develop a more rigorous mathematical approach in the same spirit as the original EMD, but using different geometric tools.

### The Impact of EMD

"We expect the impact of building a solid mathematical foundation for EMD to be enormous," says Dr. Kunik Lee at FHWA. "The results of this project are anticipated to lead to developments in a much wider variety of settings. One example is the development of an EMD that is adapted to the simultaneous decomposition of several signals that are physically linked, such as a vibrating piece of machinery," continues Lee. "Alternatively, a high-dimensional EMD could deal with the analysis of not just one or a few points, but of whole segments or surfaces, or the output of a sensor network." The resulting applications in science and engineering will be highly relevant to FHWA, allowing behavior analysis, over time, of machinery, road surfaces, structures, and even environmental markers.

This EAR project is expected to address the following about mathematical analysis of EMD:

U.S. Department of Transportation
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- Several incremental improvements on the existing EMD software.
- A new EMD software package to offer a more robust and user-friendly format.
- New application packages based on the improved algorithm and tailored toward specific applications.
- A series of theoretical papers to (a) document the theoretical foundations of the truly adaptive decomposition methodology and (b) generalize and unify the present ad hoc approach.

## Learn More

For more information on this EAR Program project, contact Dr. Kunik Lee at FHWA, 202-493-3491 (email: kunik.lee@dot.gov).

EXPLORATORY ADVANCED **RESEARCH**

### What Is the Exploratory Advanced Research Program?

FHWA's Exploratory Advanced Research (EAR) Program focuses on long-term, high-risk research with a high payoff potential. The program addresses underlying gaps faced by applied highway research programs, anticipates emerging issues with national implications, and reflects broad transportation industry goals and objectives.

To learn more about the EAR Program, visit the Exploratory Advanced Research Web site at www.fhwa.dot.gov/advancedresearch. The site features information on research solicitations, updates on ongoing research, links to published materials, summaries of past EAR Program events, and details on upcoming events. For additional information, contact David Kuehn at FHWA, 202-493-3414 (email: david.kuehn@fhwa.dot.gov), or Terry Halkyard at FHWA, 202-493-3467 (email: terry.halkyard@fhwa.dot.gov).

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