International Conference
on Structural Nonlinear Dynamics and Diagnosis
Marrakech, June 22-24, 2026

Non-Resonant Rotation: Rethinking Wave Energy Conversion

Muhammad R. Hajj and Ahmed Shalaby

Davidson Laboratory, Civil, Environmental and Ocean Engineering
Stevens Institute of Technology, USA

Abstract:
Wave energy converter design has long been dominated by the paradigm of resonance—tuning devices to amplify motion at specific frequencies. This seminar presents a combined experimental and theoretical investigation of a novel horizontal–pendulum wave energy converter that instead leverages nonlinear internal dynamics to enhance energy generation through sustained rotation rather than bounded oscillations.
The device consists of a hemispherical buoy housing an internal pendulum. Through controlled wave tank experiments, the coupled buoy–pendulum system is examined over a broad range of excitation frequencies. The results show how surge, sway, roll, pitch, and yaw motions combine to generate a time-varying horizontal forcing vector, providing a physically grounded basis for design. They further demonstrate that the pendulum response is governed not by resonance, but by the geometric structure of this forcing. Persistent rotation emerges when the forcing components organize into a coherent, circulating vector field, producing a continuous directional torque, whereas oscillatory or poorly organized forcing leads to confined motion with limited energy capture. Notably, the rotation regime occurs outside the natural frequencies of the buoy, revealing a fundamentally non-resonant pathway to broadband energy capture.
By identifying the forcing structures that promote sustained rotation, this work shows how device geometry, mass distribution, and coupling can be tuned to maximize efficiency across a wide range of wave conditions. This perspective opens new directions for wave energy technology, enabling converters that are inherently more efficient and adaptable to real ocean environments.

Bio:
Muhammad R. Hajj is the George Meade Bond Chair, Director of the Davidson Laboratory, Director of the NSF I/UCRC GoBlue Center, and Chair of the Department of Civil, Environmental and Ocean Engineering at Stevens Institute of Technology. He is an internationally recognized expert in nonlinear dynamics, fluid–structure interactions, and unsteady aero / hydrodynamics. His work bridges fundamental mechanics with practical applications, including wave energy conversion, energy harvesting, bio-inspired design, aeroelasticity, and ship hydrodynamics. Dr. Hajj has led and contributed to over $60 million in externally funded research, has co-authored more than 200 peer-reviewed publications, and has graduated more than 30 PhD students. Prior to Stevens, he held senior academic and leadership positions at Virginia Tech, including Associate Dean of the Graduate School and Director of the NSF I/UCRC Center for Energy Harvesting Materials and Systems. He is a Fellow of the Engineering Mechanics Institute of the American Society of Civil Engineers and has received multiple awards for excellence in research and service. Dr. Hajj has delivered numerous keynote and invited lectures worldwide and actively contributes to advancing engineering research and education.