Recent natural hazard disasters including Hurricane Sandy (2012) and the Tohoku Earthquake (2011) have called public attention to the vulnerability of civil infrastructure systems. To enhance the resiliency of urban communities, arrays of wireless sensors and actuators have been proposed to monitor and control infrastructure systems so as to limit damage, speed emergency response, and make post-disaster decisions more efficiently. While great advances in the use of wireless sensors networks (WSNs) for the purposes of monitoring and control of civil infrastructure have been made, significant technological barriers have hindered their ability to be reliably used in the field for long durations. Some of these limitations include, but are not limited to: reliance on portable power supplies with finite lives, limited radio bandwidth for the communication of data, and limited computational capacity retarding the processing of data for real-time decision making.

To resolve current bottlenecks, paradigm-altering approaches to the design of wireless monitoring and control systems are required. Through the process of evolution, biological central nervous systems (CNS) have evolved into a highly adaptive and robust systems whose sensing and actuation capabilities far surpass the current abilities of engineered (i.e., man-made) monitoring and control systems. In this dissertation, the mechanisms employed by biological sensory systems serve as sources of inspiration for overcoming the current challenges faced by wireless nodes for structural monitoring and control. The basic, yet elegant, methods of signal processing and data transmission used by the CNS are mimicked in in this thesis to enable highly compressed communication with real-time data processing for WSN engaged in infrastructure monitoring. Specifically, the parallelized time-frequency decomposition of the mammalian cochlea is studied, modeled, and recreated in an ultra-lower power analog circuit. In lieu of transmitting data, the cochlea-inspired wireless sensors emulate the neurons by encoding filtered outputs into binary electrical spike trains for highly efficient wireless transmission. Neural circuits are created to accept and process the transmitted spike train signals for pattern classification of sensor signal to identify structural damage and to perform feedback control in real-time. A key attribute of the thesis is its full-scale validation of a monitoring and control system assembled from the cochlea-inspired nodes using a highway bridge tested under seismic loading.