Vibration data from mechanical systems carry important information that is useful for characterization and diagnosis. Standard approaches rely on continually streaming data at a fixed sampling frequency. For applications involving continuous monitoring, such as Structural Health Monitoring (SHM), such approaches result in high data volume and require powering sensors for prolonged duration. Furthermore, adequate spatial resolution, typically involves instrumenting structures with a large array of sensors. This research shows that applying Compressive Sensing (CS) can significantly reduce both the volume of data and number of sensors in vibration monitoring applications. Random sampling and the inherent sparsity of vibration signals in the frequency domain enables this reduction. Additionally, by exploiting the sparsity of mode shapes, CS can also enable efficient spatial reconstruction using fewer spatially distributed sensors than a traditional approach. CS can thereby reduce the cost and power requirement of sensing as well as streamline data storage and processing in monitoring applications. In well-instrumented structures, CS can enable continuous monitoring in case of sensor or computational failures.

The scope of this research was to establish CS as a viable method for SHM with application to beam vibrations. Finite element based simulations demonstrated CS-based frequency recovery from free vibration of simply supported, fixed-fixed and cantilever. Specifically, CS was used to detect shift in natural frequencies due to structural change using considerably less data than required by traditional sampling. Experimental results using a cantilever beam provided further insight into this approach. In the experimental study, impulse response of the beam was used to recover natural frequencies with CS. It was shown that CS could discern changes in natural frequencies under modified beam parameters. When the basis functions were modified to accommodate the effect of damping, the performance of CS-based recovery further improved. Effect of noise in CS-based frequency recovery was also studied. In addition to incorporating damping, formulating noise-handling as a part of the CS algorithm for beam vibrations facilitated detecting shift in frequencies from even fewer samples. In the spatial domain, CS was primarily developed to focus on image processing applications, where the signals and basis functions are very different from those required for mechanical beam vibrations. Therefore, it mandated reformulation of the CS problem that would handle related challenges and enable the reconstruction of spatial beam response using very few sensor data. Specifically, this research addresses CS-based reconstruction of deflection shape of beams with fixed boundary conditions that make hyperbolic terms indispensable in the basis, which in turn causes numerical inconsistencies.

Two approaches are discussed to mitigate this problem. The first approach is to restrict the hyperbolic terms in the basis to lower frequencies to ensure well conditioning. The second, a more systematic approach, is to generate an augmented basis function that will combine harmonic and hyperbolic terms. At higher frequencies, the combined hyperbolic terms will limit each other’s magnitude, thus ensuring boundedness. This research presents fundamental studies and discusses open-ended challenges while formulating the CS problem for the field of mechanical vibrations that will pave way for further research.

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