A Haptic-Inspired Approach of Ultrasonic Nondestructive Damage Classification

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***Abstract*—This paper adopts the idea of involving human subjects in making structural damage detection and classification decisions. Inspired by human haptics, ultrasonic guided wave scattering information is transformed into audible signals rather than tactile excitations. Ultrasonic waveforms are encoded chordally or melodically into audio signals. Human subjects are trained on these encodings and subject to blind tests. Damage conditions, manifested as scattering changes, are enabled through the scattering matrix to and also audio-encoded for comparison to chordal and melodic encodings. The performance is better than the cases encoded with raw data, as there is more straightforward physics contained in the feature domain.**

Keywords—Structural Health Monitoring; Nondestructive Evaluation; Haptics; Ultrasound; Audio Encoding; Scatter Matrix

I. INTRODUCTION

There are five basic senses that humans adopt to interact with the world, namely, vision, aural, tactile, taste, and smell. Compared to computational algorithms, human decision-making is often more adaptive and robust, which leads to a better potential in interpreting engineering data and handling ambiguities [1]. Haptics has been applied to the structural health monitoring (SHM) recently, taking advantage of the human capability in processing complex information. A recent study demonstrated how nonlinear impacts due to structural damages were identified via vibro-transducer array embedded in a smart glove, which transforms SHM features to modulated tactile pulses [2]. By means of pattern recognition empowered by human subjects, different tactile stimuli are identified, indicating different damage types and locations to be classified in the SHM. Human has long history of using audio information to interact with surroundings. For example, people determine the moving direction of sound source, as well as recognize the voice from different speakers. Motivated by the successful thrust on applying tactile haptic decision-making, an audio haptic approach is investigated to detect and classify damage, and the feasibility of extending haptics-enhanced SHM to the sense of hearing [3]. Instead of encoding audio tracks based on the raw SHM data, this paper will focus more on the scattering features and generate sound series that reflect the scattering matrices under different damage scenarios.

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II. AUDIO ENCODING VIA RAW SERIES

Based on ultrasonic guided wave nondestructive evaluation technologies, Fig. 1 shows how the raw data are processed in [3]. As a tone burst of excitation is applied to the structure, the wave gets propagated through the media, and mechanical responses at different locations are recorded. Subtracting the response by corresponding signal at an undamaged baseline condition, a residual signal is obtained, which contains the time-of-flight information and may be utilized to detect and locate damage.

In [3], there are two approaches presented to encode the baseline-subtracted residual, namely chordal and melodic approach. Fig. 2 demonstrates the chordal method for encoding. Here, a section of time series is selected, and the envelope peaks are extracted to serve as the weight of certain pitches. The outcome of this algorithm is a tonal group ("chord") played with the volumes corresponding to the magnitude of each peak.

Fig. 1. Flow of audio-haptic encoding via raw series

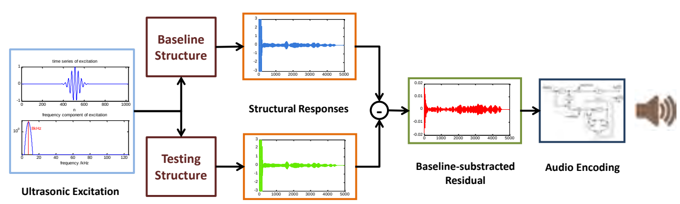

Fig. 2. Chordal encoding of raw SHM series