[innovationX]

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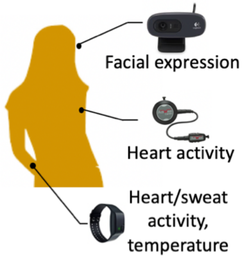
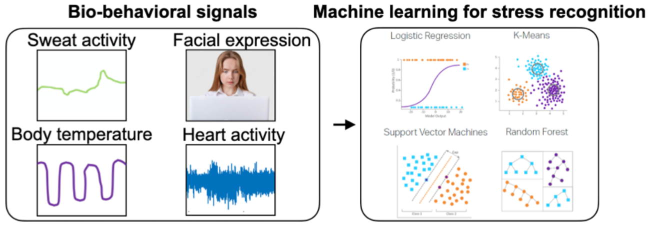
Adaptive Response Environments for Physical and Mental Health

Thrust 1: Bio-behavioral models of noise discomfort

Objectives: Noise in working environments is related to a range of problems, such as stress and productivity loss. Thrust 1 examines how different levels of noise, operationalized as different levels of speech intelligibility, impact the neurophysiology of individuals and their performance on cognitive tasks. The findings will be used to build machine learning models that can predict when an individual is about to become stressed due to the noise levels in their environment.

Methods: The research objectives will be accomplished by collecting various bio-behavioral data (skin conductance, electrocardiogram, peripheral skin temperature, blood volume pulse, and facial expressions) while participants are subjected to various noise levels (highly intelligible speech, poorly intelligible speech, and silence) and while completing cognitive tasks. Participants will be asked to fill out questionnaires during various intervals of the study for their feedback/perceived stress levels.





Equipment: Research-grade devices and software to be used for the study include: video and display capture (OBS Studio), retrospective observational coding (CARMA), physiological data measurement (Actiwave Cardio, E4), and web cameras. Undergraduate research assistants have been trained on the software and device use. The protocol of the study has been finalized. Data collection is anticipated to occur in Fall 2020.

Data analysis: Data will be pre-processed and denoised. Signal and image processing methods will measure heart rate, sweat activity measures, and relative positioning of several facial landmarks (e.g., lip/eyebrow corners). Machine learning models will be designed to learn signal-based patterns of stress reactivity. The system will be used in Thrusts 2 and 3.

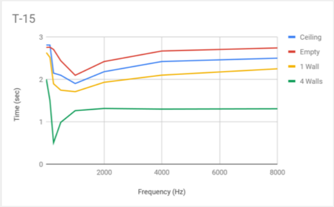
Thrust 2: Psychoacoustic experiments in virtual reality

Objectives: Virtual reality can simulate the effect of various acoustic environments on human performance. Thrust 2 compares acoustic panels of different materials through simulation experiments and user studies.

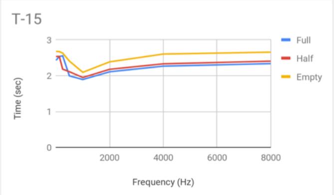
Acoustic performance simulation of a Plain Medium Density Fiberboard (MDF) panel

We conducted two phases of static simulation: preliminary and refined testing in a single room space and an open space. The configuration of the MDF panel is 0.75x0.75x0.2m with 0.08m hole diameter With fixed sound source type, position, and space dimension, we compared MDF panel with plaster and gypsum board on walls and ceiling. Results show that MDF panel has shorter reverberation time (T-15) than plaster and gypsum board. Curvatures and density of cuts on MDF panel will be further tested.

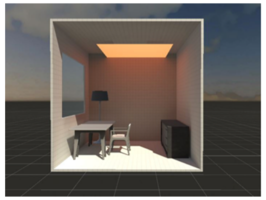
Test results in single room space



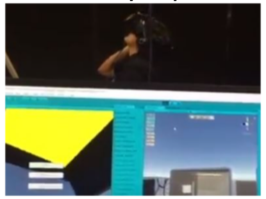
Test results in open room space



Virtual reality scene



User study snapshot



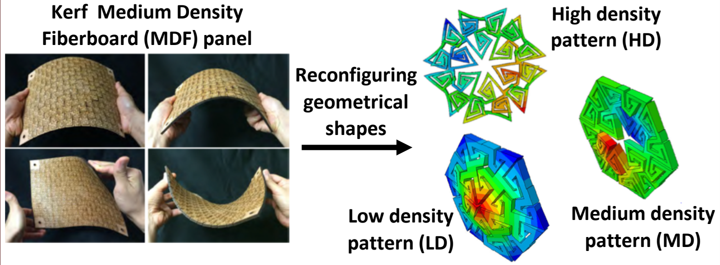
Psychoacoustic user study in virtual reality

A cube room with dimension 3x3x3 meters is modeled in Unity. An exterior sound source was added with a 10sec conversation. Audio components were manipulated to decide the sound range. Single user perceptual testing was conducted through HTC VIVE PRO. The user reported that the variation of sound volume can be recognized when the sound object is moving close or far away.

As part of the future work, an office space will be modeled. MDF will be assigned into the VR scene and additional noise sound source will be added into the human psychoacoustics experiments. Results from this will inform the design of adaptive structures in Thrust 3.

Thread 3: Adaptive responsive structures

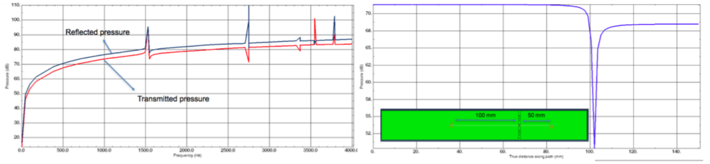
Objectives: This thrust explores the adaptive tuning of room acoustics by the reconfiguring geometrical shapes and kerf density of the Medium Density Fiberboard (MDF) panel.



Acoustic testing of Medium density Fiberboard (MDF) panel

We proposed a reconfigurable kerf Medium density Fiberboard (MDF) panel for tuning the acoustic performance. These kerf panels are made of reconfigurable unit cells. We examined the resonant performances and acoustic responses of kerf unit cells with different densities and geometric shapes using finite element analysis (FEA). Results are promising as the eigenfrequencies and mode shapes vary for different density unit cells and all lie within the human audible frequency range. The FEA simulation plots show results from acoustic structural analysis of a low density (LD) unit cell subjected to sound waves of 92.5dB. The reflected and transmitted pressure drops across the driving frequency except at resonance frequencies. Results from medium density (MD) and high density (HD) unit cells show decrease in reflected and transmitted pressure with peaks corresponding to their resonance frequencies. Therefore, these kerf unit cells can be used to alter the acoustic characteristics by changing scattering, transmission, and reflective properties of the sound wave.

FEA simulation results showing reflected and transmitted sound for LD unit cell



We will investigate the acoustic performance (i.e., absorption, scattering, and diffusion) of macroscopic kerf wood panels, having multiple unit-cells, with various shape configurations. Thrusts 1-3 will be integrated to a final evaluation.

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