Characterizing The Structural Influence On Footstep-Induced Structural Vibrations For Indoor Human Sensing

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Structural vibrations induced by human footsteps contain various information, including persons' identities, activities, and health states, which enables many smart building applications such as occupancy monitoring, activity recognition, and physical/mental wellness tracking. Prior work using structural vibrations has been successful in occupant detection, localization, identification, and gait health monitoring. While other sensing modalities, such as cameras, wearables, and pressure mats, could be used to achieve the same purposes, they have limited scalability due to direct line-of-sight, device-carrying, and dense deployment requirements. Footstep-induced structural vibration sensing overcomes these limitations by capturing floor vibrations induced by nearby human footsteps, which needs only sparsely deployed sensors, is non-intrusive, obstructioninsensitive, and is perceived as more privacy-friendly. However, one fundamental challenge in utilizing structural vibrations for indoor human sensing is the significant structural influences on the vibrations during the wave generation and propagation process. For example, the same footstep may lead to different vibration signals when it occurs in the middle versus at the edge of the slab. This results in high variability in vibration signals that buries the footstep characteristics that can effectively reflect persons' identity and health information. Many existing studies have recognized this challenge, but have not explored how the structure affects the vibration signals or how to reduce such influences. In this paper, we aim to reduce the structural influence on footstep-induced structural vibrations to improve the performance of structural vibration for indoor human sensing. To achieve this, we first identify how the structure affects the footstep-induced structural vibrations during different stages between excitation and sensing, including 1) vibration wave generation process at the excitation location, and 2) vibration wave propagation process from the excitation to the sensing location. Then, we examine how each stage affects the vibration signals and establish a quantitative relationship between the input excitation and the output vibration signals in these two stages. Finally, we develop a structural influence reduction approach based on the input-output process and then transform the signal features into a space where the human footstep characterization is enhanced while the influences of the structure are suppressed. To evaluate our method, we conducted real-world experiments on two structures with different structural components and materials - concrete and wood. Our method has achieved 70% reduction in variability caused by the structures while enhancing the footstep characterization by 30%. This results in 12% and 15% increases of accuracy in occupant identification and initial foot contact prediction for human gait monitoring.