Poster Abstract : Non-intrusive Occupant Localization Using Floor Vibrations in Dispersive Structure

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ABSTRACT

We introduce a sensing system which leverages footstep-induced structural vibration for occupant localization. Such localization is important for many smart building applications, such as efficient building management, senior/health care, and security. Compared to other sensing approaches, footstep-induced vibration provides a sensing system which is sparse and non-intrusive. The main challenge of achieving high accuracy using such approach is frequency-dependent wave propagation characteristics, such as dispersion, in floor structure. These characteristics result in distortions in the shape of signal. To overcome such distortions, we decompose the vibration signals into different frequency components using wavelet transform and focus on specific components in all the sensors. In a set of experiments in a real structure, our approach results in average localization errors of 0.41 meters, a 4.4X reduction compared to a baseline approach using raw data.

1. INTRODUCTION

Fine-grained indoor occupant localization is an important step toward many smart building applications either in residential or commercial settings. Some examples of such applications include senior/health care, efficient building management, and security. Several sensing approaches have been suggested for occupant localization in indoor settings, such as vision-based, RF-based and mobile-based platforms [5, 1]. However, applications of these approaches are limited due to installation and maintenance requirements, such as intrusiveness and dense deployment.

To overcome these limitations, we introduce a novel sensing approach which leverages structural vibration induced by occupants' footsteps. The indirect nature of this approach combined with wave propagation properties allows non-intrusive and sparse sensing. Specifically, this system provides detection range of 20 meters. To localize the footsteps, we use a multilateration approach that leverages the difference between the time at which the footstep-induced wave arrives at four sensors in the sensing range [6].

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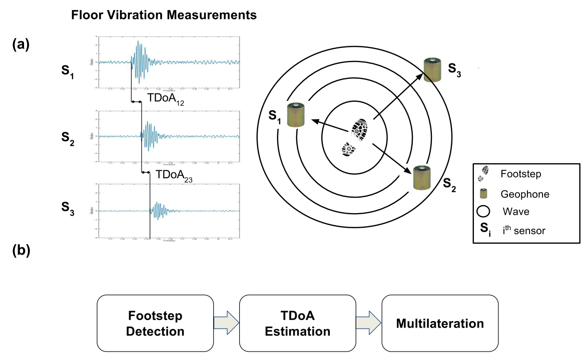


Figure 1: System overview. (a) shows the conceptual intuition behind our localization approach. Waves resulted from the footstep reach different sensors at different times. Such difference is estimated for localizing the source. (b) shows three steps of the algorithm.

The main challenge of accurately estimating footstep locations is frequency-dependent wave propagation characteristics, namely wave dispersion, which result in signal distortions. Such distortions makes the time differences of arrival (TDoA) estimation inaccurate and, in turn, results in poor localization in many buildings. To address this challenge, we first decompose the signal using wavelet transform due to its ability to analyze transient signals (such as impulses). Then, we focus on a frequency component of highest energy in all the sensors to reduce wave attenuation and noise as well as dispersion effects.

2. SYSTEM OVERVIEW

Our occupant localization system has three modules: 1) footstep detection, 2) TDoA estimation, and 3) footstep localization. Figure 1 summarizes these steps.

2.1 Footstep Detection

The objective of the footstep detection module is to measure the structural vibration and distinguish the footstep-induced vibration from the background noise. The structural vibration is acquired using a set of four geophones.

These measurements are amplified (by 1000X), digitized, and transferred to backend server for further analysis. The second step of detection module distinguishes the footstep-induced vibration from the background noise (impulse-like excitations) [2].

2.2 TDoA Estimation

Accurate TDoA estimation is an important condition for accurate footstep localization. However, wave dispersion in building structure results in different propagation velocity for different frequency components and hence distorts the shape of signals. These distortion results in inaccurate TDoA estimation. To overcome such frequency-dependent effects, we focus on specific frequency components by decomposing the signal using time-frequency representations. Specifically, wavelet transform is chosen for decomposing the signal due to its ability to capture transient signals (such as impulses). After decomposing the signals received in different sensors, the frequency components with highest energy (or natural frequency of structure) are extracted and used for peak-based TDoA estimation. This further increases the range of our sensors by reducing signal noise and also improves the localization accuracy by reducing dispersion effects.

2.3 Multilateration

The main objective of this module is to localize the occupants' footsteps using the estimated TDoA values. Multilateration is used in this paper because the time of foot strike is unknown and we can leverage the TDoAs of the signal to localize the source [3].

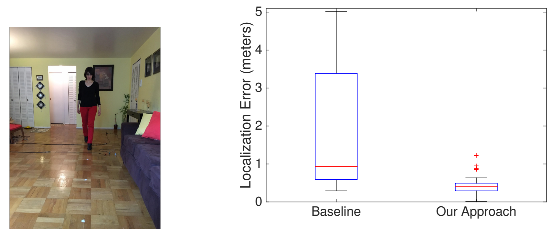
3. EVALUATION

To evaluate our system, we conducted a set of human experiments with in a residential building consisting of a wooden non-carpeted floor. The experiment structure is shown in figure 2a. The experimental setup includes four geophone sensors in a 3 by 2 meters area. These dimensions are chosen as common hallway dimensions. Geophone sensors used in this paper are SM-24 model and measure the velocity of floor vibration.

The localization results show that our signal decomposition approach significantly improves the localization error. Figure 2b compares our approach with the baseline approach using the raw signal for estimating the TDoA values. The median average localization error for the baseline approach is 0.93 meters compared to 0.41 meters using our approach which is equivalent to 2.3X improvement. Furthermore, using the baseline approach, the first and the third quartiles are equal to 0.59 and 3.39 meters compared to 0.29 and 0.49 meters using our approach. This is equivalent to 2X and 6.9X reduction, respectively. On average, our approach results in 0.41 meters localization error compared to 1.82 meters for the baseline approach, a 4.4X reduction in average error. Furthermore, standard deviation is also reduced from 1.57 meters to 0.18 meters which is equivalent to 8.7X reduction.

4. CONCLUSIONS AND FUTURE WORK

We introduce an occupant localization system which leverages footstep-induced vibration. Occupant localization is



(a) (b)

Figure 2: Evaluation. (a) shows experiment structure. (b) compares average localization error of the baseline and our approaches.

important for various smart building applications. Our localization system provides a sparse and non-intrusive alternative to traditional sensing approaches. To overcome the challenges of accurate localization regarding the use of footstep-induced vibrations, we decomposed the received signal using wavelet transform. The results show that using this approach the average localization error is 0.41 meters which improves the baseline results by 4.4X. We are currently working on simultaneously localizing multiple people by building on our prior work that counts multiple people through floor vibrations [4].

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