Demo Abstract: Vibration-Based Occupant Activity Level Monitoring System

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1 INTRODUCTION

Occupant activity level information is an essential component of occupant behaviour estimation, and has been widely used in many applications, such as energy management and customer traffic monitoring [5]. Existing approaches for obtaining occupant activity-level information can be divided into two classes: device-free and device-based. The device-based approaches require the occupant to carry a specific device all the time. However, in some applications, such as intrusion detection or market traffic monitoring, it is not possible to require the intruder or the customer to carry the specific device before they enter the space. Device-free approaches such as vision-based and acoustic-based sensing estimate the occupant activity level by sensing the physical information related to the occupant activities. These traditional device-free approaches have deployment and maintenance requirements which limit their application in the real-world scenarios. For example, visual-based approaches require line-of-sight, while acoustic-based approaches are sensitive to background noise.

In recent years, floor vibration-based sensing has been used to overcome the limitations of prior works. The main idea behind vibration-based sensing is that footsteps of the occupant cause the floor structure to vibrate. Measuring and analyzing these vibrations enables ubiquitous occupant monitoring. For example, vibration-based sensing has been used for occupant localization [3], identification [6], gait monitoring [2], and traffic estimation [5]. In this demo, we present a vibration-based approach which monitors the occupant activity level through detecting the occupant-induced vibration signals on the floor. Our system is a device-free system, and can achieve sparse configuration in deployments due to its sensing range of up to 10m. The main challenge is that the occupant-induced vibration signals have a low signal to noise ratio (SNR). To increase the resolution of vibration signals, we utilize a low-noise amplifier to amplify the vibration signal to 60db or higher, and then filter the background noise with a Wiener filter [1]. We also provide a real time display of the occupant activity level results in the demo.

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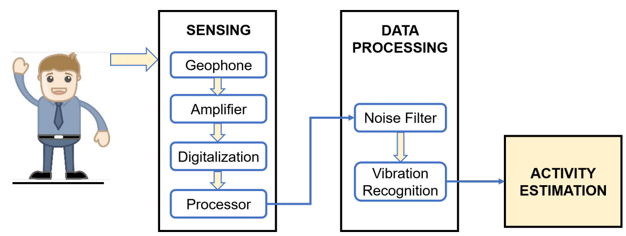

Figure 1: System overview.

2 SYSTEM DESIGN

The goal of this system is to monitor the occupant activity level by utilizing the occupant-induced vibration signals on the floor. Currently, this system is deployed in the 15th floor of Nanshan intelligence building C2 of the Tsinghua-Berkeley Shenzhen Institute (TBSI). As shown in Figure 1, our system consists of two main modules: the sensors (which measure the vibration and is described in Section 2.1) and the server (which analyze the data and are described in Section 2.2). The output of the demo is the occupant activity count in real-time which will be shown on the display.

2.1 Sensor

The sensor serves to capture the vibration signal on the floor and send the vibration data to the server. Each sensor contains three main components: a geophone, an amplifier and analog-to-digital conversion (ADC) module, and a processor module.

First, the geophone (which is mounted to the surface of the floor) senses the vibration signal from occupant activities. Geophones, which are widely used in structural vibration sensing, convert the velocity of the floor vibration into an analog voltage output. The

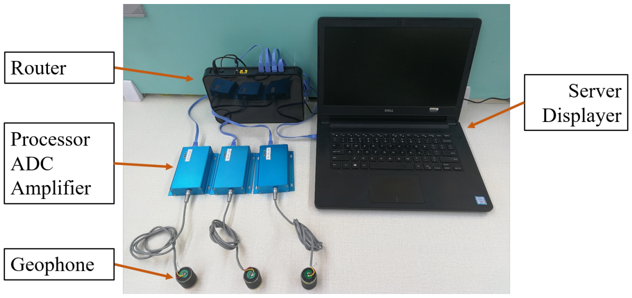

Figure 2: The system that will be used for the demo deployment.

bandwidth of the geophone output signal is from 10 Hz up to 240 Hz, which covers the frequency range of human activities. To ensure a full coupling with the floor structure, we fix the geophone on the surface of the floor with an adhesive.

Next, the amplifier improves the resolution of the vibration signal. Occupant activities (e.g. walking or standing) often result in low-amplitude vibrations due to the stiffness of the floor structure. Therefore, to increase the resolution of the signal, we utilize a low-noise amplifier which amplifies the analog signal and increases the amplitude of the vibration signal. The suitable amplifier gain is affected by two factors: 1) the background noise level, and 2) the underlying structure and floor material. Therefore, the gain of amplifier is adjustable from 20db up to 80db to account for these factors and the gain is able to be set in real time. Furthermore, our demo contains several sensors deployed in different regions. However, the layout of the underlying structure can influence the propagation of the vibration signal, which leads to sensors in different regions usually having different sensitivities for vibration signal sensing. Assuming that the variance of background noise represents the sensitivity of each sensor, we set the amplifier gains to ensure similar variance of background noise in all the sensors. The amplified signal is then digitized with a 16-bit ADC with a 10,000 Hz sampling rate and transmitted to the processor for detecting occupant activity.

Finally, the processor collects the digital signal and communicates with the server. The communication includes time synchronization, data uploading, and sensor state report. To increase the reliability of data upload, we utilize the Transmission Control Protocol (TCP) to transport data from processor to server.

2.2 Server

The server receives the vibration signal from processor, and extracts the occupant activity information from the vibration signal. The signal processing contains two steps: noise filtering and vibration detection.

Amplifying the signal (to increase its resolution) also increases the variance of the background noise. To reduce the effect of the background noise, we apply a Wiener filter to the signal. The Wiener filter minimizes the mean square error (MSE) between the noise signal and the target signal, and has a significant effect of filtering additional noise.

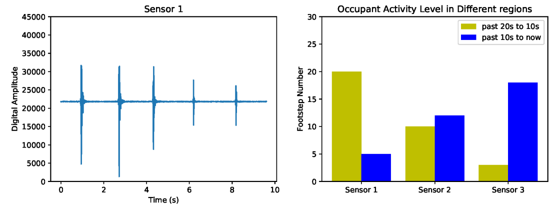

Figure 3: A visualization example in the demo section.

Then, to detect the vibration activity events (e.g., footsteps), we apply a threshold-based algorithm. The threshold-based algorithm calculates the energy of the signal in a sliding window and compares it with a threshold. Signal windows with energies larger than the threshold are marked as the activities. Assuming a Gaussian noise distribution, the threshold is defined as $\mu + n\sigma$ in which μ and σ are the mean and standard deviation of the noise [4]. n is a parameter which can be adjusted to increase the adaptability of the detection algorithm in new environments. Furthermore, a series of experiments are conducted to find the average length of signal windows which is enough to contain the activity events.

3 DEMO DESCRIPTION

During the demo, we will provide several sensors deployed in the demo platform, and display a real-time occupant activity in different sensor regions. As shown in Figure 2, for the feasibility of deployment, a laptop will work as the server and display the real-time result in the screen, and the laptop will be connected to the router by WiFi/Ethernet. In the demo, we will mark the location and the sensing range of each sensor. As shown in Figure 3, visitors can see the graphic result of the occupant activity detected by each sensor from the screen of laptop, and compare the result with the actual number of occupants in the sensing region. Furthermore, to better evaluate the performance of footstep detection, we offer a ground truth device which can be installed on the shoes to record the time of the occupant's foot striking with millisecond precision. This ground truth system will be used to better estimate and visualize the accuracy of footstep detection.

REFERENCES

[1] Jacob Benesty, Jingdong Chen, Yiteng Arden Huang, and Simon Doclo. 2005. Study of the Wiener filter for noise reduction. In *Speech Enhancement*. Springer, 9–41.

[2] Jonathon Fagert, Mostafa Mirshekari, Shijia Pan, Pei Zhang, and Hae Young Noh. 2017. Characterizing left-right gait balance using footstep-induced structural vibrations. In *SPIE 10168, Sensors and Smart Structures Technologies for Civil, Mechanical, and Aerospace Systems*, Vol. 10168. 10168 – 10168 – 9.

[3] Mostafa Mirshekari, Shijia Pan, Jonathon Fagert, Eve M Schooler, Pei Zhang, and Hae Young Noh. 2018. Occupant localization using footstep-induced structural vibration. *Mechanical Systems and Signal Processing* 112 (2018), 77–97.

[4] Mostafa Mirshekari, Pei Zhang, and Hae Young Noh. 2017. Calibration-free footstep frequency estimation using structural vibration. In *Dynamics of Civil Structures, Volume 2*. Springer, 287–289.

[5] Shijia Pan, Mostafa Mirshekari, Pei Zhang, and Hae Young Noh. 2016. Occupant traffic estimation through structural vibration sensing. In *Sensors and Smart Structures Technologies for Civil, Mechanical, and Aerospace Systems 2016*, Vol. 9803. International Society for Optics and Photonics, 980306.

[6] Shijia Pan, Tong Yu, Mostafa Mirshekari, Jonathon Fagert, Amelie Bonde, Ole J Mengshoel, Hae Young Noh, and Pei Zhang. 2017. Footprintid: Indoor pedestrian identification through ambient structural vibration sensing. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies* 1, 3 (2017), 89.