Poster Abstract: Multiple Pedestrian Tracking through Ambient Structural Vibration Sensing

Shijia Pan[1] Kent Lyons[2] Mostafa Mirshekari[3] Hae Young Noh[3] Pei Zhang[1]
[1] Dept. of Electrical and Computer Eng., Carnegie Mellon Univ., Pittsburgh, PA, USA, 15213
[2] Technicolor Research, 175 S San Antonio Rd #200, Los Altos, CA 94022
[3] Dept. of Civil and Environmental Eng., Carnegie Mellon Univ., Pittsburgh, PA, USA, 15213
{shijiapan, mmirshekari, noh, peizhang}@cmu.edu, kent.lyons@technicolor.com

ABSTRACT

Tracking multiple people in an indoor environment enables various smart building applications such as HVAC energy saving, patient/child monitoring, etc. Researchers have explored various sensing methods including vision, motion, and RF, which either require specific installation requirements or high deployment density. We introduce a passive sparse sensing method based on ambient structural vibration induced by foot strikes. Our system tracks multiple people based on the premise that human foot strikes have spatio-temporal variation, and hence do not fully overlap. The system achieved less than 0.4m accuracy in both one and two persons stepping conditions.

1. INTRODUCTION

Tracking multiple people in an indoor environment has been a challenge for decades. Various sensing methods have been explored including vision [1], motion [6], RF [5], and they need either specific installation requirements (e.g., line-of-sight) or high deployment density. We investigate an alternative sparse sensing method based on ambient structural vibration [4, 3, 2]. Foot strikes induce impulse-like vibration signals in the floor, which contain information about the pedestrian. Our prior work explored one pedestrian identification and localization [4, 2], and a group of pedestrians' traffic count [3]. Here, we further study simultaneous tracking when multiple people walk together. Our system 1) senses the structural vibrations. Then, it 2) extracts the step-induced vibration signals (Step Events) and separates individual footsteps by identifying the initial regions of step signals, which have the highest SNR due to their impulse-like properties, within a Step Event. Due to human foot strike variation, some initial regions within a Step Event will not overlap. Finally, the system 3) tracks pedestrians using TDoA from these non-overlapping initial regions of step signals. The contributions of this work are threefold:

- Design of a wireless sensor network for multi-person footstep localization.

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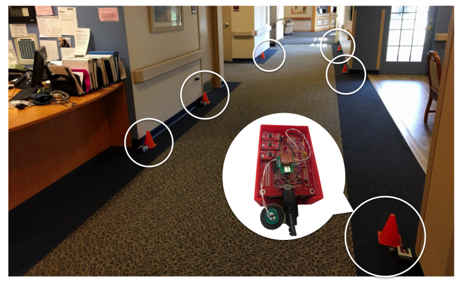

Figure 1: Sensing module deployed in a hallway.

- An energy-based segmentation method that separates overlapping footsteps of multiple persons.
- An evaluation of the system in an office setting.

2. SYSTEM DESIGN

The system consists of three modules: the sensing module, the signal segmentation module, and the tracking module. The sensing module collects the structural vibration with multiple sensors placed on the ground. These sensors are synchronized to allow Time Difference of Arrival (TDoA) based localization. The vibration signals are then sent to the signal segmentation module, where 1) the footstep-induced signals are extracted and 2) the initial region of step signals are identified from the signal segments that contain overlapping step signals. These extracted signals are then sent to the tracking module where the step locations are learned.

2.1 Sensing Module

The sensing module samples at 20kHz with all sensors wirelessly synchronized to the order of microseconds. Each sensor consists of 4 parts: 1) a geophone to detect structural vibration, 2) an amplifier array that provides multiple amplification gains to adapt to different structural responses (up to 20m sensing range [4]), 3) a controller board that stores the data, and 4) a radio that receives synchronization timestamps. Figure 1 shows a deployment of 6 sensors and our experiment below uses 4. We characterize the wave propagation velocity before deployment [2].

2.2 Signal Segmentation Module

The signal segmentation module extracts the region of the signal used for localization and segments them into individual footsteps. The footstep-induced vibration signal (Step Event) contains higher energy compared to the ambient noise signal, which can be modeled as Gaussian noise [3]. Therefore, we conduct anomaly detection based on a

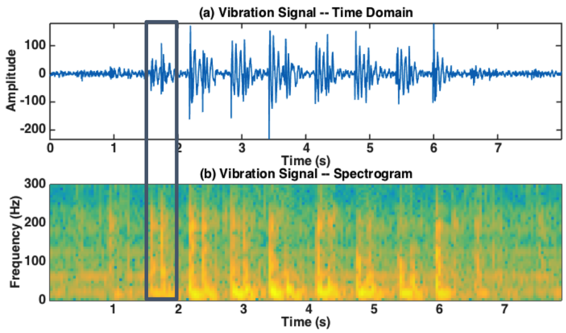

Figure 2: Structural vibration signal and its power spectrum when two people walk by a sensing module side-by-side.

Gaussian noise model from the noise signal to detect Step Events [3]. When multiple people walk side-by-side and pass the sensing area, their individual footstep signals can overlap and be incorrectly detected as one Step Event. Due to the spatio-temporal variation of the human foot strikes, the initial region of two step signals may not exactly overlap. Figure 2 shows the vibration signal when two people walk together by a sensor. We can see that even when two people's step signals overlap (Figure 2 (a)), the onset can be identified in spectrogram (Figure 2 (b)): the energy of the vibration signal concentrates at the beginning. This finding means that the signal energy in a small sliding window (0.15 s) of a Step Event is larger at the onset of each step. This corresponds to two peaks in the spectrogram as shown in the black box in Figure 2 (b).

2.3 Tracking Module

The tracking module localizes each step based on the signal segments extracted from the signal segmentation module. The signal is filtered by the fundamental frequency band to achieve high SNR and reduce structure-induced distortion for accurate TDoA estimation [2]. These TDoA values are then used to form the multilateration equations and hence localize each footstep [2]. We plan to apply particle filters to improve the tracking accuracy of footsteps.

3. EVALUATION

We conducted experiments in an office setting and discuss preliminary results to validate our approach. Four sensing modules were placed in a rectangle forming a $1.8m \times 3m$ area. We asked two persons to stand at the designated locations (X=0.6, 1.2, and 1.8m in Figure 3). They were asked to step at a self-selected pace consecutively at the target locations. Each person stepped 5 times individually, and then they stepped together 5 times after a start command. So while they stepped at approximately the same time, there are small variations thus resulting in not fully overlapping step signals. The stepping locations estimated by our system are shown in Figure 3, where steps of two persons are represented by square and diamond markers respectively. The localization results are listed in Table 1 with an overall average error rate of $0.34m$ and $0.39m$ for the one person and two persons stepping scenarios, respectively. The preliminary results indicate that when the initial regions of multiple individual step signals in a Step Event have an offset large enough to be identified (11 out of 15 overlapping signals), our system achieved similar levels of accuracy compared to that of the non-overlapping signal in a Step Event.

	P1 (5)	*P2 (5)*	*P1+P2 (10)*
Loc1(X=0.6)	5/0.31/0.08	5/0.28/0.07	10/0.44/0.35
Loc2(X=1.2)	5/0.39/0.18	5/0.22/0.03	8/0.19/0.14
Loc3(X=1.8)	5/0.61/0.10	5/0.23/0.05	8/0.54/0.26

Table 1: Detection and localization of the stepping signals: #Detected Stepping/Error Avg(m)/Error Std(m).

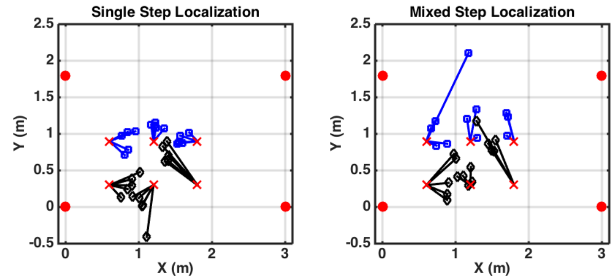

Figure 3: Stepping signal localization. Red circles are sensor locations. Red crosses are step locations. Square and diamond markers are estimated locations of two persons' step.

4. FUTURE WORK & CONCLUSION

In this paper, we present a wireless sensor network designed to track multiple pedestrians through structural vibration. Our step initial region detection method allows the system to track multiple people walking together. Then we showed the preliminary experimental results to validate our design. The system achieves similar error levels ($< 0.4m$) in both one and two persons stepping conditions. We plan to further evaluate the system with multiple subjects walking in their natural form to understand the system limitations.

5. REFERENCES

[1] R. Bodor, B. Jackson, and N. Papanikolopoulos. Vision-based human tracking and activity recognition. In *Proc. of the 11th Mediterranean Conf. on Control and Automation*, volume 1. Citeseer, 2003.

[2] M. Mirshekari, S. Pan, P. Zhang, and H. Y. Noh. Characterizing wave propagation to improve indoor step-level person localization using floor vibration. In *SPIE*, pages 90611O–90611O. International Society for Optics and Photonics, 2016.

[3] S. Pan, M. Mirshekari, P. Zhang, and H. Y. Noh. Occupant traffic estimation through structural vibration sensing. In *SPIE*, pages 980306–980306. International Society for Optics and Photonics, 2016.

[4] S. Pan, N. Wang, Y. Qian, I. Velibeyoglu, H. Y. Noh, and P. Zhang. Indoor person identification through footstep induced structural vibration. In *Proceedings of the 16th International Workshop on Mobile Computing Systems and Applications*, pages 81–86. ACM, 2015.

[5] H. Wang, H. Lenz, A. Szabo, J. Bamberger, and U. D. Hanebeck. Wlan-based pedestrian tracking using particle filters and low-cost mems sensors. In *2007 4th Workshop on Positioning, Navigation and Communication*, pages 1–7. IEEE, 2007.

[6] J. Yun and S.-S. Lee. Human movement detection and identification using pyroelectric infrared sensors. *Sensors*, 14(5):8057–8081, 2014.