Poster Abstract: *LEVO*: L̲EGO® Bricks E̲nhanced Single-Point V̲ibration Sensing for O̲ccupant Monitoring

Yue Zhang
Shikha Patel
Dong Yoon Lee
yzhang58,spatel272,dlee267
@ucmerced.edu
Univ. of California, Merced
Merced, CA, USA

Paolo Celli
paolo.celli@stonybrook.edu
Stony Brook University
Stony Brook, NY, USA

Amelie Bonde
amelie.bonde@jhuapl.edu
Johns Hopkins University
Applied Physics Laboratory
Laurel, MD, USA

Shijia Pan
span24@ucmerced.edu
Univ. of California, Merced
Merced, CA, USA

ABSTRACT

The rising older adults population has led to an increased demand for in-home health monitoring to support their well-being in daily life. For instance, localization and tracking are essential applications in elderly monitoring since they can provide various information on health, mobility and can detect falls. The required power and computational resources of traditional acoustic sensor-array solutions make them unavailable on power- and computation- constrained embedded devices. In this paper, we present *LEVO*, a single-point directional acoustic sensing system that leverages simple LEGO® bricks to build up a physical structure that can embed directional information into a signal waveform. Our preliminary results verifies the feasibility of adopting *LEVO* for signal direction recognition from signal-point sensing data.

KEYWORDS

Direction embedding, vibration sensing, metamaterials

ACM Reference Format:
Yue Zhang, Shikha Patel, Dong Yoon Lee, Paolo Celli, Amelie Bonde, and Shijia Pan. 2023. Poster Abstract: *LEVO*: L̲EGO® Bricks E̲nhanced Single-Point V̲ibration Sensing for O̲ccupant Monitoring. In *The 21st ACM Conference on Embedded Networked Sensor Systems (SenSys '23), November 12–17, 2023, Istanbul, Turkiye.* ACM, New York, NY, USA, 2 pages. https://doi.org/10.1145/3625687.3628385

1 INTRODUCTION

Older adults monitoring is essential for reducing the caregiver's burden and improving older adults' quality of life. Multiple sensing technologies have been explored, including wearable [6], vision [4], radio frequency [3], and vibration [5]. However, they often have limitations when deployed in real-world. For example, wearables require the user to wear them constantly, which may cause discomfort for long-term usage. Vision and audio sensing directly record the image/video or audio data of the user, which rise privacy concerns especially in residential buildings. Radio frequency based methods are non-intrusive solutions, however, they are often susceptible to interference and cluttered environments. Acoustic vibration based methods have been explored to acquire fine grained information (e.g., step-level localization, gait balance). However, they require multiple sensor deployment [5] due to their omnidirectional sensing properties.

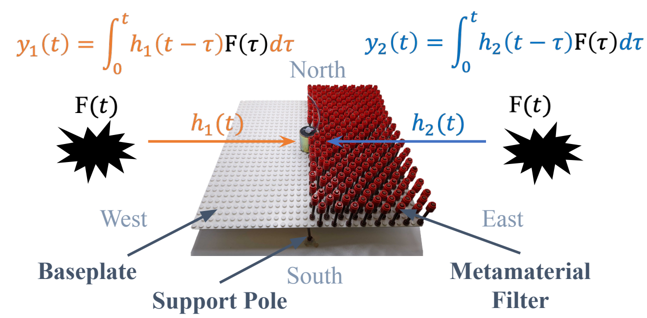

Figure 1: *LEVO* overview. *LEVO* uses configurable bricks to change the structural response function $h(t)$, which embeds a directional signature in the recorded vibration signal $y(t)$.

In this work, we present *LEVO*, a single-point vibration sensing system that leverages configurable LEGO® bricks to embed directional information in mechanical waves for direction sensing. The physical structure of a wave-carrying medium strongly affects the mechanical waves traveling through it, and impacts the frequency distribution of such waves. In particular, the physical structure properties, such as size, shape, and material [2] all affect the wave frequency distribution. By surrounding a sensor with a medium that is drastically different along different directions, the sensor will record waves with different signatures when they come from different directions. As shown in Figure 1, *LEVO* leverages this principle to manipulate mechanical waves in a direction-dependent manner – using low cost and re-configurable LEGO® bricks to create a wave-carrying medium that leaves a unique directional signature in the traveling mechanical waves [1]. By carefully designing the structure, it is possible to recognize the wave direction from the vibration data recorded by a single sensor.

2 *LEVO* DESIGN

For non-intrusive and privacy-preserving occupant tracking, we use a vibration sensor [7, 8] deployed on the structure surface to capture the occupant's activity-induced mechanical waves. To decrease the amount of sensors and computational resources required

SenSys '23, November 12–17, 2023, Istanbul, Turkiye

ACM ISBN 979-8-4007-0414-7/23/11.
https://doi.org/10.1145/3625687.3628385

for directional sensing, we design a physical structure installed between the vibration sensor and the structure surface to embed the directional information into a mechanical wave.

$$y(t) = \int_0^t h(t-\tau)F(\tau)d\tau \quad (1)$$

We can model the mechanical wave as a simplified SDOF system as shown in Eq. 1 [2], where $F(t)$ is the applied force (i.e., human footstep), $h(t)$ is the impulse response function for the structure, and $y(t)$ is the displacement of the structure. When the structure impulse response h changes, the displacement of the structure y changes with it, even the excitation force F is the same. By building a structure which has a unique impulse response in each direction, the sensor recorded mechanical wave from different directions should be distinguishable. Inspired by this intuition, we designed a physical structure between the sensor and the floor to embed the direction information into a wave.

LEVO contains three parts as shown in Figure 1: supporting poles, baseplate and metamaterial filter built with LEGO® bricks [1]. The supporting poles are to separate the base plate from the floor to control the wave propagation paths from the edge to the sensor. The mechanical waves propagates through the designate path and the metamaterial filter. By changing the LEGO® bricks' shape and pattern on the baseplate, we control the metamaterial filter properties [1]. By applying the metamaterial filter at different area of the baseplate, we configure the different metamaterial filter properties on different propagation paths, which embeds the directional information into the mechanical waves before they are captured by the sensor. With these patterns of bricks, *LEVO* represents a passive, low-cost, and re-configurable solution to embedding the direction information in the vibration waveform.

3 PRELIMINARY RESULT

Experiment Setup. To verify the design of *LEVO*, we use the excitation from dropping a ball at a consistent location and height as a standard signal. We investigate four directions (shown in Figure 1), and collect 20 ball drops induced vibration signal in each direction, which drops at same location from same height. We compare the result of two configurations: with and without metamaterial filter for embedding directional information.

Preliminary Result. Figure 1 shows the frequency domain (1 Hz to 80 Hz) of the acquired vibration signals of two configurations. We observe that the frequency domain signals of the same excitation propagating to the sensor from different directions showing different level of homogeneity with and without LEGO® bricks built metamaterial filters. Figure 1 (a) shows the frequency domain signals without metamaterial filter, where two frequency bands are excited at 22 and 40 Hz for signals from all four directions. While Figure (b) depicts that the frequency domain signal passing metamaterial filter has frequency band excited at 14, 23, and 39 Hz differently over the four directions. This indicates that the LEGO® bricks built metamaterial filter is **capable of embedding directional information into the mechanical waves.** We plan to conduct more studies to control the metamaterial filtering effects on human-induced structural vibration signals for effective single-sensor occupant tracking.

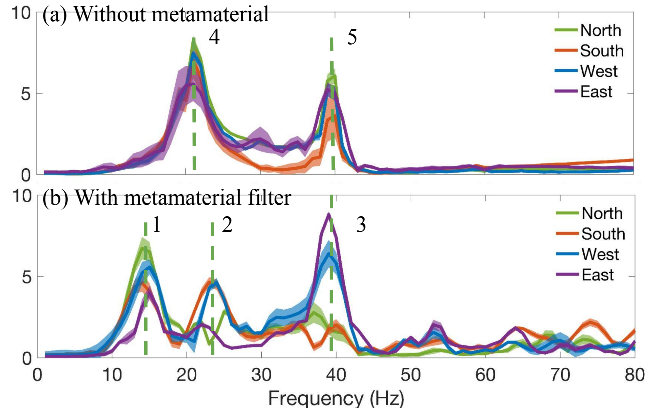

Figure 2: The average frequency response and the standard deviation (width of the curve) of the vibration signal without metamaterial filter (a) and with metamaterial filter (b).

4 CONCLUSION

In this paper, we introduce *LEVO*, a single-point direction sensing system through a passive, low-cost, and re-configurable metamaterial structure. *LEVO* utilizes the metamaterial filter made of LEGO® bricks to manipulate the frequency components of the mechanical wave, which embeds the direction information into the waveform. We report the preliminary results on direction information embedding and discuss opportunities and future plans.

ACKNOWLEDGEMENTS

This work is partially supported by a 2022 Seed Fund Award from CITRIS and the Banatao Institute at the University of California.

REFERENCES

[1] Paolo Celli, Behrooz Yousefzadeh, Chiara Daraio, and Stefano Gonella. 2019. Bandgap widening by disorder in rainbow metamaterials. *Applied Physics Letters* 114, 9 (2019).

[2] Jonathon Fagert, Mostafa Mirshekari, Shijia Pan, Linda Lowes, Megan Iammarino, Pei Zhang, and Hae Young Noh. 2021. Structure-and sampling-adaptive gait balance symmetry estimation using footstep-induced structural floor vibrations. *Journal of Engineering Mechanics* 147, 2 (2021), 04020151.

[3] Chitra R Karanam, Belal Korany, and Yasamin Mostofi. 2019. Tracking from one side: Multi-person passive tracking with WiFi magnitude measurements. In *Proceedings of the 18th International Conference on Information Processing in Sensor Networks*. 181–192.

[4] Shuo Liu, Le Yin, Weng Khuen Ho, Keck Voon Ling, and Stefano Schiavon. 2017. A tracking cooling fan using geofence and camera-based indoor localization. *Building and Environment* 114 (2017), 36–44.

[5] 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.

[6] Rui Wang, Weichen Wang, Alex DaSilva, Jeremy F Huckins, William M Kelley, Todd F Heatherton, and Andrew T Campbell. 2018. Tracking depression dynamics in college students using mobile phone and wearable sensing. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies* 2, 1 (2018), 1–26.

[7] Yue Zhang, Zhizhang Hu, Uri Berger, and Shijia Pan. 2023. Integrating On-and Off-body Sensing for Young Adults Failure to Launch (FTL) Behavior Profiling. In *Proceedings of the 22nd International Conference on Information Processing in Sensor Networks*. 320–321.

[8] Yue Zhang, Shijia Pan, Jonathon Fagert, Mostafa Mirshekari, Hae Young Noh, Pei Zhang, and Lin Zhang. 2018. Occupant activity level estimation using floor vibration. In *Proceedings of the 2018 ACM international joint conference and 2018 international symposium on pervasive and ubiquitous computing and wearable computers*. 1355–1363.