Levee and Embankment Monitoring with Novel Embeddable Passive RF Sensing System

KENT X. ENG[1], ZYGMUNT J. HAAS[2], PETAR M. DJURIĆ[4], SAMIR R. DAS[3], MILUTIN STANAĆEVIĆ[3] and BRANKO GLISIC[1]

ABSTRACT

Levees and embankments are important infrastructure for protecting industrial, commercial, residential, and agricultural regions from flooding. As global temperatures increase due to climate change, flooding is expected to become more severe in the future. As flooding occurs more often with higher levels and streamflow, levee structures face a greater risk from events exceeding prior design expectations. Existing monitoring technologies either focus on discrete or continuous measurements with complicated installation, which is a challenge in large-scale implementation. Therefore, it is of interest to develop a levee monitoring system to effectively implement on a large scale for assessing and maintaining the levee condition under extreme events.

This presentation includes preliminary research on a novel embeddable passive radio frequency (RF) sensing system and its applicability in levee monitoring applications. Previous studies have demonstrated the sensing system's ability to detect changes in displacement and water content. This study focuses on implementation challenges, particularly the use of a distant exciter to power passive RF sensors. The exciter is expected to be carried by unmanned aerial vehicles (UAV), positioned a few meters from the levee surface. Controlled laboratory experiments are conducted to analyze the exciter's effects. The main challenge of this research includes replicating the potential trajectory of the exciter and identifying the influence of the exciter's position on the system performance.

The results demonstrate the impact of the exciter's position on the collected data. These findings demonstrate the feasibility of the RF sensing system for levee monitoring while addressing the challenges associated with UAV-mounted exciters. By further investigating and addressing these challenges, the system can be made a step closer to real-world implementations.

INTRODUCTION

Levees, embankments, and dam-like structures are essential and critical infrastructures to protect human life and property from flooding. As the intensity of rainstorms, storm surges, and sea-level rise increases, the number, frequency, streamflow, and elevation of flooding are forecasted to increase [1], [2], [3], [4]. As a

[1]Princeton University, Department of Civil and Environmental Engineering, Princeton, NJ, 08544, USA
[2]University of Texas at Dallas, Department of Computer Science and Cornell University, School of Electrical and Computer Engineering, Richardson, TX, 75080, USA
[3]Stony Brook University, Department of Electrical and Computer Engineering, Stony Brook, NY, 11794, USA
[4]Stony Brook University, Department of Computer Science, Stony Brook, NY, 11794, USA

result, levees and embankments are exposed to greater risk due to extreme events which may introduce loading condition that exceeds design criteria. Meanwhile, the lack of maintenance and intentionally improper construction of the structure can lead to catastrophic failures. For example, levees in Pajaro, CA, were breached, leading to $450 million agricultural loss in 2023 due to the lack of repair [5]. Recently, the ASCE report card states that the grading evaluation of levees is D+ [6]. Structural health monitoring (SHM) can aid in detecting early deterioration, damage, and seepage of levees at an early stage, which reduces financial costs and improves safety, sustainability, and resilience.

SHM in levees faced a challenge with the capability of multi-parameter large-scale monitoring. The majority of levee failure mechanisms are based on deformation or water content. Most applications require the installation of multiple sensing systems to monitor multiple structural parameters [7], [8]. Few monitoring techniques can monitor multiple structural parameters. For example, fiber-optic monitoring systems can monitor the strain and temperature of the structures [9], [10], [11]. However, the installation and maintenance of such systems throughout the large volume of the structure is nearly impossible. Current techniques are incapable of extracting three-dimensional multi-parametric information throughout the volumes of structural material. Therefore, it is essential to develop a levee monitoring system with the capability of multi-parameter sensing to effectively extract spatial information for assessing and maintaining the levee condition under extreme events. Radio frequency (RF) based sensing systems can be the potential solution to the objective above.

Recent studies show that backscatter-based RF sensing systems are potentially feasible for pavement monitoring [12], [13]. Pavement structure and levee structure are both large-volume structures. Meanwhile, the backscatter-based RF system is capable of monitoring displacement and water content simultaneously. However, the effect of mobile exciter is unknown. This study aims to investigate the effect of mobile exciter.

Effect of Mobile Exciter

As shown in Figure 1, in the implementation scenarios, the exciter will be carried by unmanned aerial vehicles (UAV), and the UAV will be programmed with specific trajectories to activate all the sensors in the structure. The RF sensors will be embedded inside the levee structure. However, the effects of trajectories on the sensing system have not been studied yet. Therefore, the experiment has to be conducted to investigate how the collected signal changes as the exciter is moved on particular trajectories.

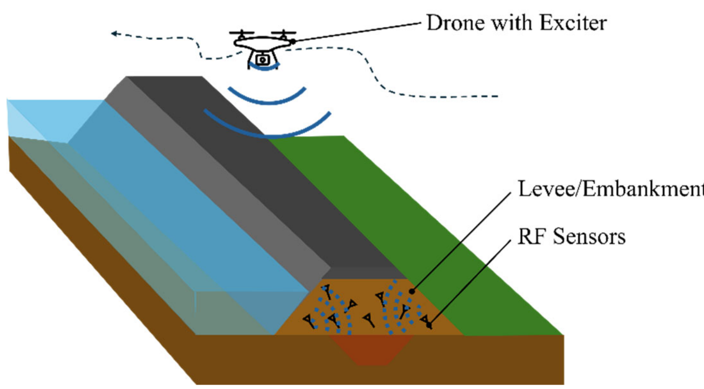

Figure 1 Conceptual Implementation of Backscatter based RF Sensing System in Levee Monitoring

Method

The experiment was performed to determine how the phase shift between the sensors changes as the exciter moves along a particular trajectory. As shown in Figure 2, a pair of two RF sensors was used, and each was encased inside a dry concrete block. Those blocks were placed 60 cm apart inside a Plexiglas box. Dry sand was filled between the blocks to emulate the scenario of sensors being embedded inside the levee. An exciter, which was operated at 915 MHz, was attached to a rail that was above the Plexiglas box to power the sensors inside the blocks. The direction of the rail was aligned with the length of the Plexiglas box, such that the exciter was moved along the length of the Plexiglas box. The position of the exciter was initially placed 5 cm behind the left block and was displaced 10 cm at each step with 3 minutes of data collection at a sampling rate of 3 seconds. The total displacement of the exciter was 70 cm, which was positioned 5 cm behind the right block.

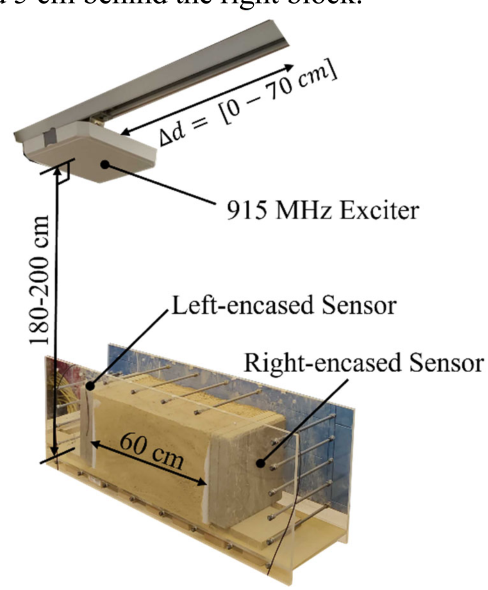

Figure 2 Experimental Setup for the Effect of Mobile Exciter

Discussion

The result of the experiment was shown in Figure 3. The boxplot represented the stability of the collected phase at each displacement. The median value of each boxplot was shown and used to calculate the average of all median values. The red line represented the average of the median values, which was 19.3°. The correlation coefficient between phases and changing displacement of exciter was -0.07, based on a total of 364 samples. By setting the null hypothesis as no linear correlation between phase and changing displacement of the exciter and the alternative hypothesis as the linear correlation exists, the p-value is 0.16, which indicates a failure to reject the null hypothesis. Therefore, there is no significant linear correlation between phase and changing displacement. However, the phase was changed when the exciter was displaced. In the implementation scenarios, the trajectory of the UAV should be set up with stationary locations for data collection of the scanned sensors.

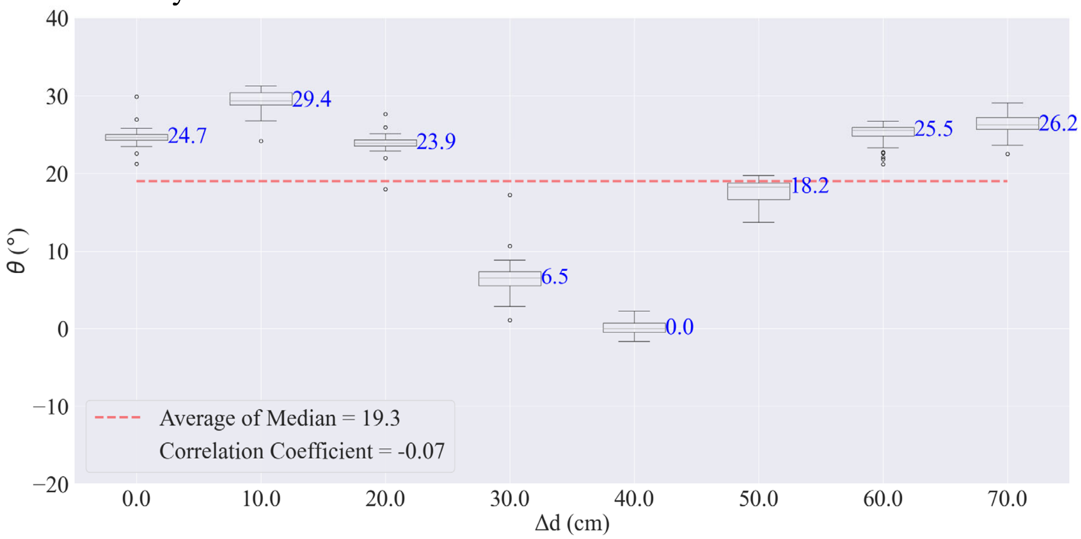

Figure 3 Experimental Result of the Effect of Mobile Exciter

Conclusion

This study investigates the effects of mobile exciter on the phase shift between sensors. The experimental result demonstrates that the phase shift will change as the exciter's location changes. However, the location of the exciter and the phase shift between sensors have no linear correlation. For the implementation of exciter, the UAV's trajectory should be set with several stationary locations for data collection to avoid the effect of the exciter on the collected phase shift.

Acknowledgement

This research was funded by the National Science Foundation under Grant No. ECCS-2329800, ECCS-2329801, and ECCS-2329802. Authors would like to especially thank Yang Xie, Yuanqing Song, Joseph Vocaturo Jr., Mauricio Pereira, Angel Dong, and Dane Utley for their help and contributions.

REFERENCES

[1] J. L. Florsheim and M. D. Dettinger, "Climate and floods still govern California levee breaks - Florsheim - 2007 - Geophysical Research Letters - Wiley Online Library." Accessed: Jan. 23, 2025. [Online]. Available: https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2007GL031702

[2] M. D. Dettinger, D. R. Cayan, M. K. Meyer, and A. E. Jeton, "Simulated Hydrologic Responses to Climate Variations and Change in the Merced, Carson, and American River Basins, Sierra Nevada, California, 1900–2099," *Clim. Change*, vol. 62, no. 1, pp. 283–317, Jan. 2004, doi: 10.1023/B:CLIM.0000013683.13346.4f.

[3] F. Vahedifard, F. H. Jasim, F. T. Tracy, M. Abdollahi, A. Alborzi, and A. AghaKouchak, "Levee Fragility Behavior under Projected Future Flooding in a Warming Climate," *J. Geotech. Geoenvironmental Eng.*, vol. 146, no. 12, p. 04020139, Dec. 2020, doi: 10.1061/(ASCE)GT.1943-5606.0002399.

[4] M. R. Islam *et al.*, "Climate-resilience of dams and levees in Canada: a review," *Discov. Appl. Sci.*, vol. 6, no. 4, p. 174, Mar. 2024, doi: 10.1007/s42452-024-05814-4.

[5] Governor of California, "Letter from California Governor Gavin Newsom to President Joseph R. Biden requesting a Major Disaster Declaration for California Counties impacted by 'Late Winter Storms Event." Governor of California, Mar. 28, 2023. [Online]. Available: https://www.gov.ca.gov/wp-content/uploads/2023/03/3.28.23-Major-Disaster-Declaration-request.pdf

[6] "2025 Infrastructure Report Card | ASCE's 2025 Infrastructure Report Card," ASCE's 2025 Infrastructure Report Card |. Accessed: Mar. 30, 2025. [Online]. Available: https://infrastructurereportcard.org/

[7] K. Radzicki, T. Gołębiowski, M. Ćwiklik, and M. Stoliński, "A new levee control system based on geotechnical and geophysical surveys including active thermal sensing: A case study from Poland," *Eng. Geol.*, vol. 293, p. 106316, Nov. 2021, doi: 10.1016/j.enggeo.2021.106316.

[8] S. Su *et al.*, "Multi-Level Hazard Detection Using a UAV-Mounted Multi-Sensor for Levee Inspection," *Drones*, vol. 8, no. 3, Art. no. 3, Mar. 2024, doi: 10.3390/drones8030090.

[9] P. Zhu, Y. B. Leng, Y.Zhou, and G. L. Jiang, "Safety Inspection Strategy for Earth Embankment Dams using Fully Distributed Sensing," *Procedia Eng.*, vol. 8, pp. 520–526, Jan. 2011, doi: 10.1016/j.proeng.2011.03.094.

[10] N. Fabbian, P. Simonini, F. De Polo, L. Schenato, and S. Cola, "Temperature monitoring in levees for detection of seepage," *Bull. Eng. Geol. Environ.*, vol. 83, no. 2, p. 69, Feb. 2024, doi: 10.1007/s10064-024-03566-4.

[11] S. Cola, V. Girardi, S. Bersan, P. Simonini, L. Schenato, and F. De Polo, "An optical fiber-based monitoring system to study the seepage flow below the landside toe of a river levee," *J. Civ. Struct. Health Monit.*, vol. 11, no. 3, pp. 691–705, Jul. 2021, doi: 10.1007/s13349-021-00475-y.

[12] A. Ahmad, X. Sha, M. Stanaćević, A. Athalye, P. M. Djurić, and S. R. Das, "Enabling Passive Backscatter Tag Localization Without Active Receivers," in *Proceedings of the 19th ACM Conference on Embedded Networked Sensor Systems*, in SenSys '21. New York, NY, USA: Association for Computing Machinery, Nov. 2021, pp. 178–191. doi: 10.1145/3485730.3485950.

[13] K. X. Eng *et al.*, "A Vision and Proof of Concept for New Approach to Monitoring for Safer Future Smart Transportation Systems," *Sensors*, vol. 24, no. 18, Art. no. 18, Jan. 2024, doi: 10.3390/s24186018.