밀리미터파 레이더와 가속도계 기반 구조물 변위 계측 방법

Millimeter-wave Radar and Accelerometer Based Structural Displacement Estimation

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In this study, a structural displacement estimation technique was developed by fusing collocated accelerometer and millimeter-wave (mmWave) radar. An automated initial calibration is first performed, and then displacement is estimated in real time from radar measurement. The radar-based displacement is further fused with acceleration measurement using a finite impulse response (FIR) filter for improved accuracy. The performance of the proposed technique was validated on a pedestrian bridge.

Keywords: Displacement estimation, millimeter-wave radar, FIR filter, accelerometer, data fusion

1. Introduction

Displacement provides crucial information regarding structural integrity and its current condition, and is commonly estimated using accelerometer. However, accelerometer-based displacement has a huge low-frequency drift. Radar has been investigated for structural displacement measurement[1]. However, when measuring displacement using radar, a manual initial calibration is needed to identify the locations of radar-detected targets, and estimate conversion factors necessary for converting the LOS displacements to structural displacements in an actual vibration direction. In addition, phase wrapping may occurs, especially when using a millimeter-wave (mmWave) radar, resulting in inaccurate displacement estimation. In this study, a structural displacement estimation technique is proposed using FMCW mmWave radar and acceleration measurements. An automated initial calibration algorithm is proposed to select the best target from the surroundings and estimate its conversion factor, and an acceleration-aided phase unwrapped algorithm is developed and applied in the radar-based displacement estimation process to solve phase wrapping issue.

2. Methodology

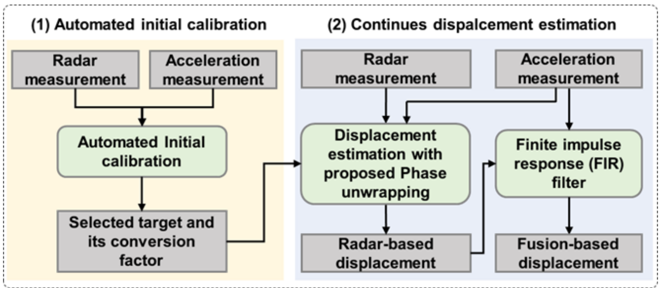

Figure 1. Overview of the proposed technique

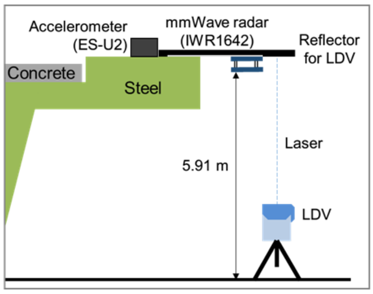

Figure 2. Overview of experimental setup

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An overview of the proposed technique is demonstrated in Figure 1. A mmWave radar and an accelerometer are placed at the same location, and the proposed technique consists of two parts:

(1) Automated initial calibration: radar and acceleration measurements are initially collected for a short-time period to automatically select the best target and estimate its conversion factor.

(2) Continues displacement estimation: radar-based displacement is first estimated using the selected best target, its conversion factor and the proposed acceleration-aided phase unwrapping algorithm, and then fused with acceleration measurement using a FIR filter [2] for improved accuracy.

3. Experimental validation

The displacement estimation performance of the proposed technique is further validated on a pedestrian steel box-girder bridge. As shown in Figure 2, a mmWave radar and uniaxial force balance accelerometer were installed at 1/2 span point of the bridge. The reference displacement was measured using a Polytech RSV-150 laser Doppler vibrometer (LDV). The displacement was estimated when 14 people slowly passing the bridge, and the RMSE is 0.03 mm (Figure 3).

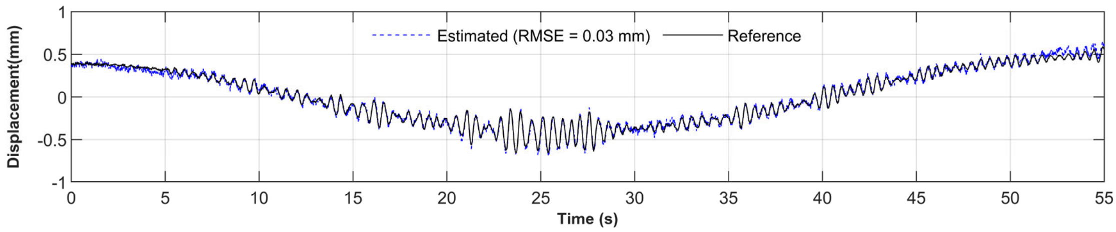

Figure 3. Displacement estimation results

4. Conclusion

In this study, a displacement estimation technique was proposed through the fusion of collocated FMCW mmWave radar and accelerometer. The main contributions lie in: (1) automated initial calibration and (2) acceleration-aided phase unwrapped algorithms. The performance of the proposed technique was experimentally validated on a steel box-girder pedestrian bridge. The RMSE of the estimated displacements was only 0.03 mm. Currently, the proposed technique was validated with the target distance up to 6 m. A follow-up study is warranted for displacement estimation for long-span bridge.

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Reference

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