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Verification of Millimeter-Wave Radar Vital Sensing Simulation Method for In Vehicle Child Presence Detection

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Child presence detection (CPD) has become a critical social issue requiring urgent measures such as the introducing performance evaluation tests in Euro NCAP and mandating the installation of safety devices on shuttle buses in Japan. Consequently, vital sensing using millimeter-wave radar has attracted significant attention due to its non-contact nature and privacy considerations. The millimeter-wave band is particularly well-suited for detecting subtle body surface movements associated with breathing and heartbeats.

However, system evaluation using real vehicles poses challenges in ensuring reproducibility. It also requires substantial time and cost to address diverse test items based on empirical measurements. Therefore, utilizing simulation is extremely effective for improving evaluation efficiency. To capture complex scattering phenomena from the human body at high frequencies, the authors proposed a method combining ray tracing with physical optics (PO) [(1)]. Previously, the authors reported the effectiveness of range-doppler imaging in in-vehicle environments using this combined analysis [(2)].

While previous work showed detection feasibility in ideal facing conditions, real-world vehicle interiors involve non-facing postures, shielding by seats, and complex multipath environments. This study verifies a frequency estimation algorithm for a single-input single-output (SISO) configuration as a fundamental study for future multiple-input multiple-output (MIMO) applications. The methodology focuses on achieving simulation efficiency through target bin selection and data extension, as well as on improving frequency estimation accuracy using the Fast Fourier transform (FFT) across various in-vehicle scenarios.

The analysis demonstrated that while non-line of sight (NLoS) environments make identification difficult using only range-doppler imaging, vital sign components can be identified by extracting paths containing phase changes. It was confirmed that respiratory frequencies could be identified even in non-facing or NLoS conditions. However, the identification of heartbeat frequencies may be hindered by harmonic interference from the respiratory signal.

Future work will focus on advancing frequency identification and conducting simulations that replicate realistic vehicle environments, including interference from body movements and vehicle vibrations. These efforts are expected to contribute to the efficiency of system evaluation and the verification of CPD technologies using machine learning.

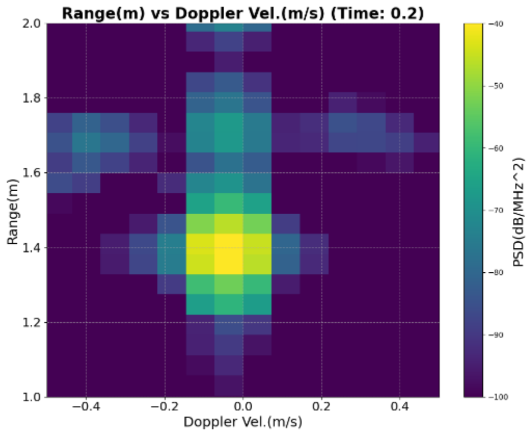

Fig. 1 Range-doppler map

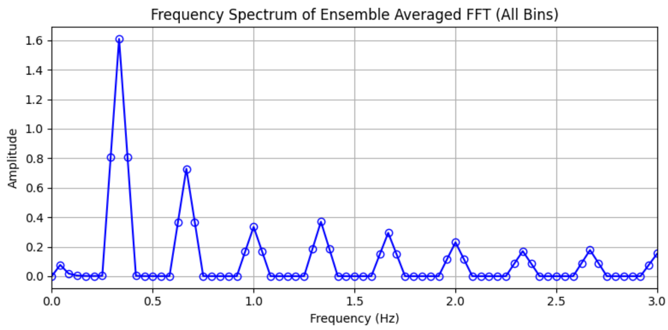

Fig. 2 Frequency spectrum of ensemble averaged FFT

Reference

(1) S. Mukherjee, B.M. Hardy, G.J. Skidmore, and T. Chawla, et al.: Animating Vital Signs in Radar Simulations: Comparing Physical Optics Against 28.5 GHz Channel Measurements, 2024 IEEE Radar Conference (RadarConf24), 1-5, 2024, doi: 10.1109/RadarConf2458775.2024.1054317.

(2) Taiki Nakayama, Yasuhiro Tada, Yosuke Saiki, and Kenshi Horihata et al.: Simulation Evaluation of Millimeter-Wave Vital Sign Sensing in In-Cabin Environment, IEICE Tech. Rep., 125(128), SRW2025-23, 13-14, 2025.