Nonlinear Radar Simulator Using MATLAB Simulink

JI WON CHOI
School of Electronic Engineering
Soongsil University
Seoul, Korea
wldnjschl01@soongsil.ac.kr

SUN K.HONG
School of Electronic Engineering
Soongsil University
Seoul, Korea
shong215@ssu.ac.kr

A. Introduction

Non-contact vital sign monitoring using nonlinear tags has recently attracted increasing attention, and frequency-modulated continuous-wave (FMCW) radar is considered a promising approach due to its capability for precise range and velocity estimation [1]. Conventional linear radars are highly susceptible to clutter-induced interference, which limits the accuracy of vital sign detection. In contrast, nonlinear radar inherently suppresses clutter by selectively receiving only the harmonic component ($2f_0$) generated by nonlinear tags, while structurally eliminating the fundamental frequency (f_0) reflected from surrounding objects. However, compared with linear radar, nonlinear radar generally suffers from lower received power and involves more complex link-budget factors, such as harmonic wavelength and effective nonlinear radar cross section (RCS), making it difficult to reliably predict system performance in advance. To overcome these limitations and provide sufficient validation prior to hardware implementation or clinical applications, we developed a nonlinear radar simulator for indoor environments, incorporating chest-mounted nonlinear tags and multiple static clutters such as walls, furniture, and plants.

B. Nonlinear Radar Scenario : Design and Experimental Results

Figure 1 shows the block diagram of the proposed simulator, which consists of the transmitter (Tx), receiver (Rx), free-space channel, and target section including vital signs. The vital signs were modeled with a heartbeat frequency of 2.2 Hz and a respiration frequency of 0.4 Hz, and incorporated into the target position by considering the link budget of the nonlinear radar. Based on the link budget, parameters such as antenna gain, transmit power, noise figure, and SNR were configured. Furthermore, five linear reflective clutters were fixed at distances of 0.4 m, 0.9 m, 1.4 m, 2.0 m, and 4.0 m, respectively.

Figure 2 shows the vital sign detection results in a multi-clutter environment using (a) linear radar and (b) nonlinear radar. Compared with the ground-truth values (respiration = 0.4 Hz, heartbeat = 2.2 Hz), the linear radar exhibits high error rates of 97.5% for respiration and 18.1% for heartbeat, whereas the nonlinear radar achieves much lower error rates of 2.5% and 0%, respectively. This demonstrates the superior detection accuracy of the nonlinear radar.

C. Conclusion

This study implements a nonlinear (second-harmonic) radar simulator based on MATLAB/Simulink and compares its respiration and heartbeat detection performance with that of a linear radar under identical conditions in a multi-clutter environment. The results demonstrate that the nonlinear radar can reliably reconstruct target range and micro-Doppler signatures even in complex indoor scenarios, exhibiting superior clutter suppression performance compared with its linear counterpart. These findings suggest that nonlinear tag-based radar can serve as a reliable tool for non-contact vital sign estimation in indoor living environments. In future work, the simulator will be extended to incorporate the effective nonlinear RCS of individual tags for simultaneous multi-tag identification. Furthermore, digital beamforming will be applied to suppress interference and residual clutter, and the derived design will be transitioned toward real-world validation.

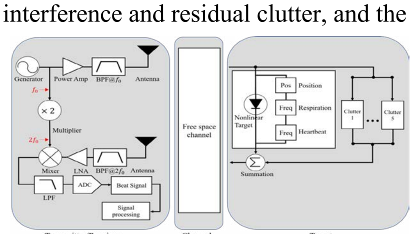
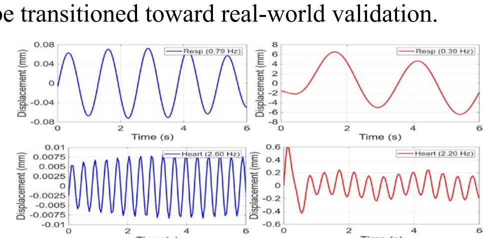


FIGURE 1 . BLOCK DIAGRAM OF THE NONLINEAR RADAR SYSTEM FOR SIMULATION



(A) (B)

FIGURE 2. VITAL SIGN IDENTIFICATION IN A MULTI-CLUTTER ENVIRONMENT : (A) LINEAR RADAR, (B) NONLINEAR RADAR

REFERENCES

[1] L. Chioukh, H. Boutayeb, D. Deslandes, and K. Wu, "Noise and sensitivity of harmonic radar architecture for remote sensing and detection of vital signs," *IEEE Trans. Microw. Theory Techn.*, vol. 62, no. 9, pp. 1847–1855, Sep. 2014.