Investigating a Portable Low-Cost Target Simulator for Doppler Radars

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***Abstract*—This article presents a study on employing a single-sideband (SSB) mixer as a target simulator for Doppler radar sensors. The SSB mixer modulates the continuous-wave radio frequency (RF) signal transmitted by the Doppler radar, similar to a moving target. To prove the effectiveness of the proposed target simulator, the response of a real human target performing a hand gesture is emulated using the target simulator. The spectrogram of the human hand gesture and the simulator-generated gesture have been compared for performance evaluation. A 5.8-GHz prototype of the proposed target simulator and the obtained experimental results are presented in the paper.**

I. Introduction

With the miniaturization of radio frequency integrated circuit (RFIC) technology and the allotment of the electromagnetic spectrum for civilian applications, low-cost, energy-efficient, and small form factor radar sensors have become ubiquitous in day-to-day assisted living and human-machine interaction [1], [2]. Radars are increasingly used for human presence sensing, non-contact vital sign measurement, activity recognition, to mention a few. Compared to wearable sensors and camera-based sensing, radars eliminate the drawbacks of the discomfort caused by continuously sporting the wearable device and privacy infringement, respectively.

Doppler radars are more sensitive to target motion than frequency-modulated continuous-wave (FMCW) radars. Doppler radars rely on the principle of Doppler effect to measure the motion parameters of the target like velocity and displacement. The effectiveness of Doppler radars to recognize/classify human gestures and activities has been demonstrated in [3]-[5]. By analyzing the micro-Doppler signature, unique features can be extracted to train machine learning algorithms to identify various gestures. For the large-scale deployment of these sensors in the smart living sector, extensive testing covering many real-time scenarios is required. In [4] and [5], the training data was limited to two human subjects. It can become burdensome to gather a higher number of human subjects to generate an extensive training data set. This creates the need for a radar target simulator focusing on emulating micro-Doppler responses. However, the existing radar target simulators in the market are tailored for automotive FMCW radar applications.

In this paper, the feasibility of a portable target simulator for Doppler radars, emulating micro-Doppler responses, is studied. A simple single-sideband (SSB) mixer generated micro-Doppler signatures identical to a human gesture. Experiments were conducted to verify the capability of the proposed target simulator to reciprocate the Doppler response of a real hand gesture motion.

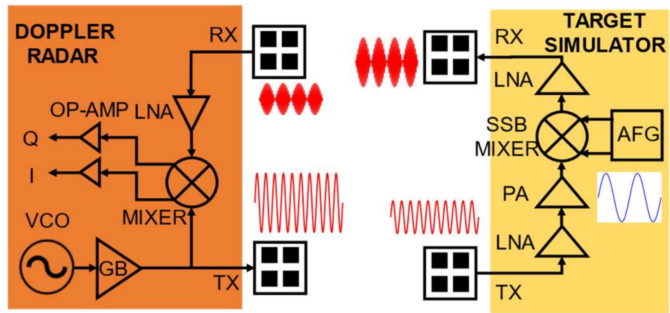

Fig. 1. Block diagram and illustration of the proposed target simulator for a Doppler radar.

II. Theory

A. Doppler Radar

A Doppler radar transmits a continuous-wave (CW) signal and receives an echo modulated by the target motion. The baseband signal generated upon demodulation preserves the information of the target motion. Fig. 1 shows the block diagram of a conventional Doppler radar. The generated in-phase ($I(t)$) and quadrature ($Q(t)$) baseband data from a quadrature direct conversion receiver can be modeled as $I(t) = A_I(t)cos(4\pi x(t)/\lambda + \varphi) + DC_I(t)$ and $Q(t) = A_Q(t)sin(4\pi x(t)/\lambda + \varphi) + DC_Q(t)$, where $DC_I(t)$ and $DC_Q(t)$ are the DC offset voltages, $A_I(t)$ and $A_Q(t)$ are the signal amplitudes, $x(t)$ represents the target motion, λ is the wavelength of the CW signal, and φ is the total residual phase. For small-amplitude motion sensing, such as vital sign detection, DC offset calibration, and amplitude/phase mismatch correction techniques are applied to extract x(t) accurately. However, in the case of gesture recognition, the short-time Fourier transform (STFT) is performed on the complex baseband signal ($I(t) + jQ(t)$) to analyze the variation of the target motion-induced Doppler frequency with time.

B. Radar Target Simulator

By having prior knowledge of the hand gesture motion (or using the demodulated baseband response of a real hand gesture), the CW signal transmitted by the Doppler radar can be electronically modulated using a single-sideband mixer. A signal resembling the hand gesture motion can be fed to the intermediate frequency (IF) ports of the mixer, thereby modulating the CW signal with the hand gesture motion. Fig. 1

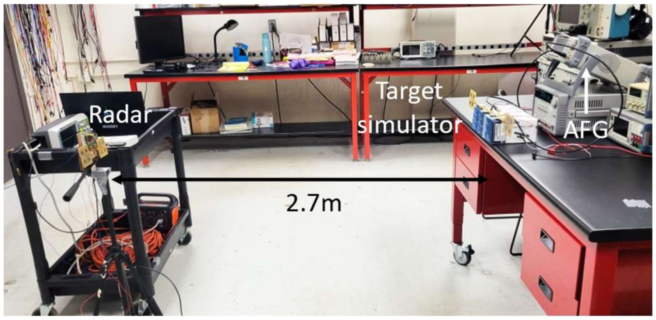

Fig. 2. Experiment setup to evaluate the performance of the proposed radar target simulator.

shows the block diagram of the proposed radar target simulator.

III. Experiments

A 5.8-GHz benchtop prototype of the radar target simulator was built for experimental validation. Two pre-amplification stages consisting of a low-noise amplifier (PE15A1010) and a power amplifier (HMC407MS8GE) were used to amplify the incoming CW signal to meet the 15 dBm local oscillator (LO) drive requirement of the mixer (HMC525ALC4). An additional LNA (HMC392ALC4) was connected to the mixer's radio frequency (RF) port for further amplification. The modulation signal to the IF ports was provided using a TELEDYNE T3AFG120 arbitrary function generator (AFG). An in-house designed Doppler radar operating at 5.8 GHz and transmitting a power of 15 dBm was used in the experiments. The in-built function generator in the RIGOL DS1104Z-S oscilloscope was used to provide the control signal to the voltage-controlled oscillator (VCO) on the radar. The baseband data was sampled using a NI USB-6210 DAQ and saved to the computer using a LabVIEW program.

The radar and the target simulator were placed 2.7 m apart. This distance was chosen based on the transmitting power of the radar, the free-space path loss at 5.8 GHz, and the P1dB requirement of the LNA used in the pre-amplification stage of the target simulator. Initially, the *I/Q* baseband data of a human subject performing a hand gesture was recorded. The human subject lowered his forearm towards the radar, with the elbow remaining stationary. Fig. 3(a) shows the STFT of the hand gesture motion, calculated using the spectrogram function in MATLAB. To verify the ability of the target simulator to emulate a hand gesture motion, the recorded I/Q response was then fed to the IF ports of the SSB mixer. The SSB mixer was configured to output the upper sideband (USB) tone. Fig. 3(b) shows the STFT of the simulated gesture motion, which matches very well with the actual hand gesture response.

In general, each hand gesture has unique characteristics such as duration, stride length, and speed. The parameters mentioned above can be randomized by observing the baseband responses to the same gesture from multiple human subjects, and the target simulator can create unique versions of the same gesture. This, in turn, helps generate an extensive training database, making the machine learning-based classification techniques more effective.

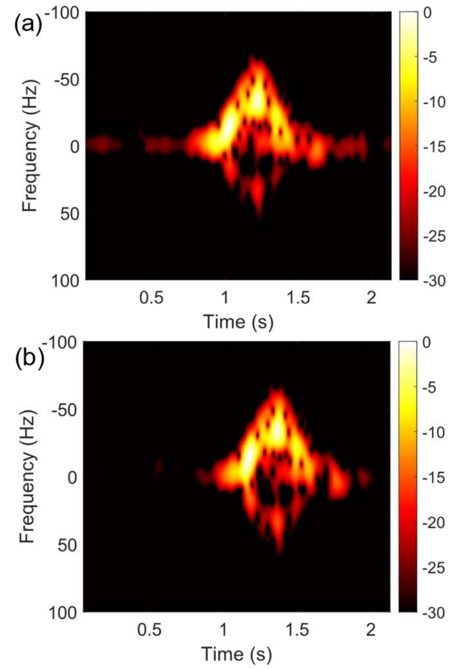

Fig. 3. Spectrogram of the hand gesture (a) performed by a human subject and (b) generated using the proposed radar target simulator.

IV. Conclusion

In this paper, a single-sideband mixer-based portable target simulator for Doppler radars has been proposed. The IF ports of the SSB mixer can be fed with arbitrary motion patterns according to the end-users need. A 5.8-GHz benchtop prototype of the simulator was assembled, and the presented experimental results successfully demonstrated the ability of the target simulator to reciprocate a human hand gesture motion.

Acknowledgment

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References

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