Live Demonstration: Real-time Gesture Recognition Using tinyRadar for Edge Computing

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Hand gesture recognition (HGR) plays a pivotal role in improving human-machine interaction across domains like smart homes/vehicles and wearable devices. While vision-based HGR systems encounter challenges with lighting, complex backgrounds, and occlusion, radar-based systems overcome these limitations by harnessing electromagnetic principles. This demo paper presents tinyRadar, a real-time, low-power, single-chip radar solution for HGR. By leveraging miniaturized mmWave radar hardware, tinyRadar offers a compact and cost-effective HGR solution. The Texas Instruments IWRL6432 radar is utilized, achieving a total power consumption of less than 80mW and a memory footprint of 11 KB for the quantized inference model and < 256 KB for the entire system. The solution utilizes quantized depthwise separable convolutions and integrates a hardware accelerator and Cortex®-M4 microcontroller for real-time inference. With its small form factor and low power requirements, tinyRadar facilitates on-edge implementation, delivering 95% real-time inference accuracy for four gestures. This paper contributes to developing wearable gadgets and IoT devices that seamlessly incorporate HGR technology.

Additional Key Words and Phrases: hand gesture recognition, IWRL6432 single-chip mmWave radar, depthwise separable convolution, edge computing, low power

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1 INTRODUCTION

Our demonstration setup showcases the capabilities of tinyRadar [S. S. Yadav and Thakur 2022, 2023], which consists of the Texas Instruments IWRL6432 board [Texas Instruments 2023] connected to a PC via the UART interface, as shown in Figure 1. The primary objective of this setup is to demonstrate real-time hand gesture recognition (HGR) using the tinyRadar device. This device is specifically designed to classify four different hand gestures that are performed in front of it. During the demonstration, the user engages with the system by executing hand gestures within the device's detection range. The tinyRadar device processes the received radar signals using sophisticated algorithms, including range, doppler, and direction of arrival (DoA) processing techniques implemented onboard. These processes generate feature maps that are subsequently fed into an onboard quantized depth-wise separable engine, enabling real-time classification of the performed gestures. The classification result is then transmitted from the tinyRadar device to the connected PC via the UART interface. On the PC, a Python script is executed to interpret the received gesture class on a Graphical User Interface (GUI).

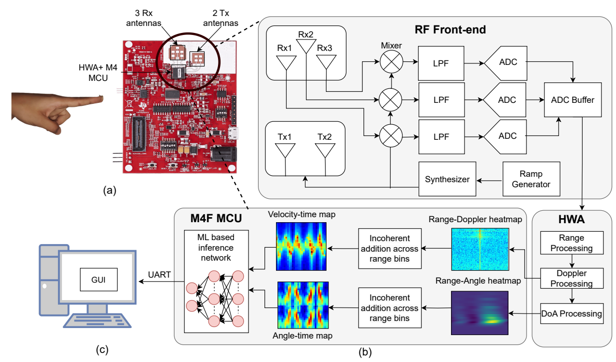

Fig. 1. Block diagram of the HGR system setup using tinyRadar: (a) Hand gesture performed by the user in front of the IWRL6432 radar board. The radar board includes the RF front-end with two transmit, and three receive antennas, along with the HWA and Cortex®-M4 for edge computing. (b) Real-time recognition is achieved through the onboard signal processing and classification pipeline. (c) A Python script reads the UART classified and displays it on the GUI.

2 SYSTEM DESCRIPTION

Figure 1 illustrates the operation of the tinyRadar system. It utilizes a frequency-modulated continuous wave (FMCW) technique, generating chirp signals through a ramp generator. These chirps are transmitted via two TX antennas and reflected by the user's hand during hand gesture performance. The reflected signals are received by three RX antennas. The radar system operates in time division multiplexing multiple input multiple output (TDM-MIMO) mode, with sequential transmission from each TX antenna. Upon reception, the signals are down-converted to an intermediate frequency (IF), digitized, and temporarily stored in a buffer. Subsequently, a series of signal processing steps are performed in the hardware accelerator (HWA). These steps encompass range, velocity, and angle processing, leading to the generation of velocity-time (VT) and angle-time (AT) maps. These maps serve as input for the quantized depthwise separable convolution network, deployed on the Cortex®-M4 microcontroller, enabling real-time inference. The VT and AT maps are acquired directly on the radar board during data collection, network training, and inference stages. They encompass four distinct

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hand gestures: slow swipe, wave, push, and circle, as seen from Figure 2. To optimize the network's efficiency, the classification engine was trained using the Tensorflow-Lite framework [Google Inc. 2017] with quantize aware training, quantizing the network to 8-bit precision.

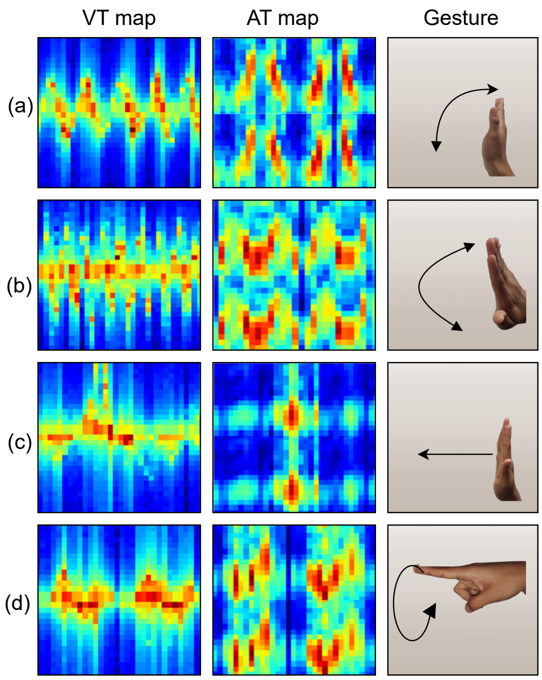

Fig. 2. VT and AT maps corresponding to each gesture: (a) Slow swipe (b) Wave (c) Push (d) Circle.

3 RESULTS

tinyRadar is a low-power, real-time, on-edge single-chip radar solution for HGR based on the Texas Instruments IWRL6432 radar. Our solution achieves a total power consumption (including the sensor and model) of less than 80mW at 160 MHz and has a compact memory footprint of 11 KB for the quantized model and less than 256 KB for the entire system. Through leave-one-out cross-validation (LOOCV), we achieve real-time inference accuracy of 95% for four different gestures trained on a dataset collected from 9 users. Our solution leverages quantized depthwise separable convolutions to achieve a compact model size while harnessing the capabilities of the HWA and Cortex®-M4 microcontroller integrated with the radar board. This integration enables the simultaneous execution of sensing and processing functions, facilitating the implementation of complex algorithmic flows in real time while operating at low power. To see our solution in action, please visit the following link: tinyRadar HGR Demo Video.

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