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High-Resolution Range Profile Target Recognition with Neuromorphic ADCs and Spiking Neural Networks

Sanjaya Herath[1,2], Matthew R. Ziemann[1,3], Kevin Wagner[2], Christopher A. Metzler[1]

[1] University of Maryland, College Park, MD

[2] Naval Research Laboratory, Washington, DC

[3] DEVCOM Army Research Laboratory, Adelphi, MD

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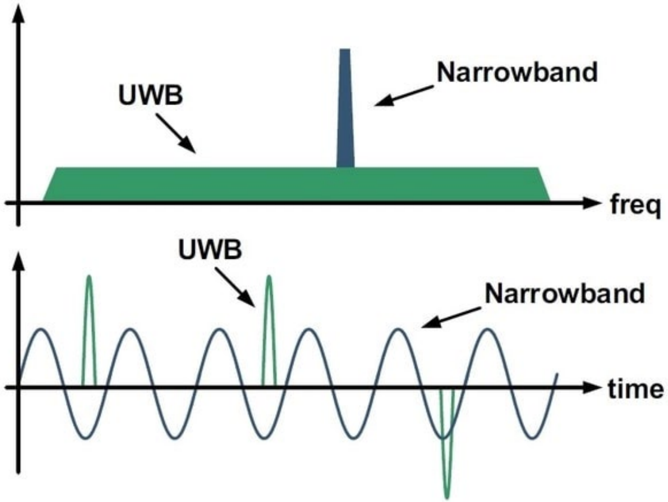
Introduction: Ultra-Wideband (UWB) Radar

leverages a wide frequency range to exceed conventional radar limits for precise detection and imaging



Key applications:

- **Aerospace & Defense:** Enhanced surveillance and guidance
- **Automotive:** Advanced safety and navigation systems
- **Healthcare:** Non-invasive diagnostics
- **Telecommunications:** Infrastructure integrity monitoring

Integration with AI and ML for smarter, autonomous decision-making systems

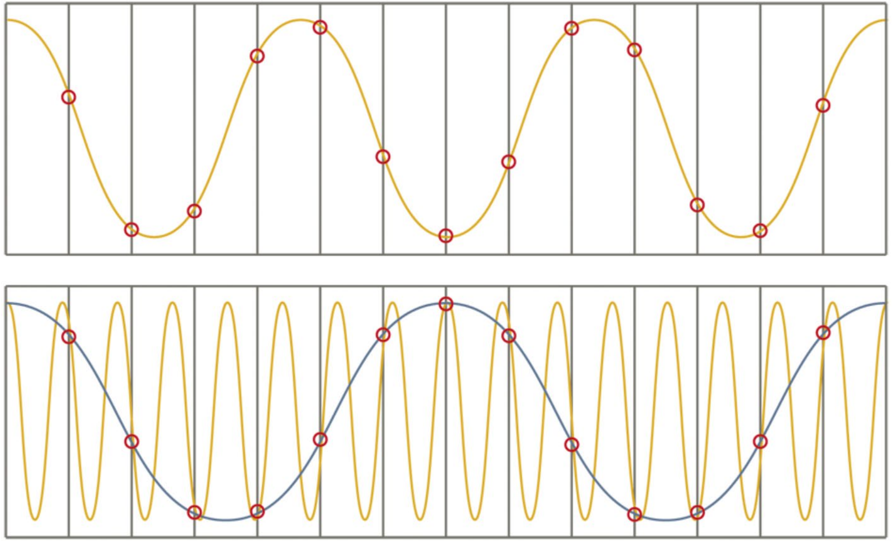
https://how2electronics.com/getting-started-with-esp32-dw1000-uwb-ultra-wideband-module/

Introduction: Challenges with UWB Radar

UWB radar systems demand high sampling rates (~Gsps)

Conventional Analog-to-Digital Converters (ADCs) face difficulties in meeting these high-rate demands

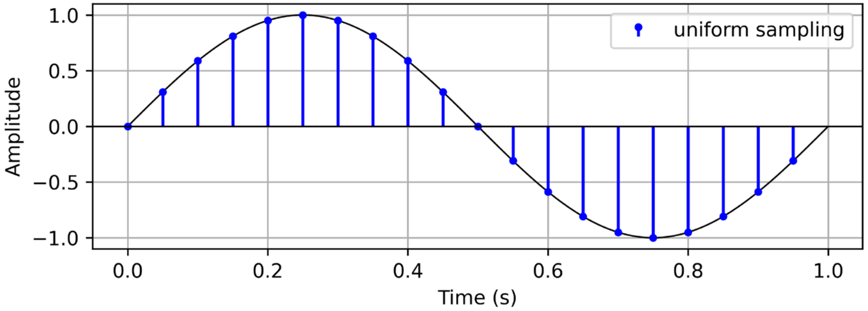
Sampled below Nyquist levels, which leads to reconstruction errors

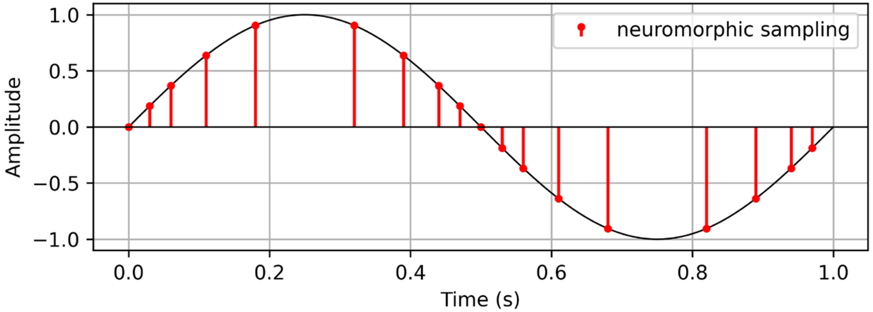


Can we sample below Nyquist levels while achieving perfect reconstructions at the same time?

https://www.fieldingdsp.com/alias

Introduction: Neuromorphic ADC





Capture data only during significant signal changes

Offer the potential for higher sampling rates compared to traditional ADCs

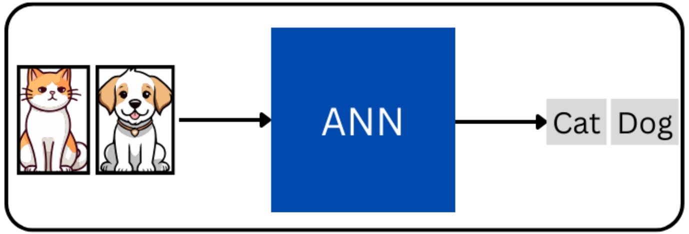
Current radar processing algorithms are primarily designed for synchronous data

They struggle with handling asynchronous samples from neuromorphic ADCs

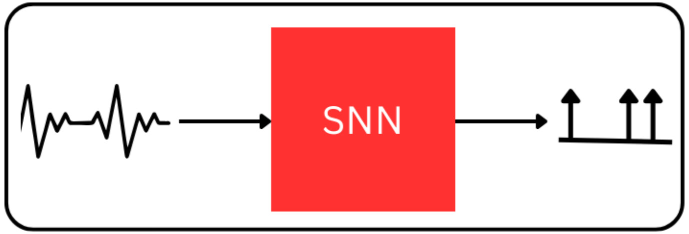
This limitation hinders their effectiveness in processing data from neuromorphic ADCs

Introduction: Spiking Neural Networks (SNNs)

SNNs handle asynchronous data by precisely timing spikes to integrate temporal dynamics



Synchronous data



Asynchronous data

Generate spikes when the accumulated input surpasses a set threshold

Align with the asynchronous data output of neuromorphic ADCs

Perfect for real-time processing of asynchronous data

Contributions

Integrate neuromorphic ADCs with a lightweight SNN architecture to enable efficient radar signal processing

Validate through simulated Radar High-Resolution Range Profile (HRRP) based target classification

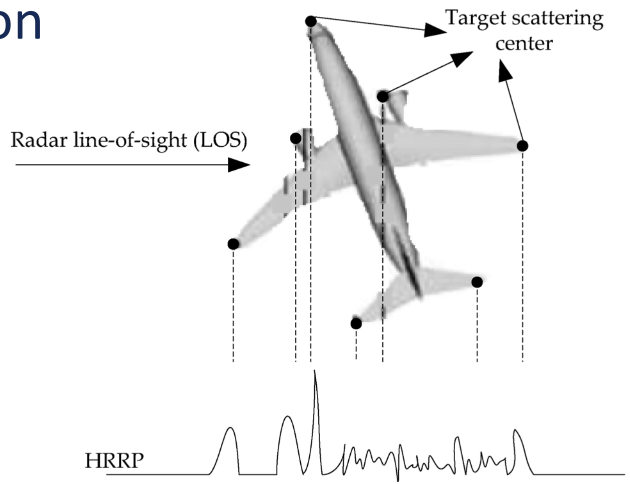
Demonstrate a sampling rate reduction of over 95% compared to conventional methods

Method: Data generation

HRRPs provide a detailed snapshot of target scatterer distribution along the range dimension

Captures amplitude, phase, and range information of target scatterers

Used in radar systems for target identification, tracking, and discrimination in various environments



https://www.mdpi.com/1424-8220/18/1/173

Method: Data generation

Generated range profiles of three distinct airplanes

Uniformly distributed scatterers along the airplane's length

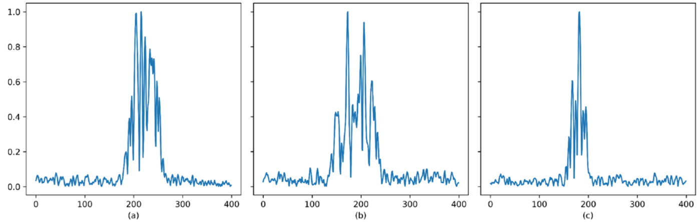
Wavelength distance between adjacent scatterers

Varied the scatterers' range, amplitude, and phase

AN-26
(23.8 m)

Yak-42
(36.4 m)

Citation S/II
(14.4m)



https://en.wikipedia.org/wiki/Antonov_An-26, https://en.wikipedia.org/wiki/Yakovlev_Yak-42, https://en.wikipedia.org/wiki/Cessna_Citation_II

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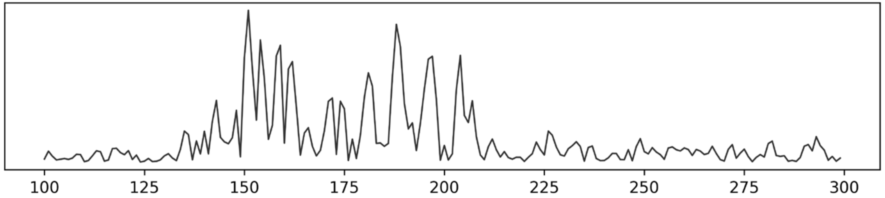
Method: Level Crossing Sampling

Sample when the signal crosses one of the predefined threshold levels along with the time it crosses

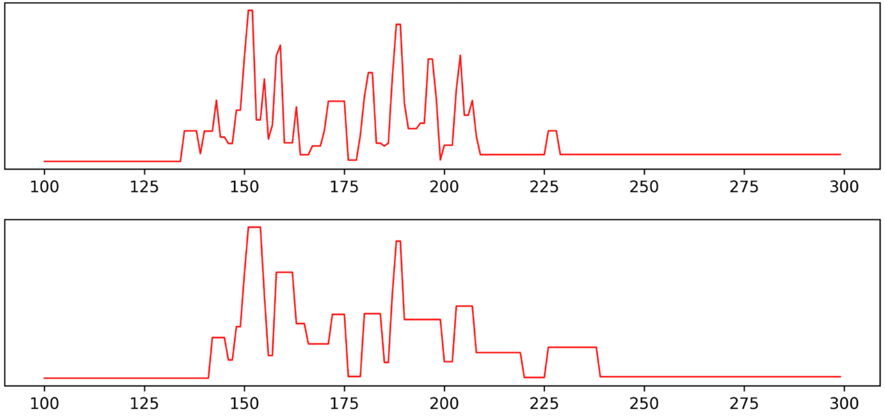


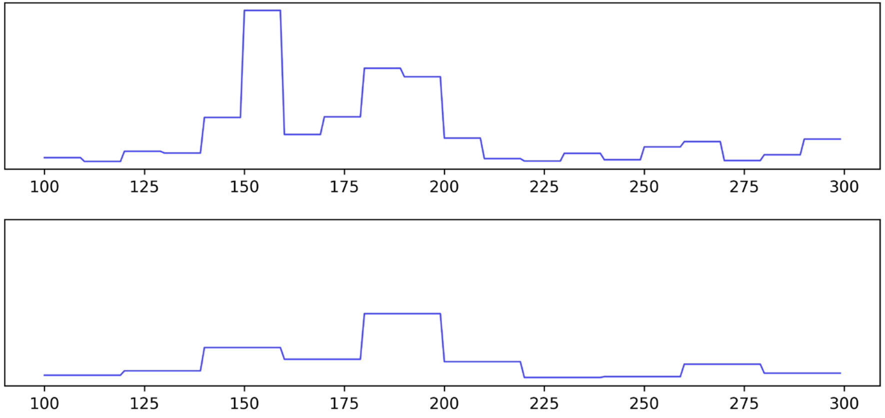
Level Crossing Reconstruction

Uniform Sampling Reconstruction

10%

5%





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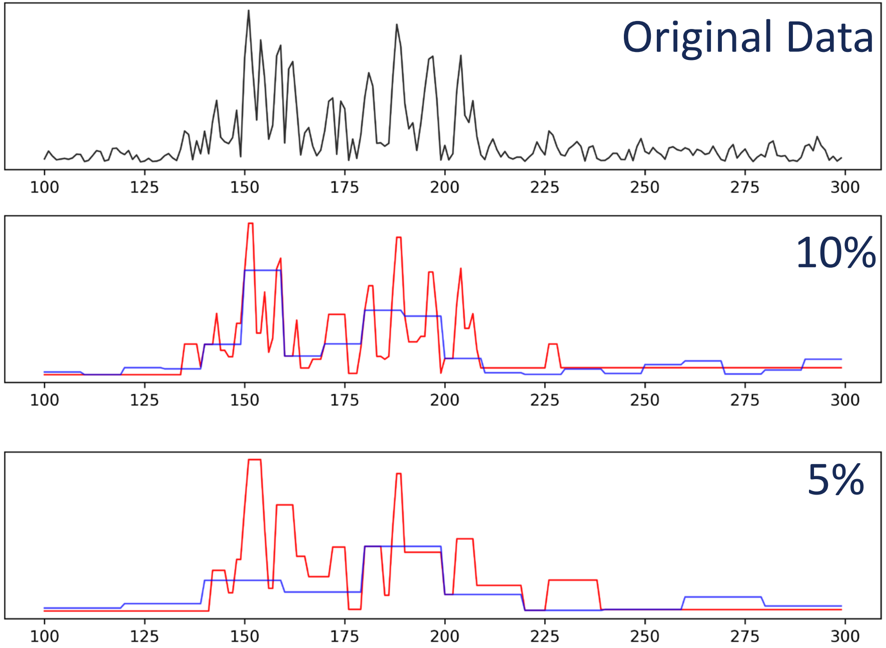
Method: Level Crossing Sampling



Level crossing (LC) sampling retains key features of the original signal with a 20x reduction in sampling rate

Uniformly downsampled (DS) data fails to capture key components with a 10x reduction

Takeaway: level-crossing ADC effectively compresses data while preserving signal integrity

Method: Neural Network Models

Tested 3 models:

- Baseline-CNN: Convolutional Neural Network (CNN) trained on the original HRRP data
- LC-SNN: SNN trained on HRRP data captured by a level-crossing ADC
- DS-CNN: CNN trained on uniformly downsampled HRRP data

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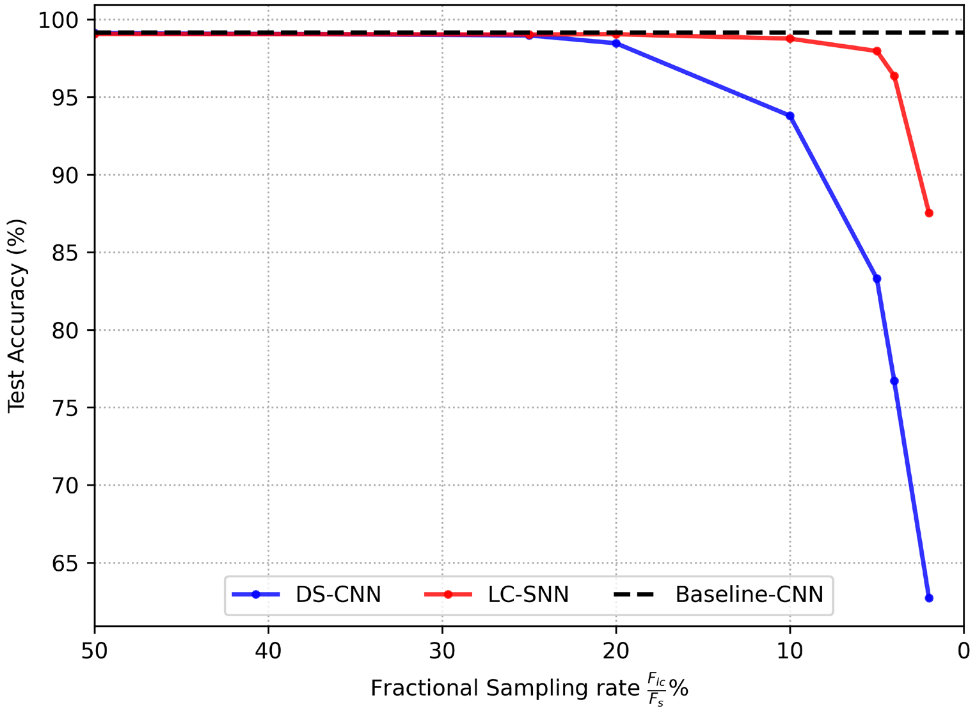
Experimental Results



LC-SNN performance matches the baseline at low fractional sampling rates (down to 5%)

The DS-CNN model performance degrades much faster than the LC-SNN model

Takeaway: The level-crossing ADC coupled with an SNN effectively compresses and processes the incoming data stream

Summary

Neuromorphic sampling advances UWB systems by enabling sub-Nyquist rate sampling

SNNs are compatible with the neuromorphic ADCs' asynchronous output

The proposed method integrates SNNs with neuromorphic ADCs for edge radar signal processing

Retains the accuracy of conventional methods while reducing the sampling rate by over 95%