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YOU-ONLY-LOOK-ONCE (YOLO) FOR RADIO FREQUENCY SIGNAL CLASSIFICATION

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Changing the World's Energy Future

Randall D Reese, Anna Thu Quach

Idaho National Laboratory

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Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

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Anna T. Quach, Randall D. Reese
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Introduction

We propose a method that uses deep learning (DL) to identify and frame various signals that are present in an environment. This DL framework is based on the *You Only Look Once* (YOLO) object detection pipeline [2, 4, 5]. Our work demonstrates a specific application of high performance computing and computer vision to the field of telecommunications.

Objectives

Existing efforts for radio-frequency (RF) signal classification focus on whole image classification and are multi-class, not multi-label, machine learning approaches. Within a defined bandwidth, we identify pre-determined signals of interest in near-real-time using a computer vision approach. Our approach:

- Allows for specific signal identification by means of bounding boxes within a given sampled image.
- Handles the presence of arbitrarily many classes within an image.

While YOLO is an established DL object detection method, our application of the method to signal classification is a unique use.

Computational Tools

Data collection was conducted using the following tools:

- Signal acquisition and analysis was performed with the Signal Hound SM200C, a high-performance spectrum analyzer and monitoring receiver with a frequency range of 100 kHz to 20 GHz.
- A Dell Precision 7770 laptop with a 12th Generation Intel Core i9-12950HX processor and a NVIDIA RTX A4500 graphics card was used for local computation and data collection.
- The WiFIRE software from Idaho National Laboratory [3] was used for signal visualization and analysis.
- Data labeling was via Yolo Mark [1].

Implementation of YOLO is in Python using PyTorch. Model training was performed on the Hoodoo cluster of Idaho National Laboratory's High Performance Computing Center (INL HPC).

- Hoodoo is a Lambda Hyperplane deep learning distributed memory system with 44 NVIDIA A100 Tensor Core GPUs
- 7.2 TB of total memory dedicated to machine learning applications.
- Hoodoo provides a maximum GPU performance of 429 teraflops double precision or 858 teraflops single precision.

Data Collection

Raw data is collected first as IQ values. Using fast Fourier transforms, the raw IQ data is converted into estimated power spectral density (PSD) plots, sometimes called waterfall plots. Relevant signals in these waterfall plots are marked with bounding boxes using Yolo Mark. These marked images act as the input to the YOLO models.

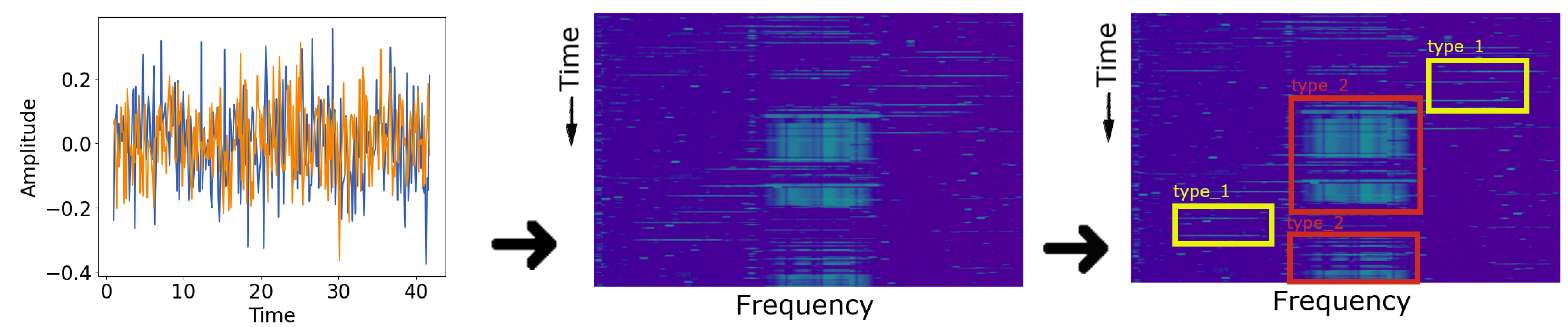
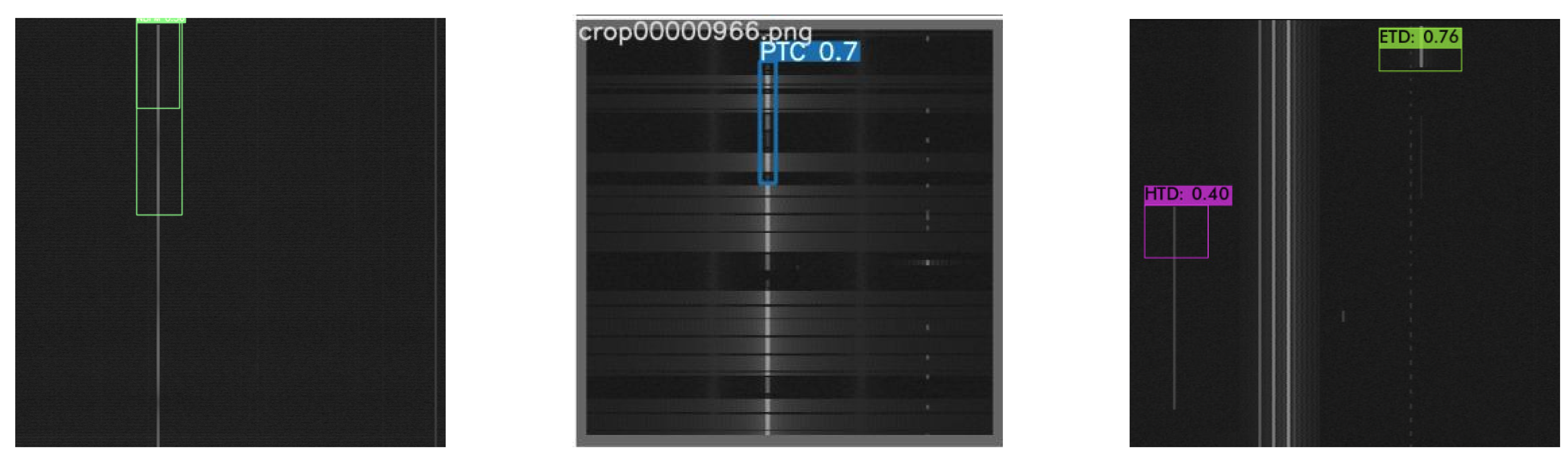


Figure 1: Data is collected as IQ values, transformed to a PSD waterfall image, then labeled with Yolo Mark.

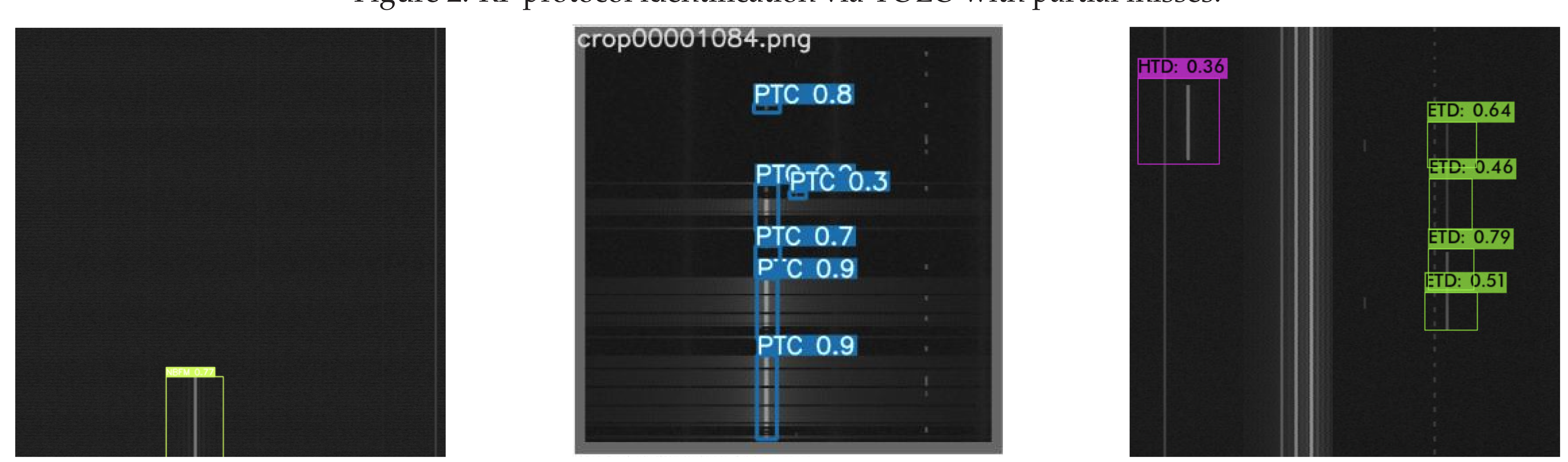
Graphical Results

Figures 2 and 3 depict a sample of the results for each protocol examined. Each sample image was taken as a grayscale image. Bounding boxes and the confidence scores are marked and the test inference threshold was set to 0.3 for NBFM and PTC. For HTD/ETD, a test threshold of 0.2 was used. The respective F_1 scores of the NBFM, PTC, and HTD/ETD models are 0.938, 0.906, and 0.861.



(a) NBFM **(b)** PTC **(c)** HTD/ETD

Figure 2: RF protocol identification via YOLO with partial misses.



(a) NBFM **(b)** PTC **(c)** HTD/ETD

Figure 3: RF protocol identification via YOLO with full identification.

Benefits of YOLO

YOLO is currently the leading object detection model. The benefits to using YOLO are:

- Handle images with multiple classes present
- Computational speed due to only looking once
- High accuracy in detecting objects
- Existing and optimized implementation in Python

Discussion

Improvements to the model could likely be achieved by:

- Adjusting the predefined anchor boxes to have thinner width. This would allow us to better capture the typically long and thin signal shapes for these protocols.
- Collecting image data that is RGB instead of gray scale could allow for full use of the input channels of the YOLO convolutional structure.

Ongoing Research

- Expanding model base to capture a larger set of RF protocols
- Better anchor box selection
- Emitter localization & device fingerprinting may also be pursued

References

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[4] Joseph Redmon, Santosh Divvala, Ross Girshick, and Ali Farhadi. 2016. You only look once: Unified, real-time object detection. In *Proceedings of the IEEE conference on computer vision and pattern recognition*. IEEE, 779–788.

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