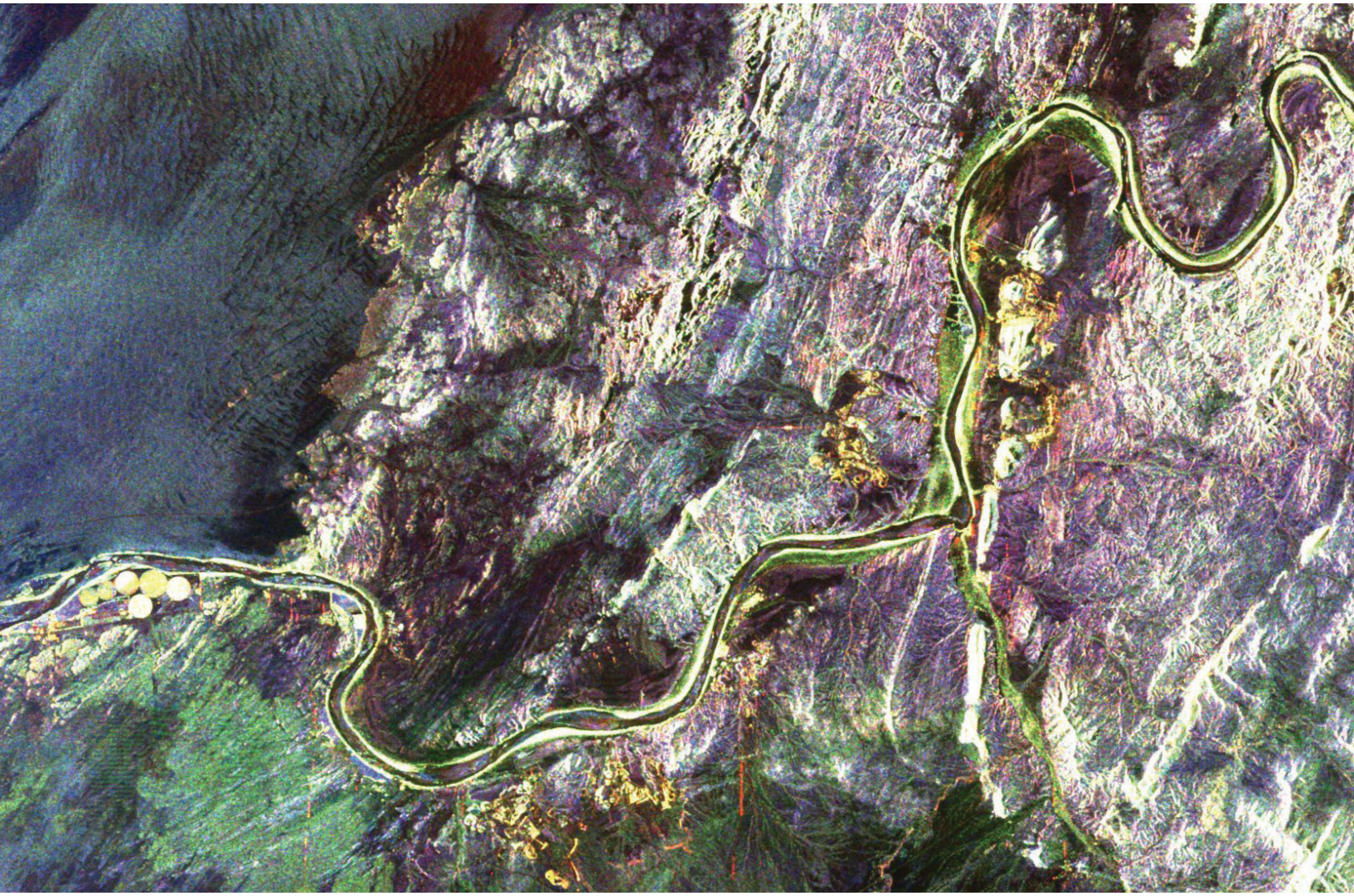
Artificial Intelligence in Radio Frequency Communications Systems



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ABSTRACT

As modern communications systems increase in both quantity and complexity, the need for sophisticated, intelligent algorithms in the signal characterization space concurrently rises. Designing and optimizing application-specific artificial intelligence (Ai) networks for use on time domain data can increase detection sensitivity and identification speed while minimizing inherent latency in conventional digital signal processing (DSP) techniques. Applied Ai can eliminate the need for common data preprocessing techniques and make decisions on raw digitized data. From electronic warfare (EW) to spectrum management, Huntington Ingalls Industries (HII) is solving complex problems associated with signal characterization, bringing applied Ai to the edge and changing the way communications systems operate.

I. INTRODUCTION

The proliferation of modern communications technology across the globe and advancements in the Ai domain provide the means to acquire large amounts of pertinent data and extract useful information in ways previously regarded as infeasible. One field of specific interest to applied Ai is the classification and characterization of signals in the radio frequency (RF) spectrum.

As modern communications schemes become more complex — both spatially and temporally — advanced algorithms are needed to optimize utilization of the signal space. From detection and classification for EW systems to dynamic spectrum allocation (DSA) management, embedded Ai will change the way systems process RF signal data and enhance overall system performance.

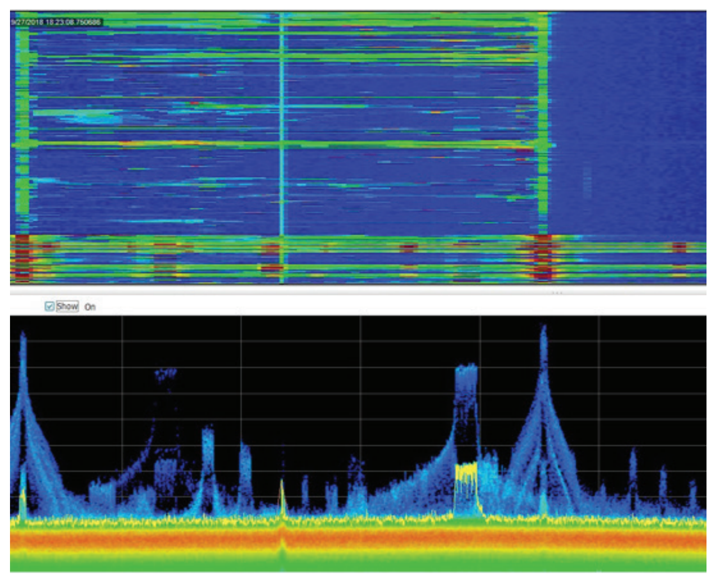


FIGURE 1: *(Top) RF spectrum waterfall; example of temporal complexity (Bottom) Instantaneous RF spectrum snapshot; example of spatial complexity*

II. PROBLEM OVERVIEW

The RF spectrum is evolving into a highly congested and contested environment, increasing the potential for instances of electromagnetic interference (EMI) in all RF systems. Compounding the problem, the advent of high-speed data converter hardware provides the capability to acquire data at much wider instantaneous bandwidths (IBW), inherently incorporating potential interference to the desired signal. The combination of excessive spectrum occupancy and advancements in signal acquisition hardware make for a complex arena that require sophisticated algorithms to optimize performance.

In recent years, modern DSP techniques have been optimized for real-time performance in low-latency systems. These techniques, although powerful, come with inherent limitations both in time and frequency domains.

For example, to optimize detection of a low-level interference signal, an averaging Fast Fourier Transform (FFT) technique implemented on digitized in-phase/quadrature (I/Q) data can optimize performance for degraded signal-to-noise (SNR) environments. Relatively simple to implement in modern digital hardware, this technique requires a fixed amount of processing time before detection decisions can be made. In practice, the processing time limitations could prove problematic for a system operating in a spectrum similar to the one shown in Figure 1.

The aforementioned spectrum is a simple example captured at a span of 40MHz. In some cases, modern systems will be required to perform the same operations with an instantaneous frequency span in excess of 1GHz— 25 times greater.

Significant trade-offs in the system design must be considered, limiting the capabilities of the deployed system when designed for a wide range of applications.

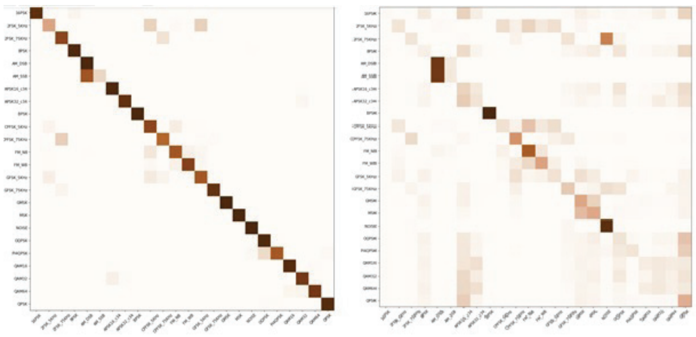


FIGURE 2: *(Left) Confusion matrix for +10dB SNR data. (Right) Confusion matrix for -10dB SNR data*

III. PROPOSED SOLUTION

As use cases push the limits of digital hardware clocking speeds and optimized DSP algorithms, applied Ai becomes an interesting supplement and/or alternative to common techniques in this arena. Current applications in this space include blind signal detection and classification using embedded Ai models on the digitized I/Q data.

In a recent task, HII designed and optimized custom Ai networks to characterize signals embedded in raw I/Q data with SNR values ranging from +10dB to -10dB.

With no data preprocessing, the Ai models ingested the raw data and characterized the signals over 24 possible modulation scheme classifiers. Multiple neural network architectures were tested to determine the optimal solution, including convolutional neural networks (CNN), recurrent neural networks (RNN), and a hybrid recurrent-convolutional network.

As shown in the confusion matrices depicted in Figure 2, complexity increased significantly between the SNR value extremes. Addressing the drastic variations in I/Q data, the custom networks were initially designed in an ensemble configuration, optimizing a network for each SNR level in the provided training data. The optimized Ai networks for positive SNR data classification were highly accurate, where negative SNR data network accuracy was significantly lower.

Most importantly, as depicted in Figure 3, certain networks even seemed to understand features embedded in other SNR data. For example, certain positive SNR networks performed well when presented with test data from different SNR levels. To take advantage of this characteristic, network weight mean was utilized as the softmax output, enhancing overall system performance.

In addition to network optimization, DSP preprocessing techniques were applied to the I/Q data in an attempt to facilitate feature extraction. Results from FFTs, instantaneous phase calculations, and constellation trajectory were all investigated with no enhancement

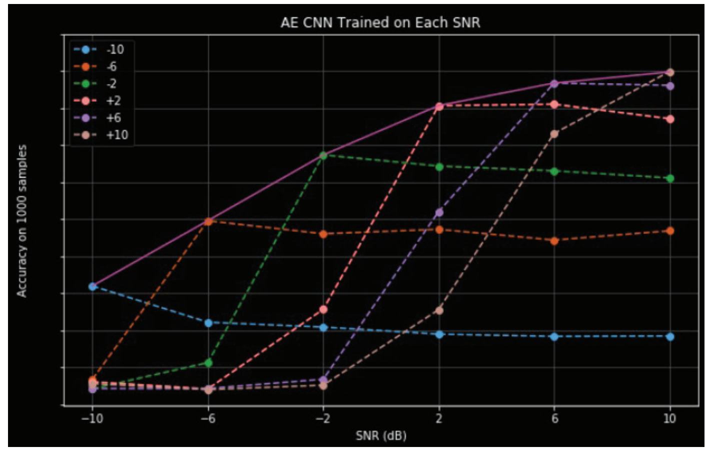


FIGURE 3: *Plot of individual network performance within the ensemble approach. Note: Training data was characterized into 6 different SNR levels.*

to system performance. All network design iterations performed optimally on raw I/Q data.

The purpose of this brief task overview is to show some of the inherent complexities of applied Ai in the RF domain. Whether the focus is detection sensitivity, classification accuracy, or identification speed, each application will require network optimization to maximize system performance.

IV. PATH FORWARD

Practical scenarios of signal characterization are generally more complex than described in the previous exercise. As system IBW increases, raw I/Q data will likely contain more than one signal of interest. With highly congested aggregate spectrum I/Q data, Ai networks will be required to parse through a summation of signals. And, with data presented in the frequency domain, conventional DSP algorithms can effectively isolate signals of interest from interference. This process has an inherent time delay defined by the complexity of the DSP processing chain.

The goal is to leverage applied Ai in the time domain and minimize — or, in certain applications, eliminate — the need for complex DSP processing chains. With networks optimized for hardware deployment, applied Ai will enable accelerated decision-making processes that take a fraction of the time of conventional techniques.

The first step in implementing applied Ai in the signals domain is the generation of a robust data set specific to the application. With an accurate and robust dataset, Ai developers can begin the iterative process of custom network development. Subject matter experts (SMEs) in the field of RF communications systems are essential when building a set of training data that accurately represents the complex spectrum previously described.

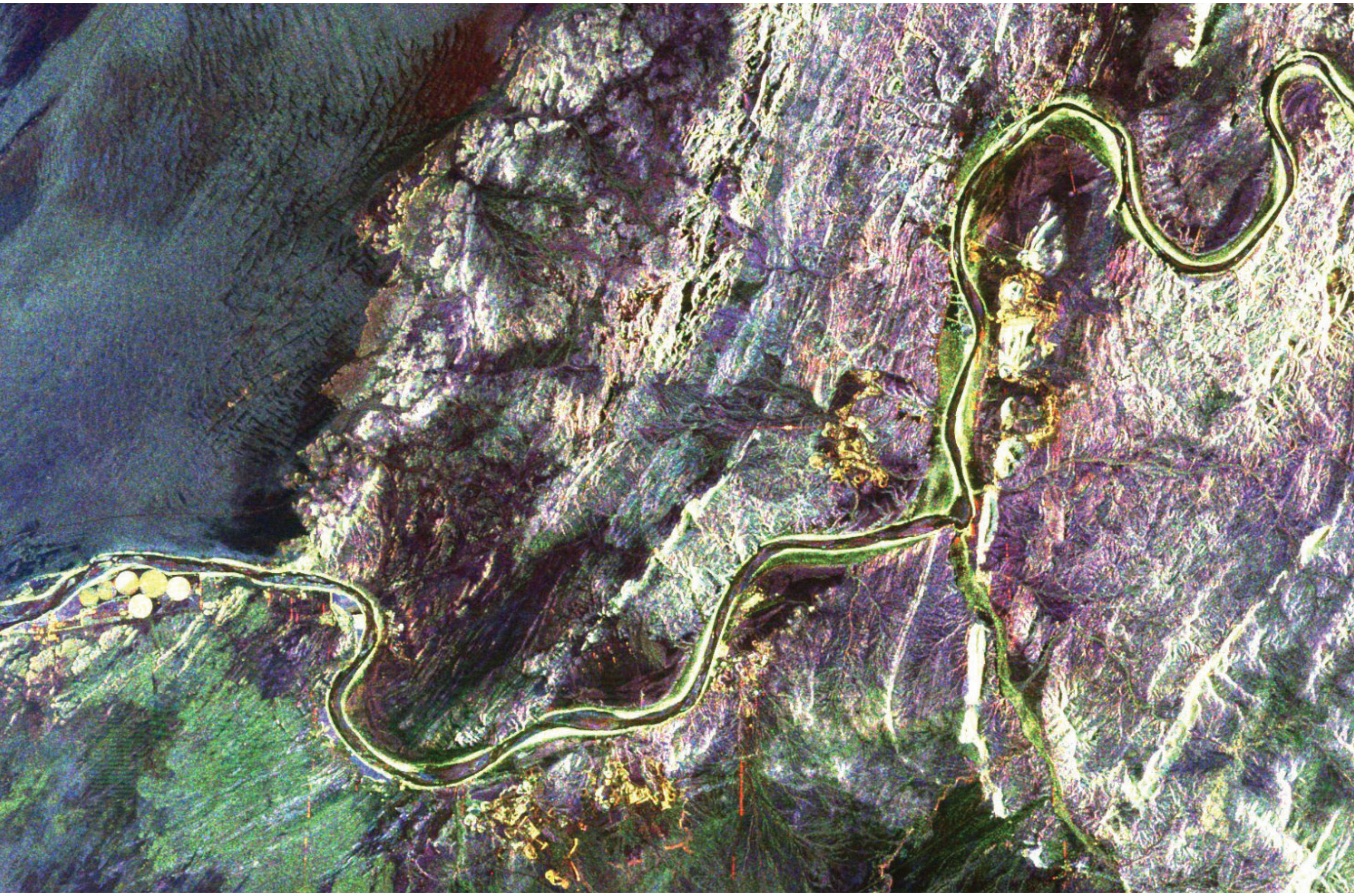
To efficiently develop an Ai solution, SMEs and Ai developers need to work cohesively. Additionally, the gap between Ai developer and hardware deployment must be addressed early in the design cycle. Low latency signals applications tend to have strict limitations on processing time and resource utilization. Certain network configurations, although offering enhanced performance, are not suitable under these stringent constraints. Trade-offs must be made to provide a functional and deployable solution.

For this and other reasons, a comprehensive team of SMEs, developers, and hardware integrators that can translate theory into practice is key to the success of applied Ai in the RF communications systems domain.

V. SUMMARY

Modern communications systems are continually evolving the RF spectrum, creating a more congested and complex environment. Custom, embedded Ai networks will play a critical role in the operation of these systems in the future.

As a leader in the RF spectrum arena, HII helps define realistic scenarios and collect and generate data with sophisticated hardware. We invest in data-set generation for a variety of signals applications, tackling problems from DSA to signals intelligence (SIGINT). With a team of RF engineering SMEs, talented Ai developers, and hands-on hardware designers, we focus on delivering a complete solution that will not only solve, but also identify, critical problems in the space.



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