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Development of AI/ML Algorithms for All-Digital Arrays OC-ALC

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Project Overview

"Development of AI/ML Algorithms for All-Digital Arrays" seeks to explore various emerging techniques in AI/ML applied to the development of cognitive radar systems. Through the utilization of a simulation framework, we implement various models and methods for dynamic resource allocation of an all-digital phased array radar system.

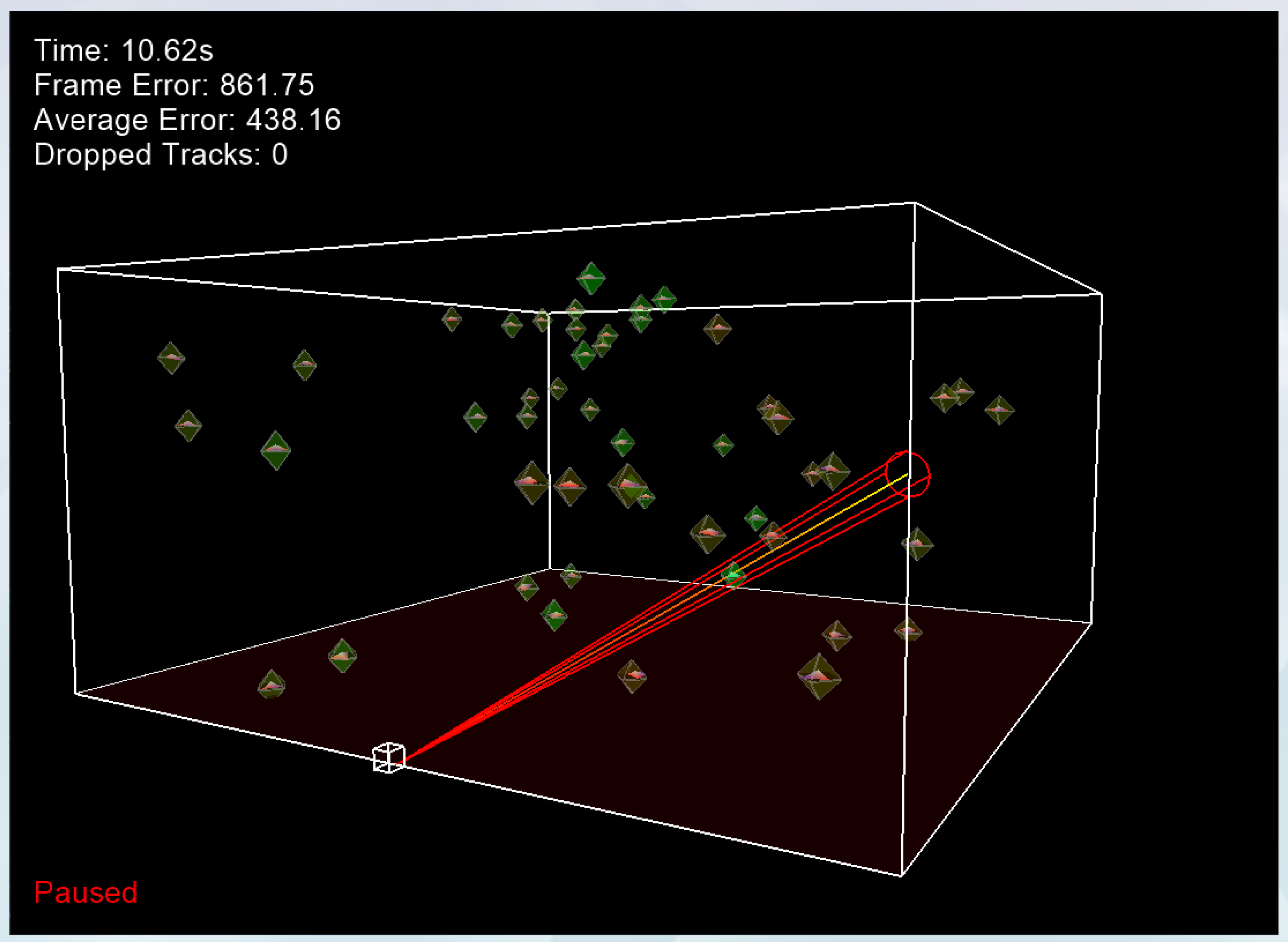

Figure 1: Visualization of the simulated target space and tracking function

Simulation Framework

A simulation framework has been developed to rapidly test various AI/ML techniques using an idealized ground-based digital phased array system. The framework simulates target motion according to predefined movement models that mimic realistic aircraft motion. The target simulation is modular, and it allows different movement models to simulate multiple types of aerial vehicles and their associated flight dynamics.

The radar model is composed of a simulated physical array and a computational tracker. The array can measure a section of space at each time step in the simulation. It can also segment the array in order to transmit multiple beams to measure wider volumes of space closer to the radar. The tracker records the target's position over time and predicts target locations into the future. Performance of each tracking method is characterized by the error on the expected location and the measured location.

Performance Evaluation

Currently, we have implemented various machine learning models to test tracker performance. Of the models and methods tested, the elastic net regression estimator has proven to be the most effective at maintaining numerous target tracks with high precision.

Prior to deployment into the simulation, the elastic net estimator is trained on a simulated target with a predetermined movement profile. After training, we deploy the model to the tracker and iteratively simulate target environments to determine performance.

Figure 2 shows the loss function for implementing the elastic net regression estimator, and Figure 3 shows its performance when compared to our baseline technique. The baseline technique simply points the beam at the last known location of the target and schedules the beams using round-robin scheduling. Given the time resolution of the radar, this simple method provides a useful measure to compare advanced targeting/scheduling techniques. Figure 3 shows that as the number of targets increases, the elastic estimator drastically improves tracking precision when compared to baseline.

$$L_{enet}(\hat{\beta}) = \frac{\sum_{i=1}^{n}(y_i - x_i^T\hat{\beta})^2}{2n} + \lambda\left(\frac{1-\alpha}{2}\sum_{j=1}^{m}\hat{\beta}_j^{\,2} + \alpha\sum_{j=1}^{m}|\hat{\beta}_j|\right)$$

Figure 2: Loss function of the elastic net regression estimator.
Source: K. Ramasubramanian, J. Moolayil, "Applied Supervised Learning with R"

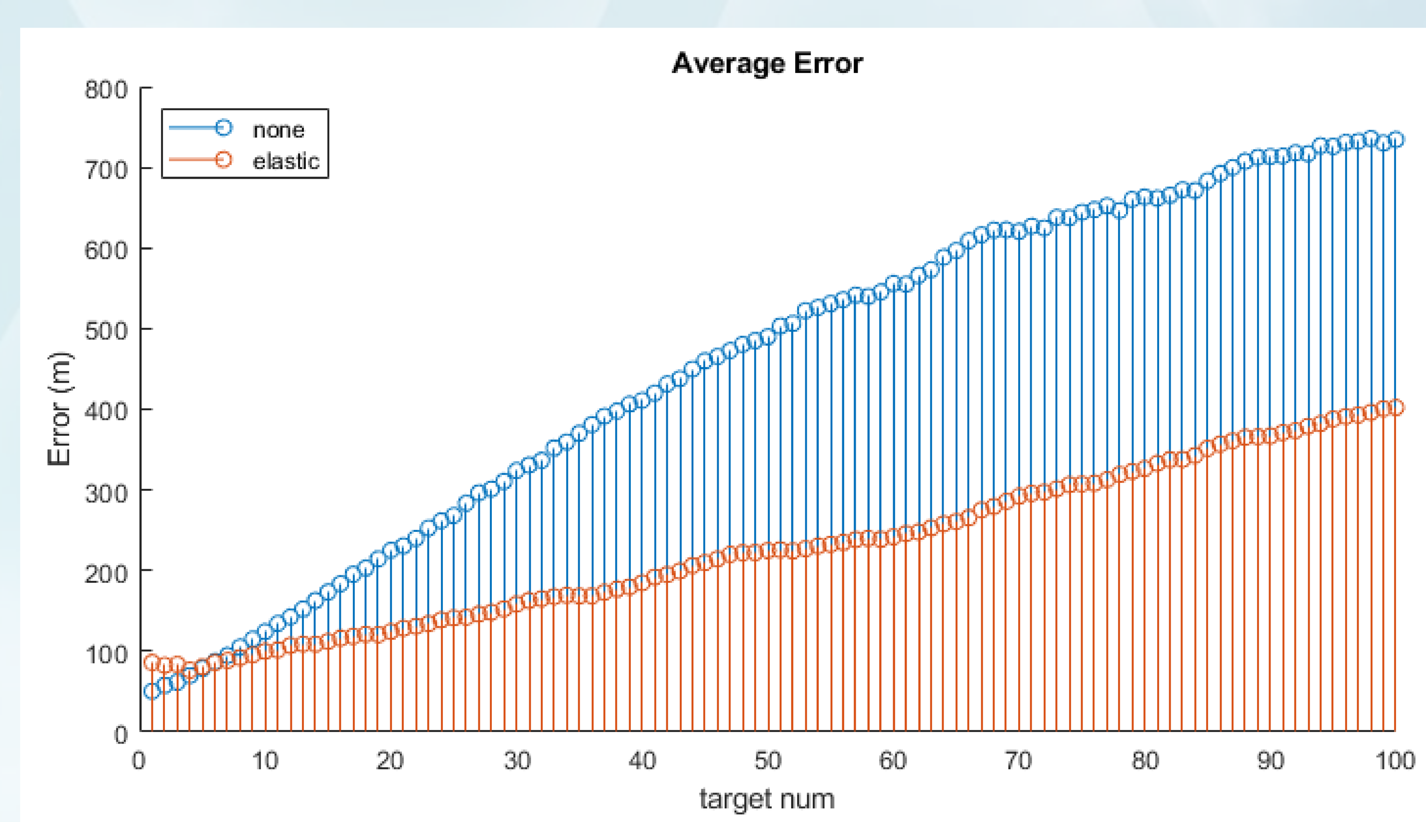

Figure 3: Average error on tracks utilizing ML elastic estimator vs. baseline

Applications to National Defense

Digital phased array radar systems possess characteristics that maximize operational flexibility. Specifically, adaptive beamforming, array segmentation, and dynamic tracking techniques can dramatically increase the efficiency and efficacy of defense radar systems.

Despite the increase in functional capabilities, with additional degrees of freedom comes increased complexity that makes implementation of these advanced techniques difficult to fully leverage and define. Therefore, optimization of a digital array's functional capabilities is critical to maximizing its performance, and the algorithms developed within our simulation framework can prove to be crucial in the current defense technoscape.

For example, consider the ability to dynamically parallelize target tracking and thereby multiply the radar's task efficiency. This may either expand the amount of time the radar can spend on various other tasks, or it can increase the precision with which it continues to track each target in the target space. Active conflicts can be won or lost in the matter of seconds, and therefore any critical time gained could make the difference between mission success or mission failure.

Second, consider the ability to alter system parameters in real time to adapt to any given and/or developing operational environment. The warfighting domain is chaotic and continuously variable. A radar system capable of analyzing the battlespace and actively determining the optimal protocol in any given situation would prove priceless to our national defense.

The Oklahoma City Air Logistics Complex's (OC-ALC) mission is to "Produce Combat-Ready Airpower". Airpower of today is multi-faceted and rapidly evolving. The research of this project fundamentally addresses the emerging challenges of modern airpower and therefore directly aligns with the OC-ALC mission.

In conclusion, it is well known that our adversaries are continuously developing innovative ways to combat our defense systems. In order to maintain command and control of the battlefield, and ultimately achieve air supremacy, modern radar systems must be agile, responsive, and dynamic to meet the challenges and threats of tomorrow.

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