FPGA Powered Infrared Imaging of Hypersonic Missiles

Mason Fruit, Electrical Engineering
Dr. David Allee
School of Electrical, Computer and Energy Engineering

Abstract

This project investigates the applicability of low-altitude hypersonic missile detection using artificial intelligence (AI) implemented on a field-programmable gate array (FPGA). The ability to defend against hypersonic missiles depends on the ability to accurately detect them. Low-power FPGAs are a potential solution to this problem. Research into how well FPGA-based, AI algorithms can detect high-speed missiles is important to the future-proofing of the world's civilian defense systems.

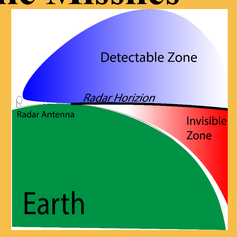
In this project, the AI algorithm was trained using a simulated dataset. It was then implemented on several FPGAs including an ultra low-power FPGA from Lattice Semiconductor.

Lattice low power FPGA

Its performance was measured, and data was collected from each of four different algorithms. This was then compared to the performance required to perform hypersonic missile detection. This setup is designed to evaluate if an AI algorithm can detect hypersonic images fast enough and accurately enough to be viable in a real-world scenario.

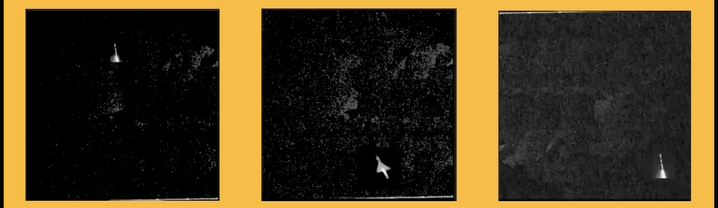
Detection of Hypersonic Missiles

- Missiles travel around 4500 mph
- Aren't easily detectable if they fly below the radar horizon
- Missile at this speed moves through the camera's view in 0.14 seconds
- Typical cameras have a 30° view and a typical radar horizon is 0.5km
- Algorithm must run in < 0.14 s.



Radar horizon non-detectable zone

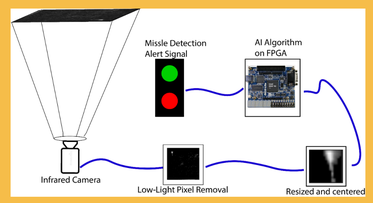
Simulated Dataset and Image Processing



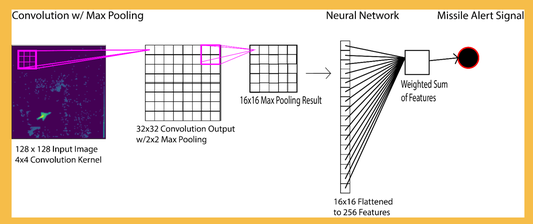
Simulated images for training a model on what a missile is and isn't

The images were passed through a filter to remove pixels that had low light content. After this step, the images were centered and cropped around the brightest pixels. The results were passed as inputs to the AI algorithm to determine if they were missiles (compared to empty or airplanes).They are sized to mimic a 10-meter-long hypersonic missile at an altitude between 0.5 and 1 kilometer.

System Design



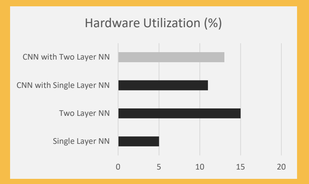
System design including image pre-processing steps



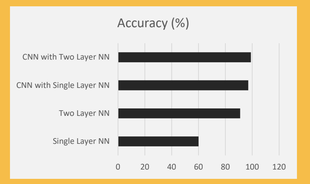
Convolutional neural network AI algorithm implemented on the FPGA

System Variants and Performance

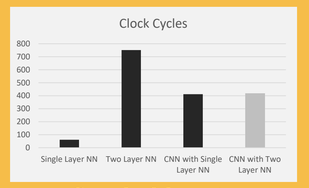
Four different algorithms were created to test their different abilities in detecting a missile. The algorithm models were developed using a high-powered computer. Three of them were then implemented on an FPGA. Although the convolutional neural network (CNN) with a two-layer neural net was not implemented on an FPGA, estimates of its metrics are provided in light grey as a comparison tool. From these metrics it is obvious that a CNN is the optimal choice as it not only greatly improves the accuracy, but it is also able to reduce hardware utilization, decision time, and power consumption.



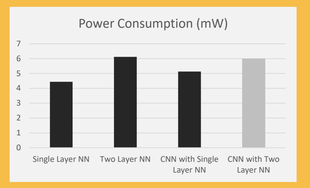
FPGA hardware utilization



Algorithm accuracy score



Speed of detection



Power use by FPGA board (iCE40)

Cost and Deployment

Since the device is inexpensive, it can be deployed in such large numbers that the system is able to cover a large area. When implemented on a low-power FPGA like the Lattice iCE40 used here, the system can be powered by a small solar panel and battery allowing for remote deployment.

Thank you to Dr. Allee for his invaluable insight and time dedicated to the success of this project and to Arizona State University for the opportunity offered and support of the FURI research program students.

FURI

Ira A. Fulton Schools of Engineering
Arizona State University