REAL-TIME FPGA-ACCELERATED VISION FOR AIRBORNE DETECT-AND-AVOID SYSTEMS

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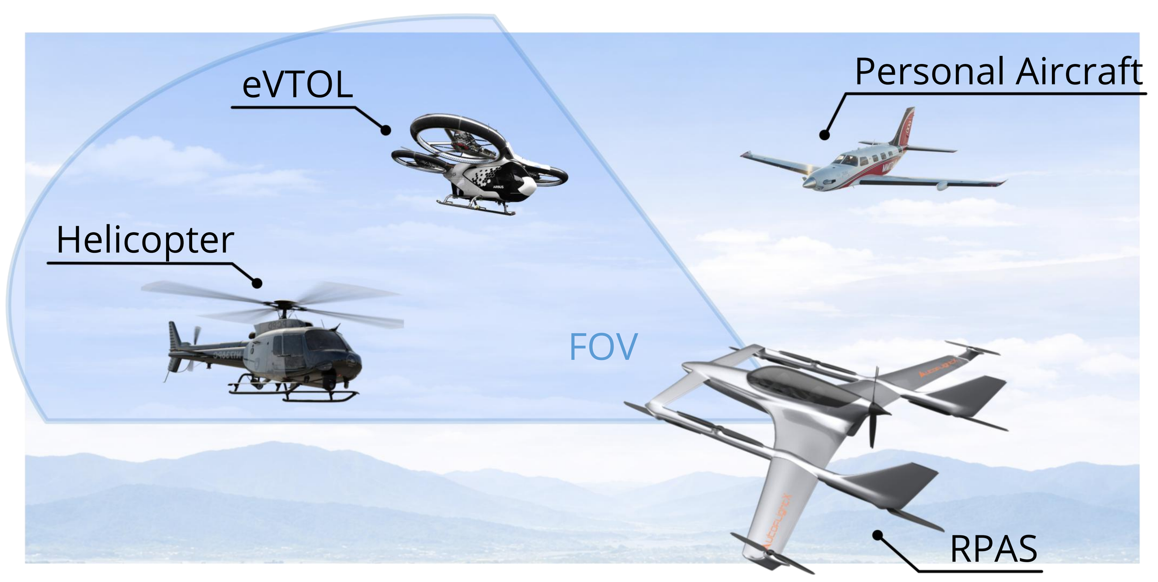
Airspace Congestion on the Rise

As airspace grows increasingly complex and congested, reliable perception becomes critical to maintaining safety. Not every airborne object announces its presence, yet safe integration demands that they be seen.



System Requirements

Integrating Remotely Piloted Aircraft Systems (RPAS) into shared airspace requires a reliable, low-SWaP Detect and Avoid (DAA) system to identify non-cooperative targets [1]. Some requirements are:

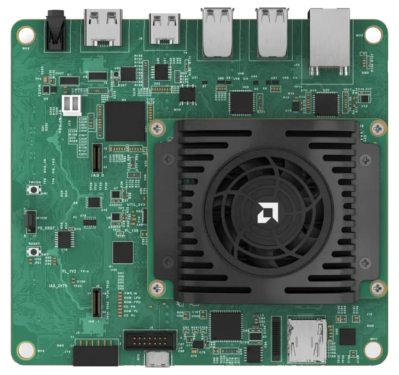
- Operate in **real time** on an embedded airborne platform
- Support continuous **multi-target** detection from streaming video input [2]
- Provide situational awareness through object **localization**
- Maintain performance within strict **size, weight, and power** constraints

Complementary Sensing Modalities

While radar systems provide robust detection of cooperative aircraft, vision-based sensing can supplement awareness of additional airborne targets [2, 3].

Radar	Vision
Long-range tracking	High spatial resolution
All-weather robustness	Detailed object classification
Detects emitters & reflective targets	Broadcast-independent detection

Xilinx Kria KV260



Initial development and prototyping will be conducted on the Xilinx Kria KV260 system-on-module.

- Rapid prototyping of real-time embedded vision acceleration using Vitis AI software [4]
- Evaluate performance, power, and architectural trade-offs prior to system integration

Detection Framework

Real-time camera feed

Flight simulation video input

The module processes continuous video input in real time, offloading intensive computation to dedicated FPGA logic to reduce overhead and improve detection speed [1, 4, 5].

For prototyping, input will be replaced by XPlane flight simulation image and video input.

FPGA

- Image Pre-processing
- Frame Differencing
- Detection Logic

Additional Details:

- Convert to RGB/grayscale
- Downsample to working resolution

- Differencing and cleanup
- Compute bounding box

- Angle/bearing computation
- Object tracking and localization

Sample detection outputs


```
Track ID: 03
Object Class: Airplane
Azimuth: +5.1°
Elevation: -3.0°
Relative Motion: Approaching
Track Duration: 2.4 s
Confidence: 0.88
```

Performance Targets

End-to-End Latency	Image Throughput	Power Consumption*
≤200 ms	**≥30 FPS**	**≤10 W**

Results from this evaluation will enable the development of a deployable vision module for integration with existing radar-based airborne DAA systems.

* Applies to final deployment configuration; FPGA prototype power reported separately.

Path to Deployment

The FPGA-accelerated vision module is designed for integration into an airborne DAA computing platform to complement an existing low-SWaP radar-based sensing system.

Steps to progress from prototype to operational deployment include:

- System validation through flight simulations and controlled flight testing to evaluate reliability, latency, and robustness under realistic operating conditions
- Transition validated prototype to industry partners for further evaluation, refinement, and consideration for integration into operational airborne systems

Development Roadmap and References

- Develop and validate a streaming preprocessing and detection pipeline for FPGA
- Characterize end-to-end latency, throughput, and power performance
- Incorporate learning-based classification to enhance detection

[1] Price, Andrew, et al. "Real time object detection for an unmanned aerial vehicle using an FPGA based vision system." Proceedings 2006 IEEE International Conference on Robotics and Automation, 2006. ICRA 2006.. IEEE, 2006.
[2] Khawaja, Wahab, et al. "A survey on detection, tracking, and classification of aerial threats using radars and communications systems." arXiv preprint arXiv:2211.10038 (2022).
[3] Briese, Christoph, Andreas Seel, and Franz Andert. "Vision-based detection of non-cooperative UAVs using frame differencing and temporal filter." 2018 International Conference on Unmanned Aircraft Systems (ICUAS). IEEE, 2018.
[4] Rathod, Gayatri, et al. "Implementation of real-time object detection on FPGA." 2023 7th International Conference on Trends in Electronics and Informatics (ICOEI). IEEE, 2023.
[5] Al Amin, Rashed, and Roman Obermaisser. "FPGA-based resource efficient high throughput object detection using pipelined CNN and custom SSD." 2024 IEEE Nordic Circuits and Systems Conference (NorCAS). IEEE, 2024.

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