Computer Vision Air Traffic Detection Technologies to Enable UAS Operations in the NAS

Chad Frost, Xavier Bouyssounouse and John Goebel - NASA Ames Research Center
San Gunawardana – Stanford Univ. and Craig Bowers - SV Star Inc.

Background

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- NASA, DoD and commercial sector have strong interest in routinely operating UAS in the NAS
- FAA is now mandated to make this happen
- Pilots are afraid of a midair collision with an unmanned aircraft

Still from an on-board video taken by German Army Luna UAS vs. Airbus A300, near Kabul (near miss)

This is a Luna… big enough that you don't want to run into it

UAS operators have poor SA

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- Like trying to fly while looking through a straw
- UAS need to be able to take care of themselves

Luna control station

Predator control station

Challenge

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- Access to National Airspace System (NAS) by UAS is limited by FAA requirement for level of safety equivalent to human-occupied aircraft
- "Equivalent level of safety" is considered to include ability to ***detect*** and ***avoid*** non-cooperating aircraft
- Capability is needed even for “small” UAS, where power/mass/size/cost are most constrained

Innovation

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- Humans are pretty good at visually spotting moving objects… and not running into them. This is how pilots aviate!
- Can we use **computer vision techniques** to perform the same task?
- **Parallels to human approach mean least impact to current operations**
- Can we use "Moore's Law" of technology improvements, driven by consumer electronics industry, to deliver the capability to small UAS?

Innovation

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- Published work demonstrated capability to track a/c against clear sky

- Tracking against complex backgrounds (ground, urban clutter) key to success, but not yet demonstrated – ***hard problem***

Technical Approach

1. Assess requirements to achieve capability
2. Develop conceptual system architecture
3. Collect representative data with which to develop and evaluate computer vision algorithms
4. Develop detection and tracking algorithms
5. Assess performance

Capability Requirements

- A UAS detect-and-avoid system needs three elements:
  - Sensor system
  - Detection and tracking system
  - Collision avoidance system

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Capability Requirements

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- A UAS detect-and-avoid system needs three elements:
  - Sensor system ← *Required for development*
  - Detection and tracking system ← ***Focus of work***
  - Collision avoidance system ← *Being considered by FAA, UAS-in-the-NAS, others*

Sensor System Options

- We recognized many possible aircraft sensor solutions:
  - Radar
    - All weather
    - Direct measurement of range
    - Higher power requirement
    - Higher cost
  - Lidar
    - Requires good weather
    - Direct measurement of range
    - Higher power requirement
    - Higher cost
  - Acoustic
    - Only detects "noisy" targets
    - Short range
    - Low cost
    - Low accuracy
  - Electro-optical (e.g. Camera)
    - Has potential to be light, small, low-power, low cost
    - Best analogy to human capabilities in VFR mixed-use environment

Phase I Results

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- Architecture
- Tools
- Reference Camera System
- In-flight Imagery
- Algorithms
- Knowledge

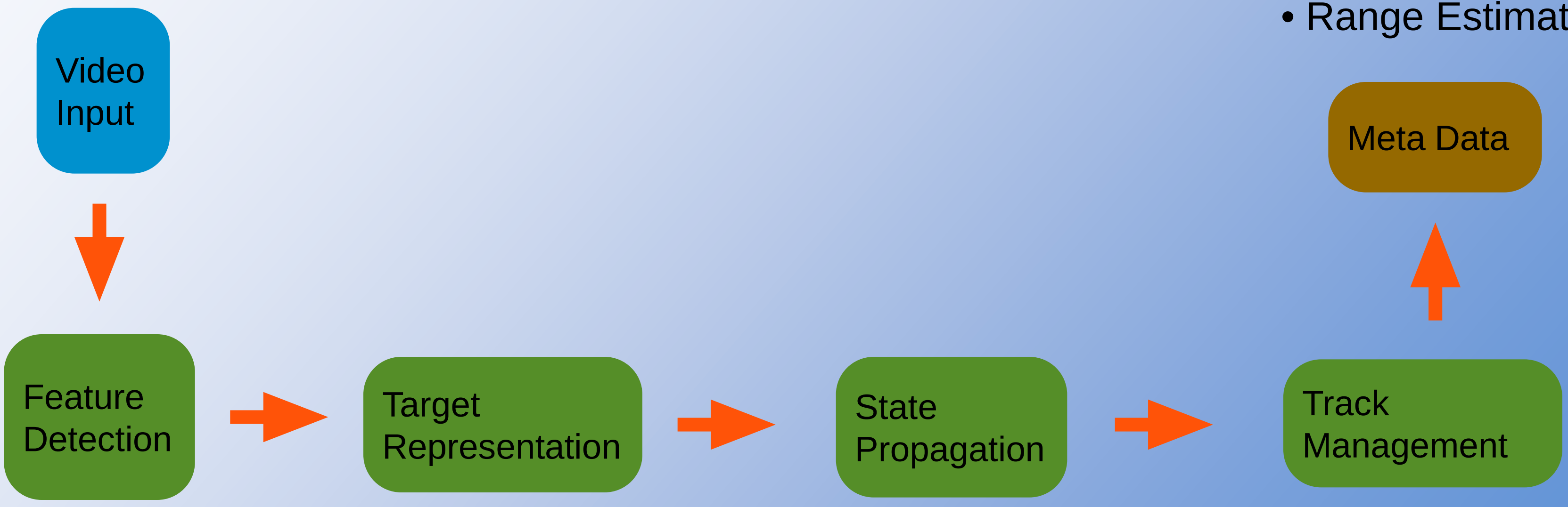
Reference Architecture

Data In

- Camera images

Data Out

- Positions
- Velocities
- Range Estimates



How do you know what you need?

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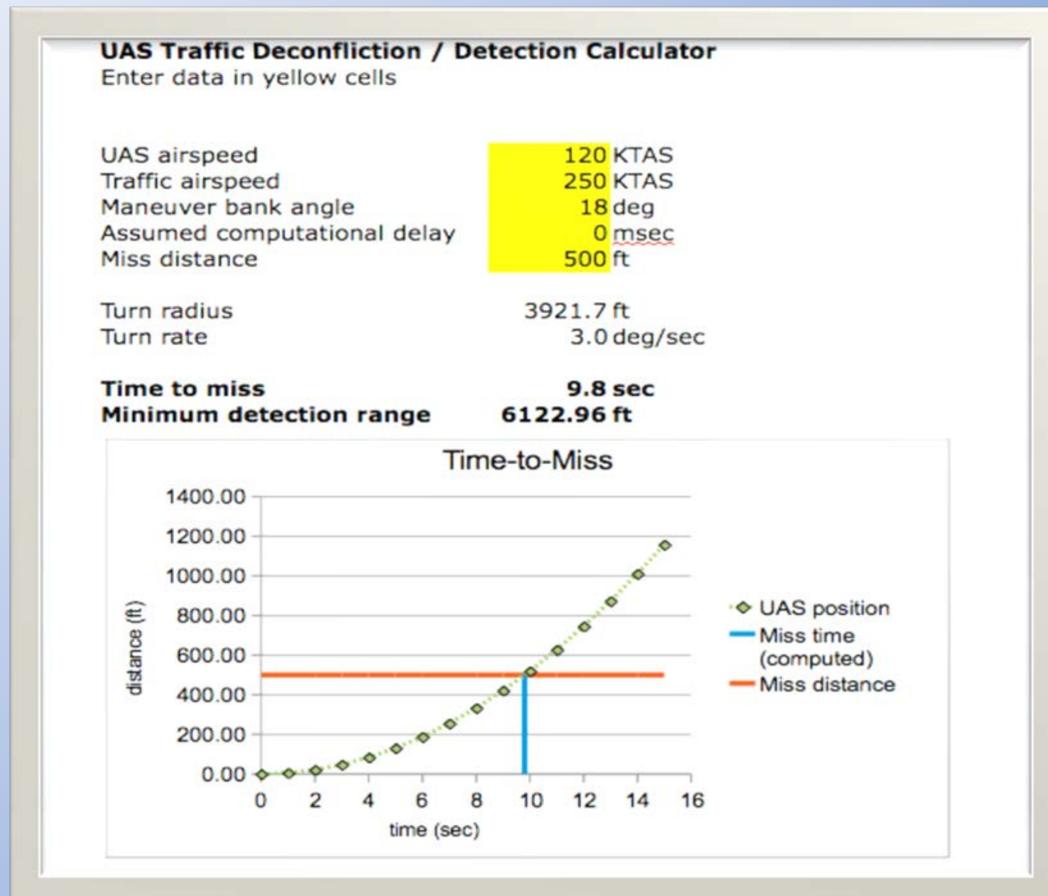
- Developed prototype tool for computing system requirements based on UAS and air traffic characteristics



How do you know what you need?

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- Minimum detection resolution can be computed for various scenarios
- This allows definition of electro-optical system characteristics, and detection range
- We wanted hardware that would be capable of better results than almost anything likely to be used operationally on small UAS

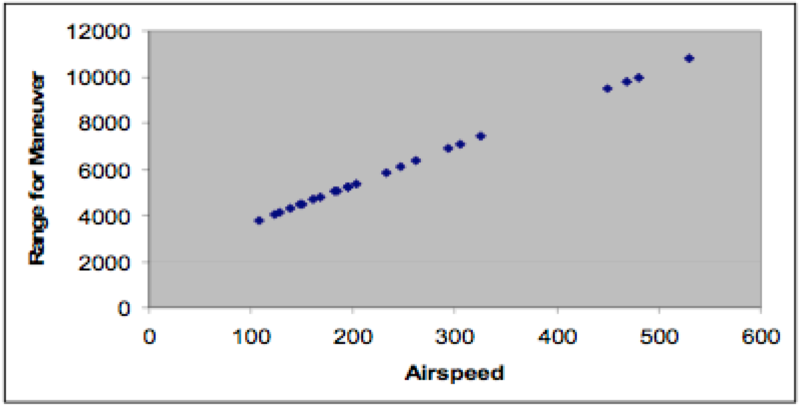

Figure 7: Maneuver Range

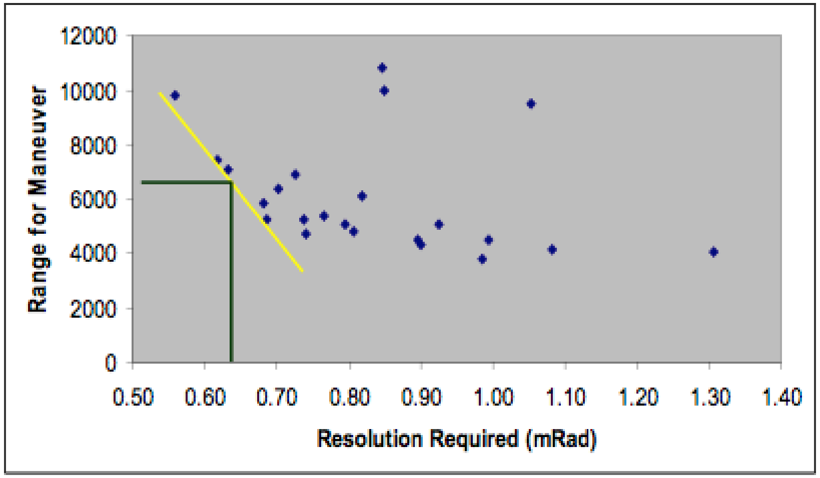

Figure 8: Resolution Requirement

Under 10k ft, speed restricted to 250 kts, giving bound on maneuver range

Camera System Requirements

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- 180 degree field of view *desirable*.
  - Fish-eye lens = BAD! Much lower res away from center.
  - Panamorphic lens = Very expensive and heavy.
  - Multiple cameras = Requires alignment & blending, but technically feasible; delivers highest pixel concentration.

Example wide-field cameras

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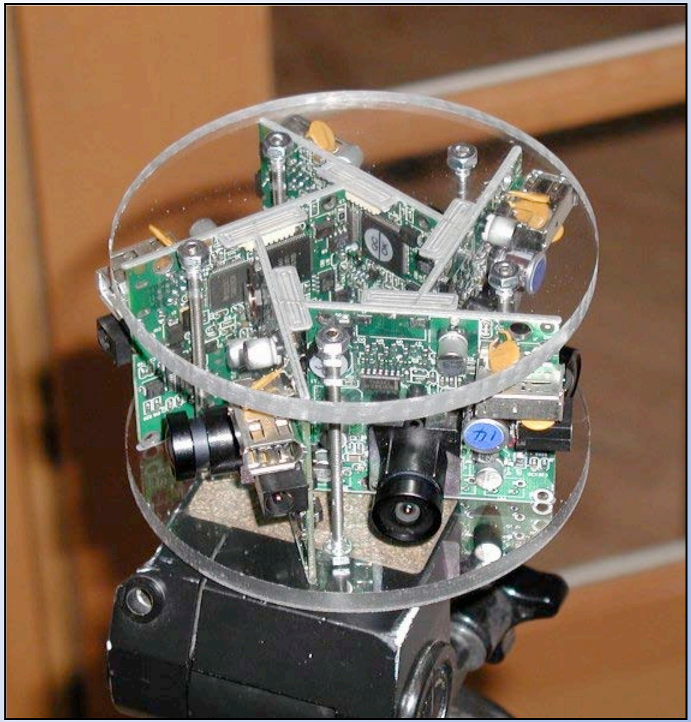
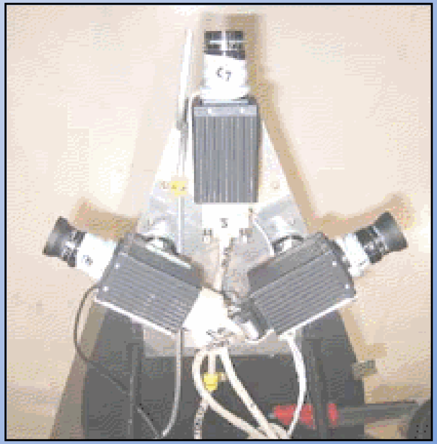
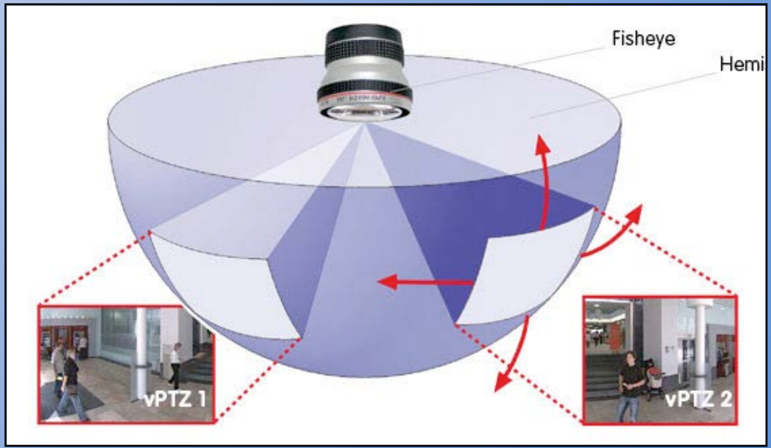
Broadly developed, no need to re-invent the wheel







Camera Requirements

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- Camera system
  - For experiment, defines “reference standard”
    - High frame rate
    - High resolution
    - High quality lens
  - For operational use, somewhat different:
    - Low cost
    - Light weight
    - Wide field of view (possibly achieved with mult. cameras)

Camera System Design

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- ~10 pixels req'd for detection & tracking at ~3nm
- ~100 pixels across target for recognition at ~3nm

- **Our Proof-of-Concept System: ~10 pixels on-target at 3nm, 60 ° FOV**
- Analyzed over 500 system components to identify best configuration
- Represents high end of COTS hardware today
  - More expensive and larger than likely to be used on small UAS
  - Very well documented and highly controllable
- Quality is rapidly coming down in cost
- Capability is rapidly decreasing in size

Camera system

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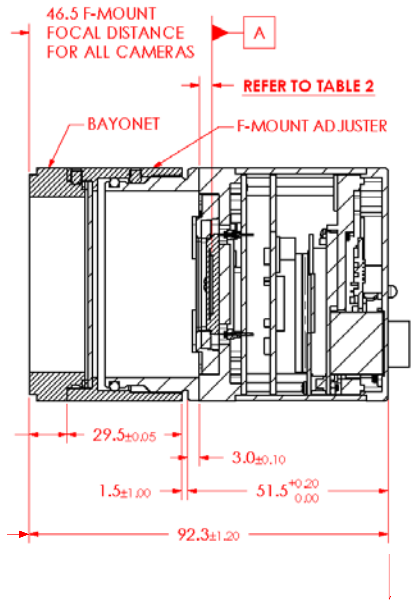
Lens: Carl Zeiss Distagon T* 2/28 ZF

- Very low distortion
- Large aperture
- F-mount
- 60 deg field of view

Camera: Imperx Bobcat IGV-2020

- 4 Mpixels
- 7.4 micron
- 20 FPS
- Color
- Gigabit ethernet

Plus, laptop with big SSD for camera operation & data-collection… this thing generates data ***really*** fast!



Aircraft mounting options

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How to put the camera on the airplane…

Options:

1. Wing-strut pod ← most desirable
   - Found local source of STC'd design
   - Not cheap, but looks feasible
   - Mods required to point forward
   - Too expensive
2. Belly pod ← can borrow, but:
   - Oil/soot from engine & exhaust
   - Camera can't face forward
3. Inside cabin
   - Have to look through windscreen, and/or prop, or out a side window

Our aircraft has a convenient vent in the right window, to allow for option 3!

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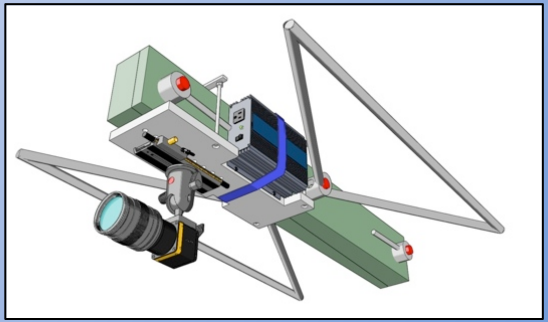
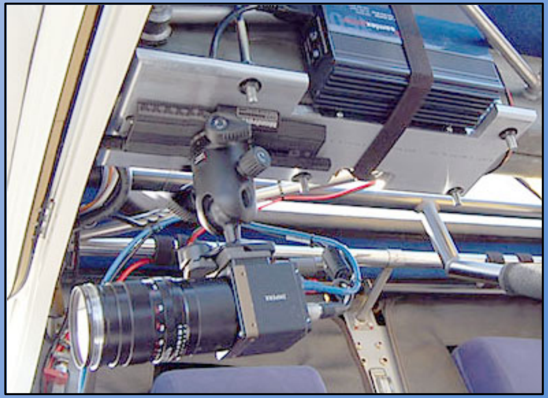
- **Partnered with SV Star for collecting flight imagery and data.**
  - Piloted Pipistrel Sinus Aircraft as UAV surrogate.
  - Camera mounted inside aircraft from wing spar, facing side window.





Flight Campaign

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- To collect in-flight imagery using computer-vision camera and lens system:
  - Requirements defined
  - Candidate components identified and reviewed (approx. 580 cameras assessed!)
  - Design developed and documented
  - System procured
  - Assembly, integration and test completed
  - Aircraft installation designed and fabricated
  - Test plan developed
  - Airworthiness Flight Safety Review Board signed off
  - Camera system installed in aircraft and tested

Examples of Flight Imagery Collected

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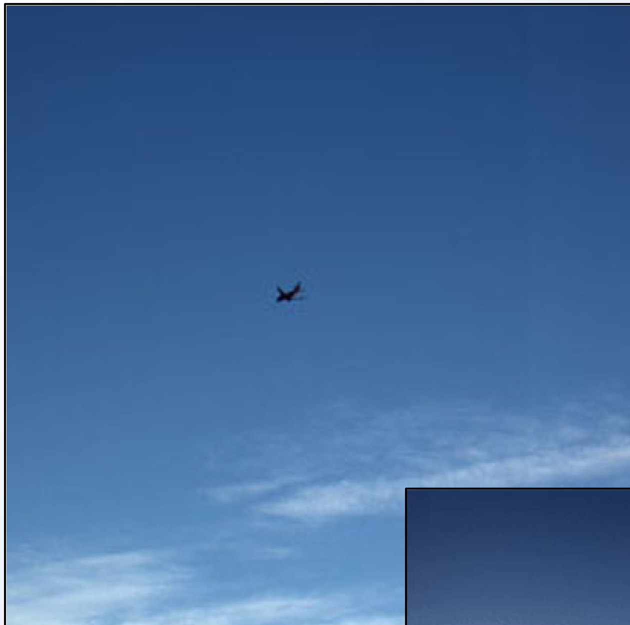

Uncluttered Background

Uncluttered - Cluttered Transition

Cluttered Background

Obscured Track

In-flight Imagery Collected

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- To date (75% complete):
  - 21,178 individual images
  - Over 330GB of data
- Completion expected June 15

Algorithm Functionality

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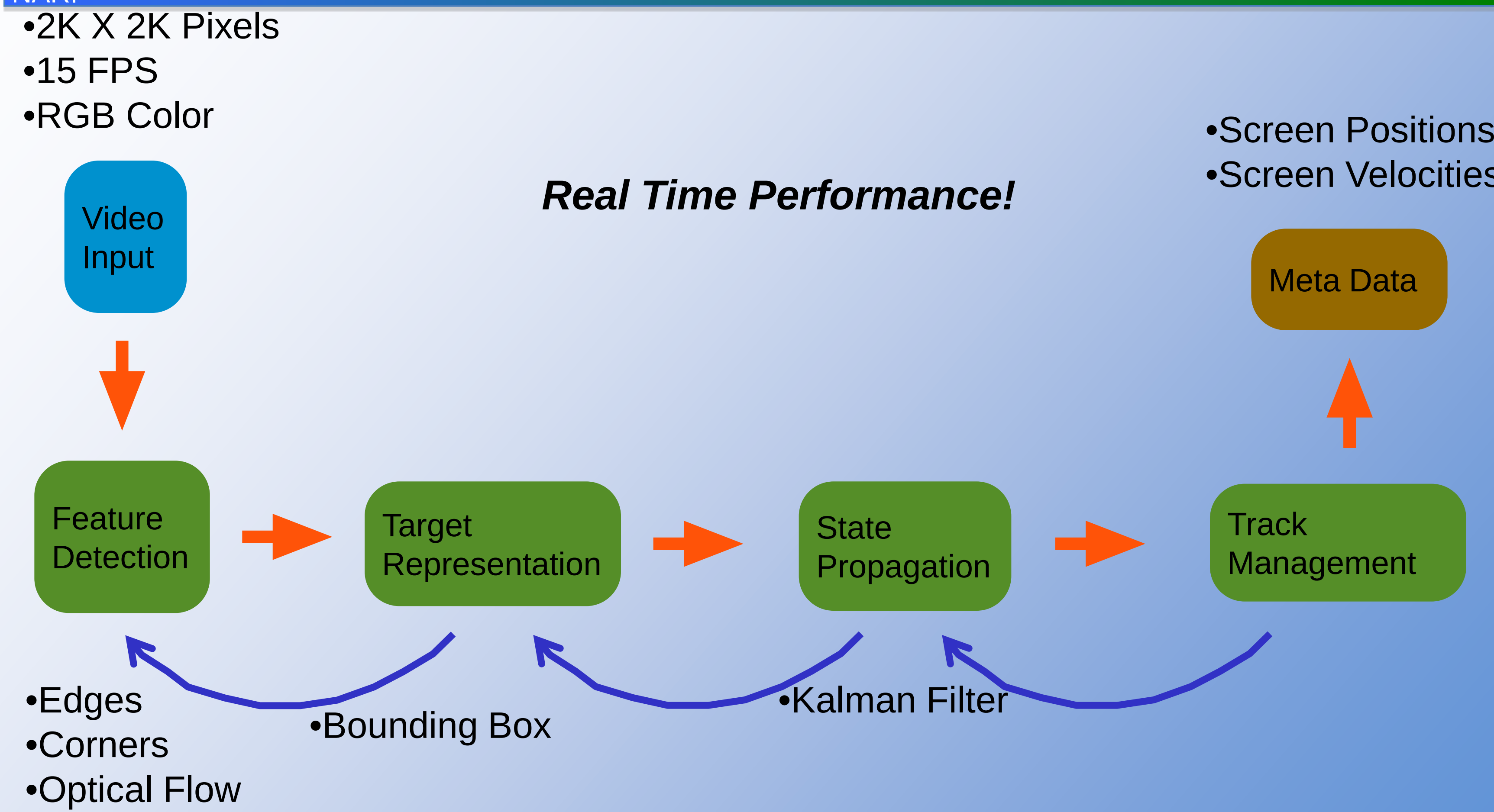

Performance Evaluation

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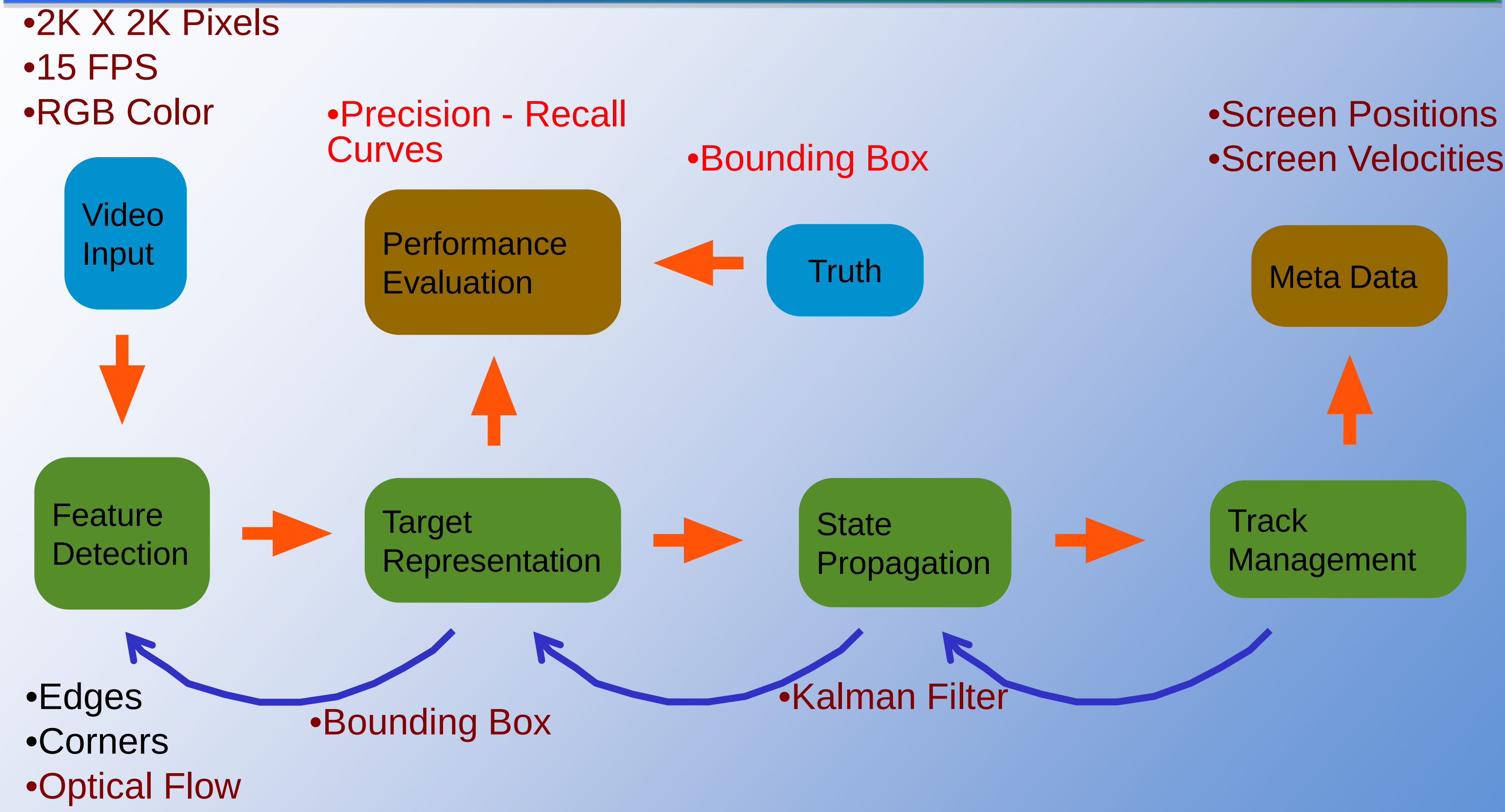
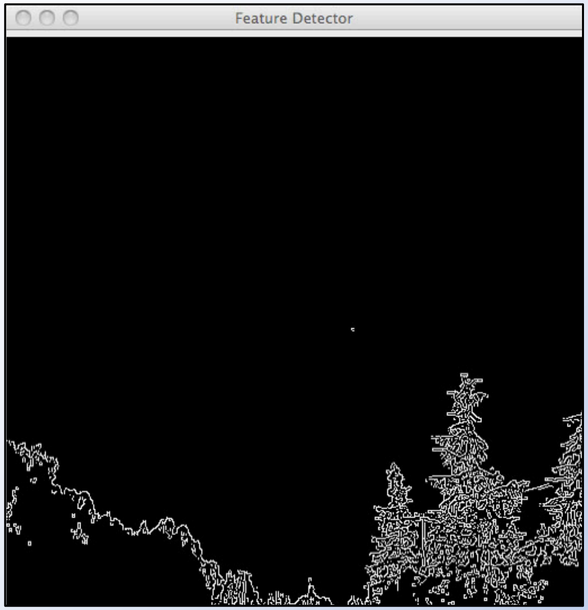
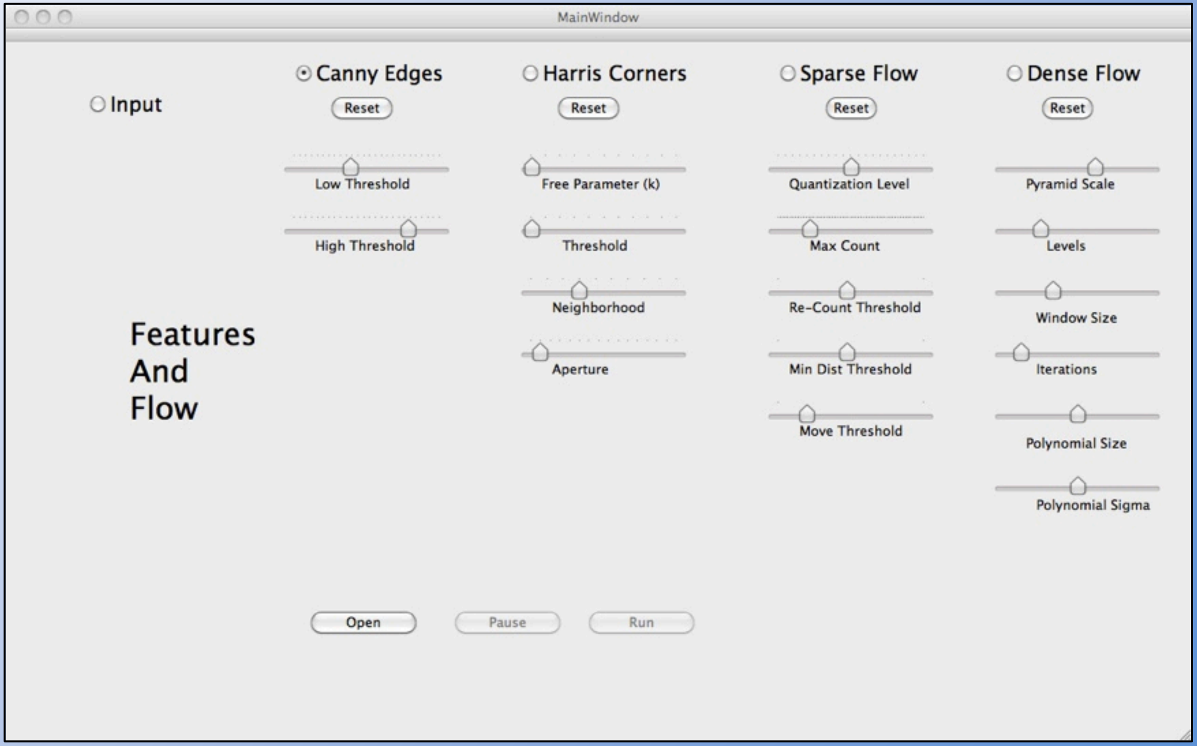


- Developed UI for experimentation with feature extraction algorithms





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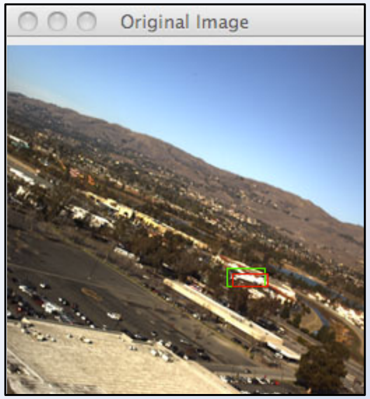

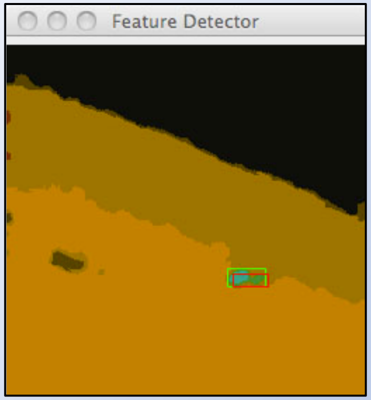

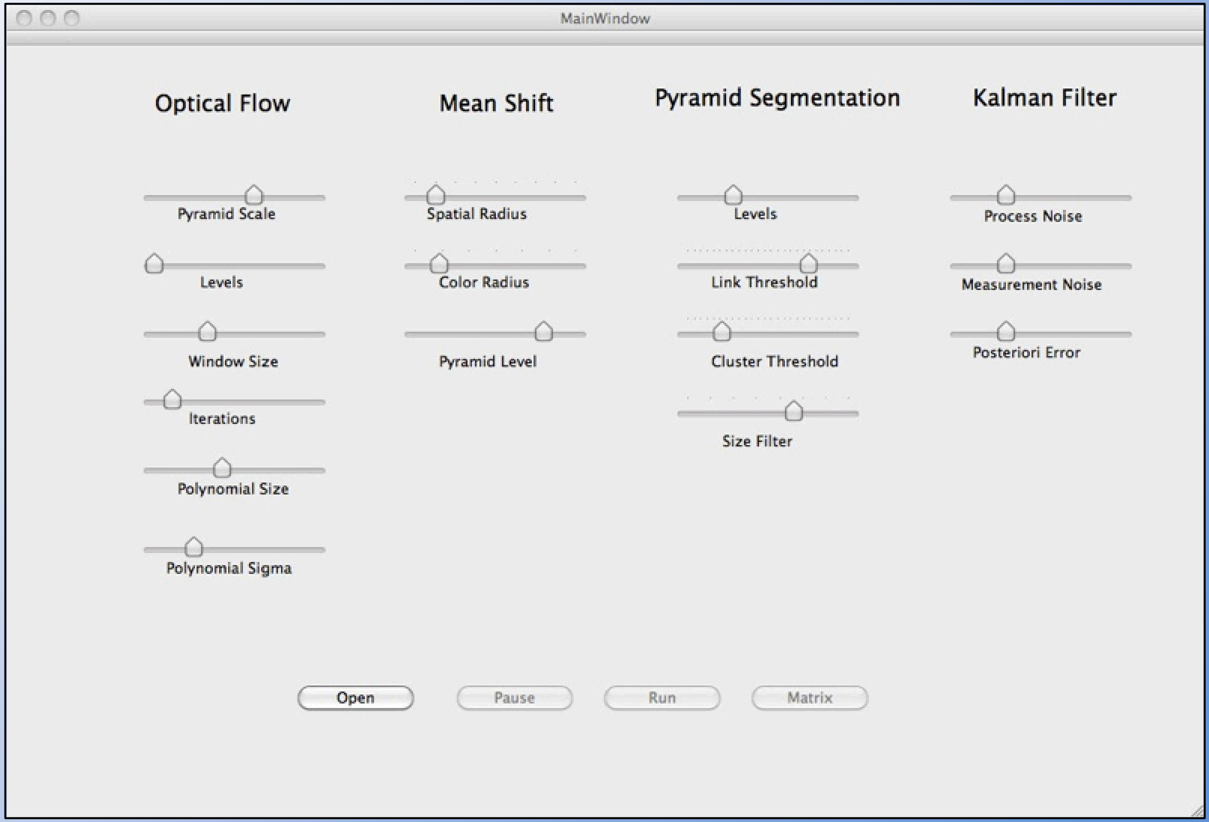

Detection & Tracking results

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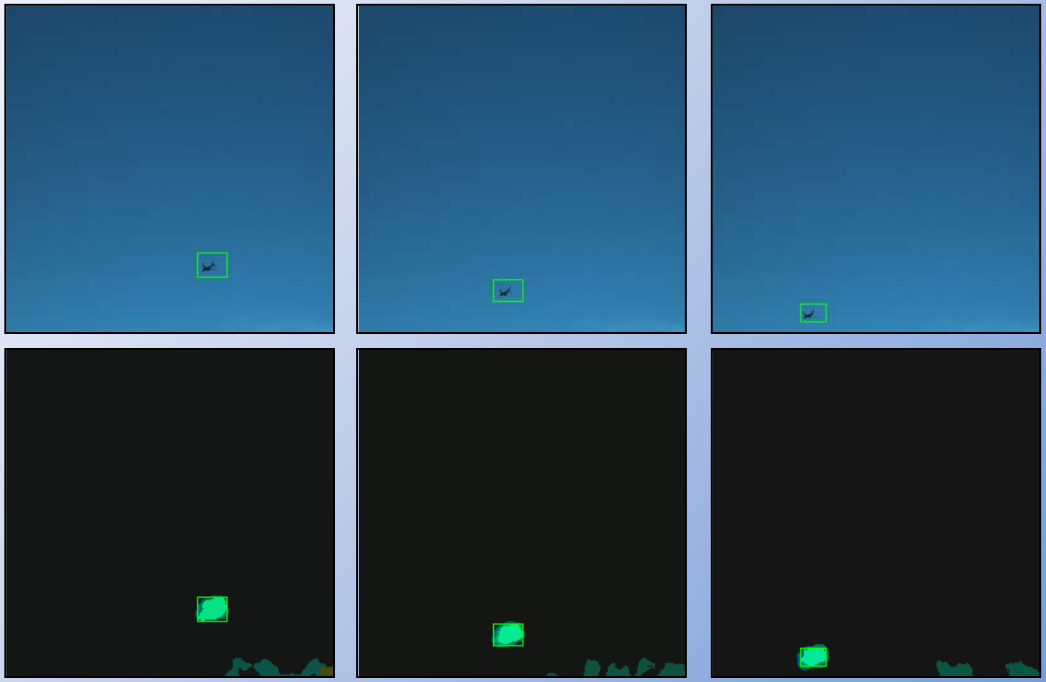
- Detection and tracking of a Boeing 737 against a simple background



Detection detail

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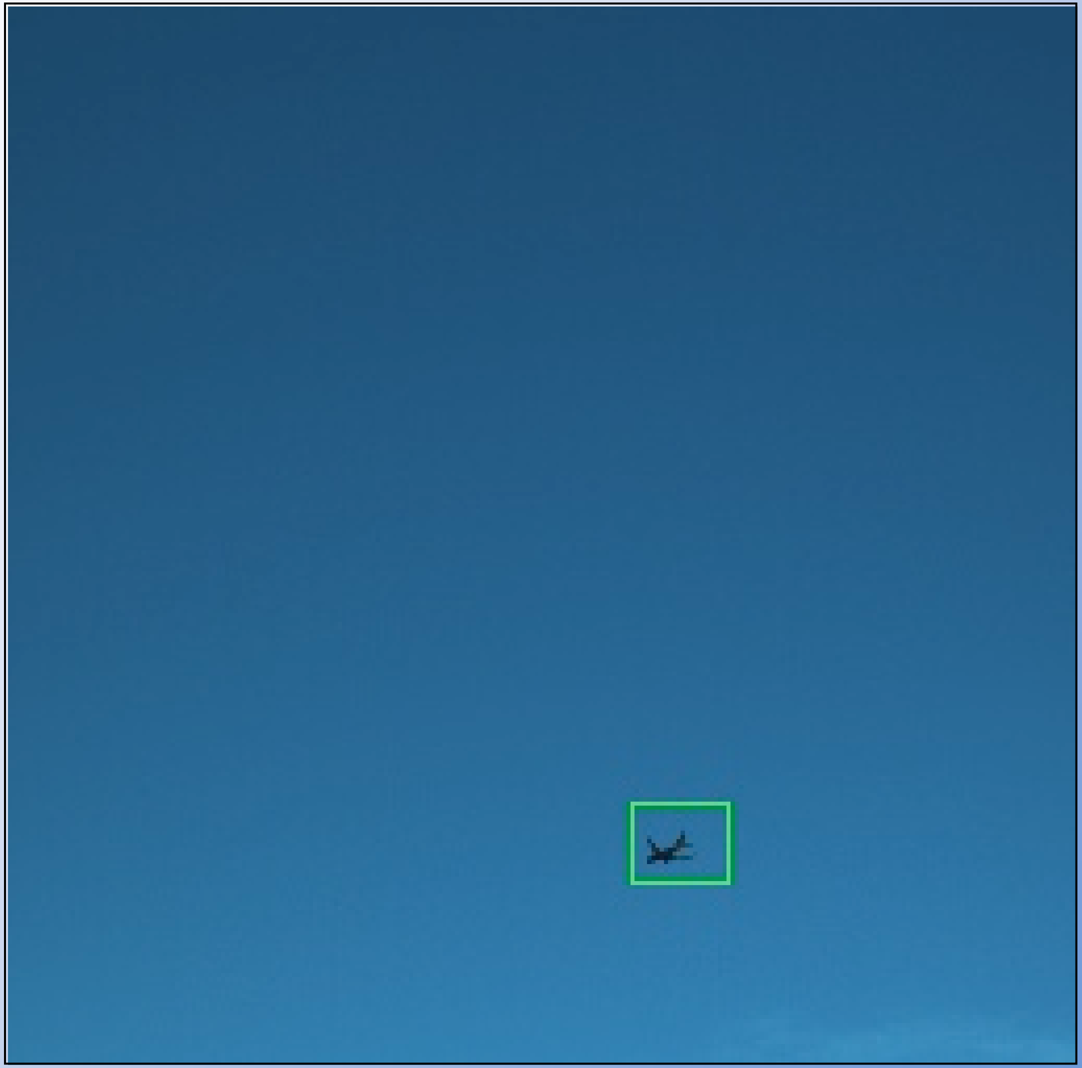

Detection & Tracking results

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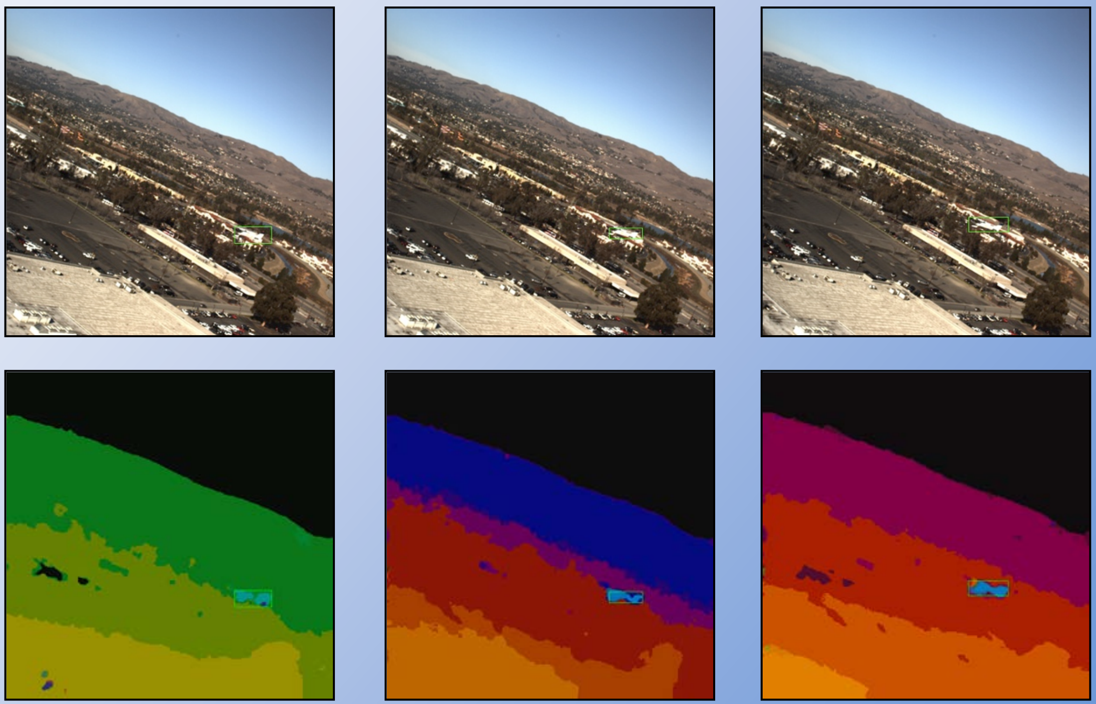
- Detection and tracking of a Cessna 172 against a cluttered background. This showcases a scenario where the algorithm succeeds even though a human observer would find it difficult to detect the aircraft



Detection detail

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Phase I Algorithm Capabilities

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- Detects multiple moving objects in the camera field of view
- Able to track a single aircraft against cluttered background
- Reports aircraft's location and size in image

Impact

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- An operational system incorporating this technology potentially:
  - Enables small UAS operations in mixed-use airspace
  - With minimal changes to current operations
  - Enhances safety for GA or future commercial single-pilot operations
  - Serves as another set of eyes for any aircraft

Dissemination

- Submitting abstracts to one or more of:
  - IEEE Aerospace Conference
  - AIAA InfoTech Conference
  - International Conference on UAS
- Mid-term results presented at ARC seminar
- Planning to present Phase I results at local Association of Unmanned Vehicle Systems (AUVSI) meeting

Next Steps

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- Continued development of the detection and tracking algorithm pipeline is required to achieve robust results
  - Simultaneous tracking of multiple aircraft
  - Feature extraction to identify target as a class of aircraft
  - Estimation of position & velocity using knowledge of target's class

- All data collected and lessons learned represent valuable knowledge for use by the broader community seeking to operate UAS in the NAS

Phase II Proposal

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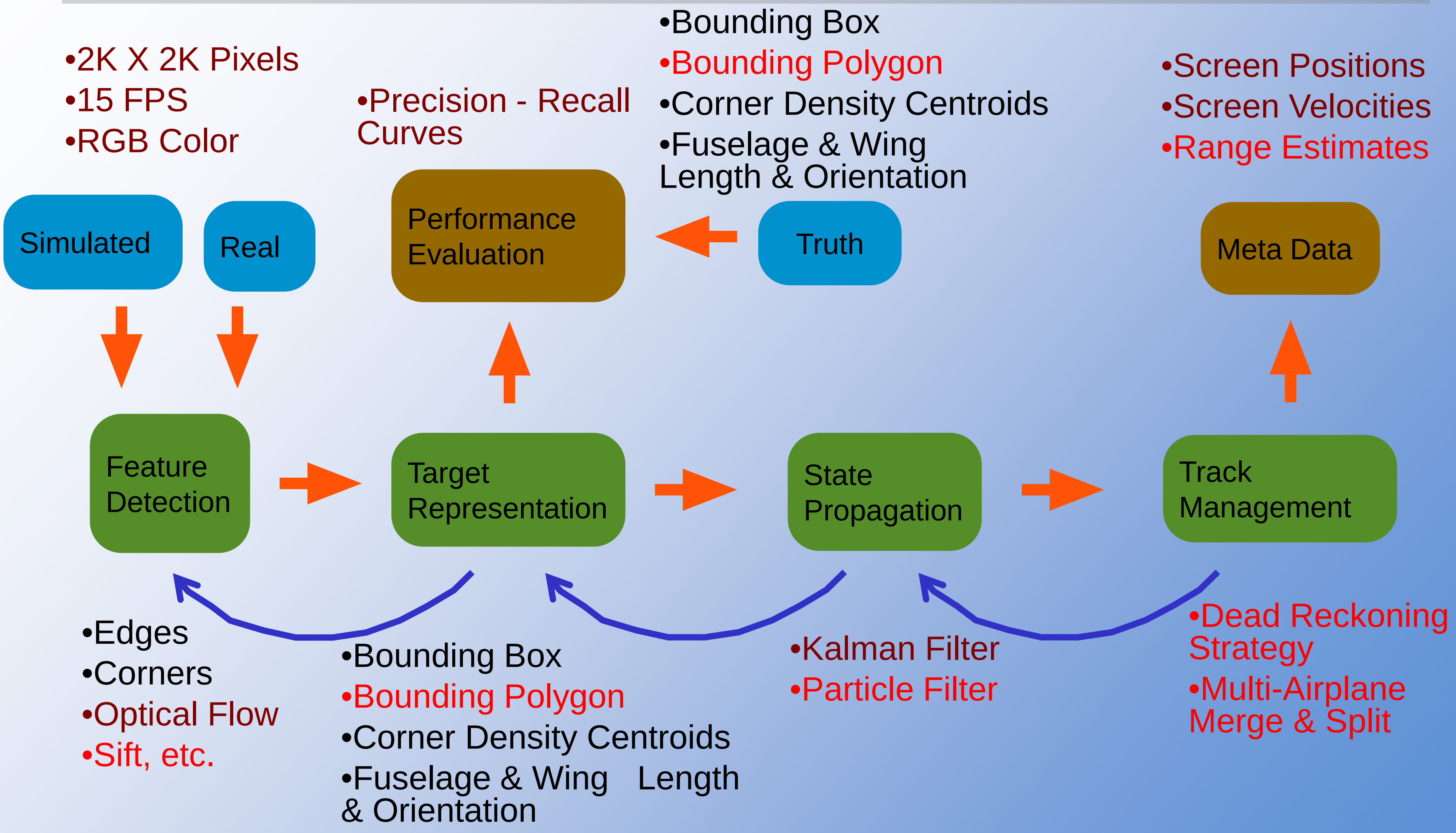

Summary

Problem statement:

- To achieve integration into the NAS, UAS must be capable of autonomous detection, tracking, and avoidance of non-cooperative aircraft
- This includes small UAS operating in mixed-use airspace

We focused on the key technology gaps:

- Detection and tracking of aircraft against cluttered backgrounds
- Using technology suitable for deployment on small UAS
- Delivering documented performance of a baseline reference system (camera, test imagery, and algorithms)

Achievements:

- Developed tools and a reference camera system
- Compiled base of data and knowledge
- Algorithms achieved Phase I goals

Thank You!

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Questions?