Software-Defined Multi-Spectral Imaging System

Image and Information Fusion Experiments for Aviation and Marine Sensor Networks
Goals and Objectives

Feature Rich Software Defined Multi-Spectral Imaging System
- Geo-1: Southwestern Sonoran Desert, Colorado Plateau
- Geo-2: Alaska and US Arctic Environments
- In-situ monitors (rooftops, buoys, poles) – Share and Add Geos
- Light Aircraft (ERAU RV-12)
- Marine Vessel and UAS Detection, Tracking, Classification, Identification

Complimentary High Spatial, Temporal, Spectral Resolution
- Specific Geolocations, Campus, Airport, Marine Port
- Compliments Satellite Remote Sensing
- Cooperative ADS-B and S-AIS
- Active RADAR/LIDAR Systems
- Adds EO/IR and Acoustic Passive Sensing to Active Existing
- Enhance Information Aggregation (flightradar24.com, MarineTraffic.com)
- Networked Instruments with Image Fusion for Information Fusion
- Low Power (Battery of Fuel Cell Extended Operation) < 10 Watts Peak

Low-Cost, Simplified Use Sensor Fusion Instrument - Open Reference

Detect, Track, Classify and Identify Aerial and Marine Objects
- Determine Performance Methodology for EO/IR and Fusion Sensor Networks
- Compare Candidate Methods to Baseline
2015/16 – ADAC & ERAU Sponsored

- **UAA – ADAC, SmartCam**
- **ERAU (Undergraduate Research Team)**
  - Sam Siewert, PI, Assistant, Prof.
  - Demi Matthew Vis – AE/SE Student
  - Ryan Claus – SE Student
  - Nicholas DiPinto – SE Student
  - Arctic Power Team – Power Team Poster
- **CU Boulder – Embedded Systems Engineering Graduate Program**
  - Ram Krishnamurthy – MS EE
  - Surjith Singh – MS, ESE
  - Akshay Singh – ME, ESE
  - Shivasankar Gunasekaran – ME, ESE
  - Swaminath Badrinath – ME, ESE
- **Industry Advising/Collaboration Participants**
  - Randall Myers, Mentor Graphics

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2016/17 Team – ERAU Sponsored

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- **CU Boulder – Embedded Systems Graduate**
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  - Surjith Singh – MS, ESE
  - Akshay Singh – ME, ESE
  - Shivasankar Gunasekaran – ME, ESE
  - Omkar Seelam – ME, ESE

- **Industry Advising/Collaboration Participants**
  - Randall Myers, Mentor Graphics (PCB, CAD, Systems)
  - Joe Butler, Intel Corporation (IoT)
Open Reference SDMSI Configuration

- 2 Basler Pulse Visible Cameras
- 1 FLIR Vue LWIR Camera with ZnSe Window
- Jetson TK1, Panda Wireless, USB3 Hub, Power, NEMA Enclosure
USCG – Arctic Shield

Potential SDMSI Buoy and Pole Mounts to Enhance AIFC (Arctic Information Fusion Concept)

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http://www.uscg.mil/d17/ArcticShield/Documents/USCG%20Arctic%20operations.pdf
Smart Camera Deployment - Marine

- Land Towers (Light Stations, Ports, Weather Stations)
- Self-Powered Ocean Buoys
- Mast mounted on Vessels

http://www.uscg.mil/d17/cgcspars/
http://www.esrl.noaa.gov/gmd/obop/brw/
http://www.oceanpowertechnologies.com/
Smart Camera Deployment - Aerial

- UAV Systems - ERAU ICARUS Group
- Experimental Aviation and Small Aircraft - ERAU
- Kite Aerial Photography, Balloon Missions (ERAU, UAA, CU Boulder)

Sam Siewert – ERAU ICARUS Group

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Actual - Roof Mount Experiment

- Starting point – evolve to aircraft, buoy and UAS later
- Embry Riddle flight line provides lots of light aircraft traffic
- Simple UAS testing in Campus (semi-Urban) environment
- Wildlife – insects, bats, birds, etc.
Information Fusion Concepts

Integration and System of Systems Between ADS-B and S-AIS for Vessel / Aircraft / UAS Awareness

Smart Cameras Can Monitor and Plan Uplink Opportunity as Well as Wake up and Uplink
Ice Detection/Tracking Feasibility Tests

Clear Segmentation of Ice, Rock, Water, Drainage over Rocks, Vegetation – As Expected for 14 micron LWIR

Melt-water drainage
Preliminary Ice Tracking Feasibility

- Bergs of small size easily segmented for detection and tracking

- High contrast to water (air @ 63-52F 7/10/15)
Preliminary Vessel Tracking Feasibility

- Good detection of engines and exhaust in fog
- Idle or adrift vessels harder to detect than underway (active)

Exhaust stacks for Tanker at TAP

200mm DSLR Visible

25mm Visible

25mm Athermal Lens - LWIR
Visibility of Thermal Features in Fog

- Hot-spots (engines, exhaust, cabin, lights) segment well
- Improve with Common Intrinsic/Extrinsic Characteristics and Image Fusion
- Valdez Harbor, Alaska
Feasibility Testing in Marine Domain

- Vessel Detection, Tracking, Identification
- At Ports, Light Stations, and In Straits
- Integrate with Arctic Information Fusion Concept (S-AIS)

- Marguerite Ace Leaves Long Beach
- HD visible imaging of departures
- And transits with ID
- LWIR night/fog detection and tracking
- Correlation to S-AIS and DBMS
- (Field Test – June 2015, Long Beach)
Feasibility for SAR Ops / Port Security

Detect bodies in the water, Port trespassing, Complements USCG Aircraft FLIR Systems

Surfers in the Water
Hand-held, Cutter Mounted, Buoys
Complements Existing Helicopter and C130 FLIR
(Field Test – June 2015, Malibu)

Trespassers at Night Shown on Jetty
Hand-held, Port Drop-in-Place, Buoys
Complements Existing Security
Off-Grid Installations
(Field Test – June 2015, San Pedro)
Conceptual Configuration

Thermal Fusion Assessment

Panchromatic, NIR, RGB

Jetson Tegra X1 With GP-GPU Co-Processing

Saliency & Behavioral Assessment

Cloud Analytics and Machine Learning

Flash SD Card (local database)

LWIR

Many multispectral focal planes ...

2D/3D Spatial Assessment
Experimental System Block Diagram

- 2 Watts at Idle, Plus 1.5 Watts per Camera = 6.5W
- E.g. Sobel, 30Hz, 20 Mega Pixels/Sec/Watt, 7.3W Peak – SPIE Sensor Tech + Apps

1) Sync’d Capture
2) Resolution Match
3) Image Registration
4) Detection
5) Classification
6) Identification
Detection Experiments for Aircraft and UAS

Preliminary Roof-top Field Trials at ERAU Prescott

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Baseline Motion Trigger Detection

- Difference Images over Time (adjustable)
- Threshold - Statistically Significant Pixel Change
- Filters (Atmospheric, Cloud, Constant Background Motion) – Dispersion of Changes
- Detection Performance – **ROC**, PR-Curve, F-measure [TP, FP, FN, TN analysis]
- Classification/Identification - Confusion Matrix

**https://en.wikipedia.org/wiki/Precision_and_recall**

PR best for Image Retrieval
E.g. **https://images.google.com/**

ROC best for Target Detection

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Frame by Frame Analysis

- TP – Determined by Human Review
- Frame by Frame
- Alternative is by Physical Experiment Design
- “Autoit” Program to Analyze
Aircraft Detection Performance - Baseline

Video Links – Aircraft, Bugs, FP, TP+FP, [TN], [Full]

Aircraft ROC for Motion Detect

True Positive Rate

False Positive Rate

MD

RAND

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UAS Detection Performance – Baseline

Video Link – UAS+Aircraft, Bugs, FP, TP+FP, [TN], [Full]

Drone ROC for Motion Detect

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Candidate SOD (BinWang14) - Aircraft

- Modified to Run BinWang14 SOD => MD Baseline
- Video Links – TP+FP, [TN], [Full]
Candidate SOD (BinWang14) - UAS

- Modified to Run BinWang14 SOD => MD Baseline
- Video Links – TP+FP, [TN], [Full]

Drone ROC for Modified BinWang14

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Search and/or Development of UAS & Aircraft SOD + Classifier + Identification

- Likely Requires Custom Detection – SOD

- Classification Based on Shape, Behavior and Contrast/Color/Texture in Multiple Bands (RGB, NIR, LWIR)

- Considering Acoustic Cue Fusion

- Cross Check with ADS-B, RADAR/LIDAR Data

- Produce Improved flightradar24.com Meta-data

- Find Ghost UAS and Aircraft [Non-compliant], Log Others
Needs Debugging – Literally!

- Many Insects Detected in Visible to LWIR
- Opportunity to work on Bird / Aviation Interaction Testing
Summary and Future Work

- Methods to Evaluate UAS/Aircraft Shared NAS Instruments (EO/IR)
- Open Reference Design to Replicate (HW, FW, SW)
- Bench Testing – 2 Watts Idle, < 10 Watts Peak Operation
- Detection Performance Baseline to Compare To
  - Test Candidate SOD Algorithms
  - Deep Learning ANN
  - Research Customized SOD
- Please Download our Benchmarks, Detectors, Test Cases
  - https://github.com/siewertserau/fusion_coproc_benchmarks
  - https://github.com/siewertserau/EOIR_detection
- Open Source Hardware, Firmware, Software for Multispectral EO/IR and Information Fusion Applications
- Build a Drone Net – Campus, Port and at Multiple Geos!
Backup Slides and References
References


References


References


26[flightradar24.com](http://flightradar24.com), ADS-B, primary/secondary RADAR flight localization and aggregation services.