Software-Defined Multi-Spectral Imaging System

“Smart Camera” Research

September 2016 - Status
Overview and Goals

- Create a Feature Rich Software Defined Multi-Spectral Imaging System for Security and Environmental Surveys, Monitoring for Extreme Environments
  - E.g. Southwestern Sonoran Desert, Colorado Plateau
  - E.g. Alaska and US Arctic Environments
  - Locations with Significant Climate Change, Resources at Risk
  - In-situ monitors (buoys, poles), Light Aircraft (ERAU RV-12), UAV/UAS

- High Spatial, Temporal, Spectral Resolution in Specific Areas (Complimentary to Satellite Remote Sensing)

- Lower Cost, Simplified Use Instrument (Security Camera)
Y2 Team – 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 – ME, ESE
  - Akshay Singh – ME, ESE
  - Shivasankar Gunasekaran – ME,ESE
  - Swaminath Badrinath – ME, ESE
- **Industry Advising/Collaboration Participants**
  - Randall Myers, Mentor Graphics
Y3 Team – ERAU CoE Sponsored

**ERAU**
- Sam Siewert, PI, Assistant, Prof.
- Demi Matthew Vis – AE/SE Student
- Ryan Claus – SE Student
- TBD – CE/SE Student (Machine Vision Inspection)

**CU Boulder – Embedded Systems Graduate**
- Ram Krishnamurthy – MS EE
- Surjith Singh – ME, 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)

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Y2 SmartCam SDMSI Configuration

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

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Alaska – Global Perspective

- Russia–US Border Between Big & Little Diomede Island
- Kamchatka Peninsula to South
- Bering Sea, Chukchi Sea, Beaufort Sea, Arctic Ocean

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https://www.google.com/maps/place/Anchorage,+AK

Petropavlovsk Kamcetskij
Alaska - Arctic

- North of Aleutian Islands, Western AK to Beaufort Sea
  - Winter Sea Ice Above Aleutians down from Circle (66.6 deg N.)
  - Route to Northern Passage (Canada, Hudson Bay)
  - Siberian Arctic (E. Siberian, Laptev, Kara, and Barents Sea)

https://nordpil.com/portfolio/mapsgraphics/arctic-topography/  
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https://www.google.com/maps/place/Anchorage,+AK
Climate Change

- Risk, Impact, and Mitigation Methods - Policy
- Arctic Sea Ice Extents Have Retreated - Measurement
- Practical Changes to Region (Shipping) – Monitoring, Management

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http://nsidc.org/arcticseaicenews/
USCG – Arctic Shield

SmartCam Buoy and Pole Mount Enhances AIFC (Arctic Information Fusion Concept)

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/cgcspar/

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)
Opportunistic Uplink

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

Smart Cameras Can Monitor and Plan Uplink Opportunity as Well as Wake Up and Uplink

System Fusion For Uplink
The Goal

Low-Cost Multi-Channel Imager
- Primary: Visible + IR for Multi-spectral Imaging
- Secondary: Two Channel Visible for Passive 3D Imaging

Smarter “Go-Pro Like” Instrument for Safety, Security, Resource Monitoring (DHS, USCG, USGS, NOAA, …)
- Integrate Off-the-Shelf LWIR, Visible and LIDAR for Fusion
- Drop-in Place on UAV, Marine Vessel, Buoy, Port
- Smarter (Fusion, 3D mapping, Saliency Metrics), Multi-Channel
- Power Efficient (2 Watts Idle, < 10 Watts fully active at 30Hz)
- Intelligent Uplink (Walk By to Download Salient Images)
- Less than 10 Watts Max Power, Less than $3000 BOM cost
- Open Hardware, Firmware, Software Design (Anyone can Build)

3D and Multi-Spectral Fusion using GP-GPU or FPGA Co-processing

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SmartCam SDMSI
(Software Defined Multi-Spectral Imager)

- Low-cost, software-defined, smart “Go-Pro” style device with visible and multi-spectral image fusion
  - Efficient energy use with image analysis on the device itself
  - Emphasis on software intelligence for automatic detection, tracking, and data fusion analysis

Examples

Bergy bits may be difficult to detect with a search light (left) but could be automatically detected by SmartCam software with a thermal camera (right) using machine learning [FLIR].

Visible image of a forest fire obscured by smoke (left), while a thermal satellite image indicates hot spots (right), leading to calculation of Normalized Burn Ratio (SWIR, NIR) [O’Connor, Exelis]. SmartCam on a UAV could provide higher resolution, real-time data for situational awareness.

Automatic hazard and threat identification and annotation from a car [nVidia PX] could be adapted by SmartCam for marine environments.
Research Goals

Near Term (2016)
- Hardware Acceleration – GP-GPU vs. FPGA
- Embedding and Efficiency – Watts / Transform / sec
- Fusion Algorithms for Near Field LWIR+Visible
- Basic Target Tracking and Threat Detection, Standard Algorithms, Improved Performance
- Duration Testing on ERAU and UAA CoE Rooftops

Longer Term (2017)
- Battery Life and Power from Solar Re-charge, Super-capacitor and Fuel Cell
- Opportunistic Uplink/Downlink
- Test Deployment in Arctic (Port, Vessel, Buoy)

Fundamental
- Passive 3D and Multi-Spectral Scene Understanding Algorithm Improvements, Invention
- Layered Architecture From Scene Segmentation to Machine Learning Recognition and Threat Assessment
- Wider Application (Intelligent Transportation, SAR, SLAM)
Preliminary Ice Detection/Tracking Feasibility Tests

- Clear Segmentation of Ice, Rock, Water, Drainage over Rocks, Vegetation – As Expected for 14 micron LWIR
- Break-Up Melt Scenario (Compared to Formation) – Portage Glacier
- Improve with Common Baseline and Lens (Intrinsic/Extrinsic Stereo Matching)

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)
- Break-up scenario (Formation needs more testing)
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 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
Ideas for Field Testing

Monitor Unimak and Bering Strait (Visible, LWIR, [LIDAR])

- Current Tracking is Voluntary S-AIS and VHF Radio Communications
- Limited Communications and USCG Patrol in this Region

Unimak Strait is a 12 mile wide Transit for Majority of Great Circle Shipping Traffic Passing Through Arctic

SmartCam System Could Be Used with LWIR + Visible Long-Range Optics And/Or Low-Cost LIDAR Sensors

Cross Check S-AIS with Secondary Record for Improved Domain Awareness

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Marine Traffic Spotting, Tracking, ID

- Low-Cost Visible, LWIR, and LIDAR Testing Can be Completed in Similar Geographic Regions for Feasibility
  - E.g. Channel Islands, San Francisco Bay, Etc. for Feasibility Test
- Transition to Unimak (Accessible by Alaska Marine Highway and a Hike)
- Transition to Bering Strait
- Much Like Air Traffic, Goal is to Cost Effectively Track Vessels not Using S-AIS and Not Maintaining Radio Contact
- Research Goals – Feasibility of Vessel Spotting, Tracking and Identification with More Intelligence and Lower Cost than RADAR stations
- Complements Rotary FLIR for SAR-Ops
Marguerite Ace

- Visible Identification at 200mm
- LWIR Detection and Tracking at 25mm
Marguerite Ace

- Detected, Tracked and Identified Departure from Long Beach
- Correlated to S-AIS
Feasibility Testing in Marine Domain

- Basic Vessel Detection, Tracking, Identification
- At Ports Light Stations, and In Straits (E.g. Unimak Strait – Great Circle Route to Asia, Bering Strait)
- Big Data Analytics Combined with Sensor Networks (Potential To Enhance Situational Awareness)

- 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

- Add camera systems to Cutters (around, mast)
- Detect bodies in the water, Port trespassing, Complements Aircraft FLIR

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)
Year-1 Accomplishments

Milestones Achieved

- Testing power consumption
  - Low power (0.6W) to normal (6W at 3000mAh → 2-3 hours); need sleep and wakeup with periodic sense if off the grid
  - Couple with hybrid power, OTS leveraging

- Testing LWIR range and Night/Fog Conditions
  - Can see vessels **2 to 13 kilometers** with out with 25 degree field of view (25mm lens)
  - Can see vessels **TBD** miles with out with 9.6 degree field of view (65mm lens) – Next Planned Test
  - Can identify Vessels with HD Visible (200mm lens)
  - Visible + IR Fusion Feasibility Testing (Night, Day)

Anchored Vessels Over Night Waiting for Long Beach Port Access
(Field Test – June 2015, San Pedro)
Anchor Points Shown on S-AIS in Excess Of 10 Km From Observing Point
Year-2 Accomplishments

- UAV Test Flights (Fall 2015), ERAU Prescott
- Field Testing (Valdez Alaska, ERAU Army ROTC)
- Power Testing and SoC Selection
- System Design and Bench Testing
- 3D Design Completion and Start of Test Fabrication
- AIFC Integration and Use Cases
Concept #1 - FPGA Acceleration

USB3.0 SD (Panchromatic, NIR, RGB)

FPGA CVPU (Computer Vision Processing Unit)
DE1-SoC

Cloud Analytics and Machine Learning

Flash SD Card (local database)

Many multi-spectral focal planes …

SD Analog (LWIR)

Saliency & Behavioral Assessment

Thermal Fusion Assessment
Concept #2 – GP-GPU Acceleration

Jetson Tegra X1
With GP-GPU Co-Processing

USB3.0 HD
(Panchromatic, NIR, RGB)

Cloud Analytics and Machine Learning

Saliency & Behavioral Assessment

Flash SD Card (local database)

SD Analog (LWIR)

Many multi-spectral focal planes ...

Thermal Fusion Assessment

2D/3D Spatial Assessment
Test Config. #1 – DE1-SoC FPGA

- 5 Watts at Idle, Plus 1.5W per Camera = 9.5W
Test Config. #2 – Jetson TK1 GP-GPU

- 2 Watts at Idle, Plus 1.5 Watts per Camera = 6.5W
Year-2 3D Modeling

Solid Works Model for 3D printing of Custom Components and Overall Assembly and Integration
Year-2 Conclusions

- Bench Testing – 2 Watts Idle, < 10 Watts Full Rate

- Please Download our Benchmarks
  - [https://github.com/siewertserau/fusion_coproc_benchmarks](https://github.com/siewertserau/fusion_coproc_benchmarks)
  - MIT License

- Test on NVIDIA GP-GPU or FPGA SoCs (Altera, Xilinx)

- Share Results Back Please

- Help Us Add Benchmarks Critical to Continuous 3D Mapping and Infrared + Visible Fusion (Suite of Primitives)

- Open Source Hardware, Firmware, Software for Multispectral Smart Camera Applications
Arctic Power

- Primary Use on Buoys with Tidal Power

- Pole Mount or Remote Mount with Fuel Cell + Alternative Power Generation (Capstone Project at ERAU)

- Fuel Cell Operation (Winter – 4380 hours)
  - H2 PEM
    - 12W PEM Fuel Cell, 552L H2 Supply
    - 10% to 50% for Continuous Operation (0.6 to 6W for Jetson)
    - 0.18L/min, 0.09L/min to 0.009L/min is 100 to 1000 hours
    - Test Configuration Cost - $420.00 + $299.00

- Battery and Solar Recharge Operation (Summer – 4380 hours)
  - Potential Continuous Operation, Summer
  - OTS Larger Solar Kits - Automotive Batteries

- Super-capacitors (Quick Charge)
  - Combine with Batteries and/or Fuel Cell

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Computational Photometer Goals

1. **Education** – Reference Hardware, Firmware, Software for Students (Analog IR/Visible Photometer Interface, CameraPort HD Snapshots)

2. **Innovation** – Product Exploration and Definition for CV Applications (Wound Care, Ice Hazards, UAV natural resource surveys, Robotics & Automation)


4. **Fundamental Research** – Emulation, Interaction and Augmentation of Human Visual System
Smart Cam Educational Activities

Arctic Domain Awareness Center
U. of Alaska

(Joint Smart Camera Project with UAA, ERAU and CU Boulder)

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Year-0 – Multi-Channel System Prototype

- Custom PCB Work Abandoned in Favor of USB3 and PCIe Integration using GP-GPU SoC or FPGA SoC
- Comparison of Camera Integration Methods, Resulted in USB3 Baseline
- Move Toward Software Definition and System Integration
- Open Hardware, Firmware, Software – Open Design Files

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Why Build a Multi-Camera System?

- USB3 Integration is Simple and Open
- Cost, Open, RT Performance, Battery Power, 2+ Channel, Flexible Optics, Continuous Image Processing


<table>
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<th>Configuration</th>
<th>Cost</th>
<th>Openness</th>
<th>Performance</th>
<th>Efficiency</th>
<th>Score</th>
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<td>CP Analog (Digital)</td>
<td>Low (3)</td>
<td>Open HW, FW, SW (3)</td>
<td>*RT (3)</td>
<td>High (3)</td>
<td>12</td>
</tr>
<tr>
<td>Digital Camera Port⁵</td>
<td>Low (3)</td>
<td>Proprietary HW, Open FW, SW (2)</td>
<td>Variable (1)</td>
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<tr>
<td>Analog Camera with PC Frame Grabber</td>
<td>Low (3)</td>
<td>Proprietary HW, Open FW, SW (2)</td>
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<tr>
<td>CameraLink⁴</td>
<td>High (1)</td>
<td>Proprietary HW, IP FW, Open SW (1.5)</td>
<td>RT (3)</td>
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<td>8.5</td>
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<tr>
<td>USB Webcam, GoPro or Active Depth Mapper</td>
<td>Low (3)</td>
<td>Proprietary HW, FW, Open SW (1)</td>
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</tr>
<tr>
<td>Ethernet CCTV⁶</td>
<td>Medium (2)</td>
<td>Proprietary HW, FW, Open SW (1)</td>
<td>Predictable (2)</td>
<td>Low (1)</td>
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<tr>
<td>HD and SD-SDI</td>
<td>High (1)</td>
<td>Proprietary HW, FW, SW (0)</td>
<td>RT (3)</td>
<td>Low (1)</td>
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</tr>
</tbody>
</table>

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CP Interface PCB Design

- Dual TI Video Decoders, DE0 Cyclone III or DE2i
- Cyclone IV FPGA FIFO with Transform State Machines,
- Dual FTDI Uplink, I2C Configuration
Small CP Interface PCB + System

- CP Custom PCB
- Replaces Lucite on DE0
- Cyclone III FPGA (50K LEs) – DE0
- 2 Component Inputs
- Dual USB 2.0 Uplinks
- Suitable for UAV Use
- Drop-in-Place
- Robotics & Automation
- Beagle CameraPort for Leopard HD Cameras
- Any NTSC Optics + CCD
- TI-OMAP + Linux
3D Scene Parsing - Research

Human Depth Cues (Physiology, Psychology, Physics)
- Between 9 and 15 Recognized Cues – James Cutting, Peter Vishton

Machine Vision Methods (Active vs. Passive)
1. Passive
   - Structure from Motion (Suitable for UAV, Photogrammetry Elevation Estimations)
   - Binocular Stereopsis (Two Channel Registration and Triangulation with Camera Extrinsic and Intrinsic Calibration)

2. Active
   - Structured Light Projection (PrimeSense)
   - Time of Flight (LIDAR)

IEEE RAS Paper on CV Improvement with 3D – “Change Their Perception”, December 2013 IEEE RAS
Feature Vector Key-points

- Continuous Feature Vector Key-point Generation
- Requires Pyramidal Gaussian Resolution Decimation and Interpolation for Up-conversion (FPGA)
- **OpenCV Image Pyramids** – Low Pass Filtering (Gaussian kernel convolution) followed by pixel decimation (removal of odd or even numbered rows and columns)
- Requires Gradient (Edge) Computations
- Software-based Storage and Search

L=0, e.g. 9x9
L=1, 5x5
L=2, 3x3

Rows 0…8, Col 0…8
Drop rows 1,3,5,7 to go to L=1 5x5

Drop rows 1,3 to go to L=2 3x3
Image Correspondence for Depth

- Mosaics (Stitching)
- Stereopsis
- 3D Recognition
- Optical Flow
- Structure from Motion

Left-Eye

Right-Eye

Awareness, Recognition, Security, Safety
Alaska Arctic Applications - DHS

- Ice Flow Monitoring, Hazards – UAV and Drop-in-Place
- Roadway, Port, Runway – Animal Hazards, Shipping
- Volcanic and Geothermal Activity – UAV, Drop-in-Place

“If you Live with an 800 pound gorilla, you should listen to and observe every burp and hiccough” – Michio Kaku

Pavlov Volcano Eruption, Alaska

Arctic Shipping Security & Safety
http://www.arcticsecurity.org/?p=490
Security, Safety, and Resource Management Applications

- USGS – Counting Animals, Ground Truth for Vegetation, Water Resources, Crop Damage – Surplus Raven SUAV
- DHS – Low-Cost Remote Sensors for Arctic Monitoring, with focus on low power (solar) and ad-hoc sensor networking protocols to uplink data with minimal power and opportunistic uplink to maritime vessels and UAVs.
Research & Education Goals - Summary

Education
- Open Hardware, Firmware and Software – Analog layer, Digital, Firmware, and Linux Software
- Probing and Tracing at All Layers
- Starting Point for Capstone Design and Student Research

Research
- Compare Passive Binocular Vision with Computational Photometry Parallelism to Active RGB-Depth
  - Binocular = 2 Visible Coordinated Channels (UAV)
  - RGB-D = Active Structure IR Projection, IR & Visible Channel
- Low-Cost Infrared + Visible Computational Photometer for Remote Sensing and Safety/Security Applications
- Addition of IMU-on-Chip for Proprioception (Coordinated 3D Vision and Robotic Actuation)
3D Active Computational Photometry Concept (Rev-A + TI Kit)

TI DLP Light-crafter Kit
http://www.ti.com/tool/dlplightcrafter

IR Pattern Projection

Analog Camera #1
RGB (Visible)

Analog Camera #2
(Near Infrared)

Altera FPGA
CVPU
(Computer Vision Processing Unit)

HD Digital Camera Port
(Snapshot)

USB 2.0, PCIe Host Channels

Mobile Sensor Network Processor
(TI OMAP, Atom)

Flash SD Card

Depth Map

Networked Video Analytics

Photo credits and reference:
Dr. Daniel Aliaga, Purdue University
https://www.cs.purdue.edu/homes/aliaga/

2D Computer Vision Transforms

- Enable Intelligent Systems with Human-like Vision, but Wider Spectrum (Visible & Infrared)
- Real-Time 2D Scene Parsing & Understanding (OpenCV)

Canny Transform

Skeletal Transform

Hough Linear Transform
3D Computer Vision Transforms

**Long Range ( > 5 meters) Using Passive Binocular Methods**
- Impractical to Project from a UAV or Long Range Observer
- Requires Image Registration
- Accurate Camera Intrinsic (Camera Characteristics) & Extrinsic (e.g. Baseline)

**Short Range ( < 5 meters), Structured IR Light Projection for RGB-D**
- Compare to ASUS Xtion and PrimeSense – Off-the-Shelf
- Robust Depth Maps with Less Noise
- Showing Significant Promise to Improve CV Scene Segmentation and Object Recognition Compared to 2D

Noise in Passive Depth Maps

Robust Active Depth Map

The UAA Computer Engineering Prototype and Assembly Lab

- Supports Operating Systems (with Hardware)
- Computer Vision Lab – DE2i, DE0, TI-OMAP
- Alaska Space Grant Fellowship Lab (Autonomous Submersible, Computer Vision Guided)
- General Computer Engineering and Capstone
Related Research & Education

- Temporal and Spatial Locality (Memory Access) - Halide API (E.g. OpenCV) vs. Language (E.g. Halide)
- Impact of Lossy Compression on Computer Vision
- Impacts of Encode/Decode on Latency
Multi-Spectral: Visible, NIR, LWIR

- **Visible** – 350 to 740 nm (0.35 to 0.74 micron)
- **NIR** – 0.7 to 1 micron (Vegetation – NDVI)
- **LWIR** – 8 to 14 micron (Thermal Imaging, Water/Ice)
Sensor Development

- Super-Human Capabilities?
  - Beyond 5 Primary Senses (Adaptation to Them)

- E.g. LWIR – Long Wave IR or Thermal Imaging

- Black Ice, Moisture, Night Vision, Animals on the Road
Sensor Development

- **Near Infrared**

- **Segments Vegetation Well**
  - Plants Optimized for Photosynthesis
  - Agriculture
  - NDVI (Landsat – Normalized Difference Vegetation Index)
  - Useful for Tractors and Agricultural UAV/UAS Systems
LWIR – Thermal Imaging

- LWIR 8 to 14 micron
  [8000 – 14000 nm]
- NIR 0.74 micron to 1 micron
- Visible 350-740nm
- DRS 640

http://mivim.gel.ulaval.ca/

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Liquid Water Absorption


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LWIR Glass Transmission


© Sam Siewert
Glass Transmission

http://www.photoplotstore.com/pages/images/transmission_curves_v2.gif
Vapor, Water and Ice Absorption

Multi-spectral – Absorption Peaks for Vapor vs. Liquid and Solid

HOH Molecule Absorption Bands:
- $3657 \text{ cm}^{-1}$ ($v_1, 2.734 \mu m$), OH symmetric stretching
- $3756 \text{ cm}^{-1}$ ($v_3, 2.662 \mu m$), OH asymmetric stretching
- $1595 \text{ cm}^{-1}$ ($v_2, 6.269 \mu m$), HOH bending

Liquid=RED, Ice=BLUE, Vapor=GREEN


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Multi-Spectral & Passive 3D

- Real-Time Fusion of IR + Visible **with FPGA Efficiency**

![Image of real-time fusion](image1)

- Threat assessment, With Annotation

- Amount of hot Liquid detected And Quantified

- Passive 3D Depth Mapping with FPGA Efficiency

![Image of passive 3D depth mapping](image2)

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Visual Perception is Complex

- 8 or More Visual Cues for Human Depth Perception
- Relative Importance of Cues (Context Driven)

- Motion perspective
- Texture gradient
- Binocular disparity
- Accommodation
- Relative size
- Motion perspective
- Height in visual field
- Occlusion
- Aerial perspective (Contrast decreases, Rayleigh Scattering)
- Texture gradient
Visual Cues

- Depend Upon Space (Scene) of Interest
- James Cutting & Peter Vishton – Perceiving Layout

Diagram with axes labeled as follows:
- Depth Contrast
- Personal Space
- Action Space
- Vista Space
- Height in Visual Field
- Motion Perspective
- Binocular Disparities
- Convergence & Accommodation
- Aerial Perspective
- Occlusion
- Relative Size
- Relative Density
- Assumed utility threshold for information
Multi-Spectral Value – Education

- Value of Multi-spectral and Hyper-spectral Smart Cameras includes many Adjacent Applications
- E.g. Here LWIR and Visible are Used to Examine the ERAU Eagle Space Flight Team Rocket Test (8/3/15)
- Shows Thermal Image of Casing for Corresponding Test
Machine Learning Intelligence

- Detection of Safety and Security Threats (Visual)
- Threat Assessment and Characterization
- Annotation and Fusion with Real-Time Digital Video
- E.g. Potentially Unsafe Approach at Ted Stevens
Scene Understanding

- Behavior Modeling of Targets and Threats
- Skeletal Transformation, Posture, Threat Assessment
Comparison Baselines

- Passive 3D and Multi-spectral Fusion with OpenCV (software only) and OTS hardware using GP-GPU and Multi-core
  - FPGA vs. GP-GPU Efficiency and Battery Life
  - Hybrid Reconfigurable vs. All Software Approach

- Active RGB Depth Mappers – E.g. PrimeSense
  - Limited to Indoor Robotics Typically
  - Less Useful for DHS, USGS, NOAA and other Outdoor Missions

- Goal is to Offload to a Purpose Built CVPU (Computer Vision Co-Processor) and Open up CPU and GPU for Intended Purposes – Machine Learning and Graphics
OTS Uncooled LWIR – Many Options

High Resolution (640x480, 1024x768)
- **DRS Tamarisk** 640 - NTSC, 640x480, 8-14 micron (6.8-65mm lens), $6K OTS
- **FLIR Tau 2 640** - NTSC, 640x480, 7.5-13.5 micron (7.5mm-100mm lens), $TBD OTS
- **ATOM 1024** – GigE, 1024x768, 8-12 micron, (9.5-50mm), $TBD OTS

Medium Resolution
- **SEEK Thermal XR**, USB2 AOS, 206x156, 7.2-13 micron, (36 & 20 degree FoV), $250 OTS
- **Therm-App**, USB2 AOS, 384x288 17 micron (6.8-35mm lens), $939 OTS

Low Resolution (80x60)
- **ATOM80** USB2, 80x60, $900 OTS
- **FLIR Lepton** MIPI & SPI, 80x60, 8-14 micron, SDK Available, $183 OTS

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SDMSI Team Participation History

1. Sam Siewert – PI at ERAU, Adjunct CU-Boulder
2. Kenrick Mock – PI at UAA, ADAC Sensor Networks and Smart-Cam Lead
3. Matthew Vis ERAU URA - OpenCL Software on NVIDIA Jetson
4. Ryan Claus ERAU URA - DE1 FPGA Board, OpenCL for FPGA
5. Ram Krishnamurthy – MS EE
6. Surjith Singh – ME, ESE
7. Akshay Singh – ME, ESE
8. Shivasankar Gunasekaran – ME, ESE
9. Swaminath Badrinath – ME, ESE
10. Randall Myers, Industry Advisor, Mentor Graphics – PCB design

Previous Team Members:
1. Vivek Angoth – MS Student, OpenCL on DE1-SoC
2. Saurav Srivastava – MS Student, OpenCL on DE1-SoC
3. Nilendra Nimbalkar, CU – MS Student, OpenCV Software
4. Jeries Shihadeh, CU – Ph.D. Student, CU-Boulder, HW and FPGA FW
5. Vitaly Ivanov, UAA – BS Student, UAA, Verification, Lab Content
6. Jay Khandhar, CU – MS Student, CU-Boulder, DE2i & Linux
7. Sagar Sidhpura, CU – MS Student, CU-Boulder, Linux Real-Time Kernel
8. Arielle Blum – CU BS/MS Student, Capstone Program, PCB Design
10. Chris Wagner CU – MS Student, OpenCL for DE1-SoC

Current Sponsors: Arctic Domain Awareness Center - DHS Center of Excellence, ERAU Internal Research Grant
University Collaborators: ERAU Prescott, UAA, CU Boulder
Past Industry Sponsors: Intel, Altera, Mentor Graphics
Sensor Fusion - Basic Concepts

Visible Image Includes 3 Wavelengths
- Red, 650 nanometers
- Green, 510 nanometers
- Blue, 475 nanometers

Add Thermal LWIR Imaging
- Thermal Image Intensity
- False Color?
- Match Resolution and Overlay with Visible?

Many Applications for LWIR Multi-Spectral
- Cold Spots and Hot Spots - Ice, Fire Hazards
- Vegetation, Soil Moisture
- Animals and People
- E.g. SEEK Imager, 206x156, 7200 to 13000 nanometers

USGS Landsat Images

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Software-Defined Photometer – Port Security

Computational Photography Extension – Continuous Computer and Machine Vision Processing

CV Co-Processor – Between Photometer and CPU
  - Performs Function Like a GPU, but For CV
  - Computer Vision Turing Test - Inverse Rendering
  - Create a World/Scene Model From Image Sequence
  - Multi-Channel (Passive 3D, Multi-Spectral)

Open Hardware Reference, Low-Cost, Real-Time Performance

Black Bear Visits to Port of Anchorage & Government Hill
OTS Block Diagram

Sensor Fusion Processing – TI OMAP / Atom Microprocessor running OpenCV or **Networked Video Analytics in Cloud**

- **Analog Camera #1** (LEFT) (NIR, Visible)
  - Sony NTSC, Visible
- **Analog Camera #2** (RIGHT) (LWIR, TIR)
  - Xenics Rufus, FLIR Tau-2, DRS Tamarisk, L3, DST 640
- **Off-the-Shelf NTSC-to-USB Frame Grabber**
- **USB 2.0, PCIe Host Channels**
- **Mobile Sensor Network Processor** (TI OMAP, Atom)
- **Flash SD Card**
- **HD Digital Camera Port** (Snapshot)

Networked Video Analytics
Software CP Bottleneck

Sensor Fusion in the Cloud
Pass through – no intelligence

Analog Camera #1
LEFT (NIR, Visible)

Off-the-Shelf NTSC-to-USB Frame Grabber

2D Skeletal Transform

Networked Video Analytics

Mobile Sensor Network Processor (TI OMAP, Atom)

USB 2.0, PCIe Host Channels

Flash SD Card

HD Digital Camera Port (Snapshot)

Analog Camera #2
RIGHT (LWIR, TIR)

2D Hough Transform

Xenics Rufus, FLIR Tau-2, DRS Tamarisk, L3, DST 640

Sony NTSC Visible

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Concept #1 - FPGA Acceleration

Thermal Map Threat Assessment

Dynamic Hazard Assessment

Cloud Analytics and Machine Learning

HD Camera #1 (NIR, Visible)

Vector Processing CVPU (Computer Vision Processing Unit) DE1-SoC

USB 3.0, GigE Vision Host Channels

Mobile Sensor Network Processor

Flash SD Card (local database)

HD Digital Camera Port (Snapshot history)

2D/3D Spatial Safety Assessment

Many multi-spectral focal planes …

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Concept #2 – GP-GPU Acceleration

Thermal Map Threat Assessment

Dynamic Hazard Assessment

Jetson Tegra X1
With GP-GPU Co-Processing

Cloud Analytics and Machine Learning

Flash SD Card
(local database)

2D/3D Spatial Safety Assessment

HD Camera #1
(NIR, Visible)

HD Camera #N
(LWIR, UV)

Many multi-spectral focal planes …
Concept #1 - FPGA

- Transforms / second / Watt
- Linux OS and FPGA Fabric OpenCL Kernel
- DRS NTSC LWIR
- ATOM80 LWIR, Logitech USB Visible

Block Diagram of the DE1-SOC Board

SD LWIR

ATOM80 LWIR

HD Visible
Concept #2 – GP-GPU

- Transforms / second / Watt
- Linux OS and GP-GPU Vector Co-Processor OpenCL Kernel
- CSI MIPI Cameras [TBD]
- ATOM80 LWIR, Logitech USB Visible

ATOM80 LWIR

OV5640

© Sam Siewert
Smart Cam Arctic Power Subsystem

Arctic Domain Awareness Center
U. of Alaska
(Joint Smart Camera Project with ERAU and CU Boulder)
**ADAC Sensor Network Goals**

**ADAC**

**New Low-Cost Wireless Sensors for Arctic Monitoring**

ADAC is developing low-cost, wireless sensors that **do not require batteries for remote Arctic monitoring**. These low power sensors can form ad-hoc sensor networks for remote vessel tracking, surveillance, and monitoring of climate change (e.g., ice flow, depth). These sensors can collect, transmit, and **store data for long periods of time without external power**. They can then **transmit the data to unmanned aerial sensors or vessels of opportunity**.

**Smart Cam Node - Power Requirements [estimate 20 Watts]**
- LWIR Cameras – ≈1.5W in Continuous Operation x 2 = 3W [**DRS Tamarisk, FLIR Vue**]
- Processing [**Jetson TK1, DE1-SoC**] – ≈6W in Continuous Operation
- Networking (Unknown)
- Storage (Unknown)
- Efficiency and Margin (Unknown)

**Operate for 1 Year Unattended [6 months of DARKNESS, 6 months of SUN], Nominal Operating Temperature Range of -40F to 80F**

<table>
<thead>
<tr>
<th>Month</th>
<th>Jan (°F)</th>
<th>Feb (°F)</th>
<th>Mar (°F)</th>
<th>Apr (°F)</th>
<th>May (°F)</th>
<th>Jun (°F)</th>
<th>Jul (°F)</th>
<th>Aug (°F)</th>
<th>Sep (°F)</th>
<th>Oct (°F)</th>
<th>Nov (°F)</th>
<th>Dec (°F)</th>
<th>Year (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Record high</strong></td>
<td>36 (2)</td>
<td>38 (3)</td>
<td>34 (1)</td>
<td>42 (6)</td>
<td>47 (8)</td>
<td>72 (22)</td>
<td>79 (26)</td>
<td>76 (24)</td>
<td>62 (17)</td>
<td>43 (6)</td>
<td>39 (4)</td>
<td>34 (1)</td>
<td>79 (26)</td>
</tr>
<tr>
<td><strong>Average high</strong></td>
<td>-7.3 (-21.8)</td>
<td>-8 (-22)</td>
<td>-5.9 (-21.1)</td>
<td>8.5 (-13.1)</td>
<td>25.8 (-3.4)</td>
<td>40.5 (4.7)</td>
<td>46.9 (8.3)</td>
<td>43.9 (6.6)</td>
<td>35.8 (2.1)</td>
<td>21.8 (-5.7)</td>
<td>6.2 (-14.3)</td>
<td>-1.8 (-18.8)</td>
<td>17.2</td>
</tr>
<tr>
<td><strong>Daily mean</strong></td>
<td>-13.4 (-25.2)</td>
<td>-14.2 (-25.7)</td>
<td>-12.5 (-24.7)</td>
<td>1.8 (-16.8)</td>
<td>21.1 (-6.1)</td>
<td>35.6 (2)</td>
<td>40.9 (4.9)</td>
<td>39.0 (3.9)</td>
<td>32.1 (0.1)</td>
<td>17.2 (-8.2)</td>
<td>0.7 (-17.4)</td>
<td>-7.8 (-22.1)</td>
<td>11.71</td>
</tr>
<tr>
<td><strong>Average low</strong></td>
<td>-19.5 (-28.6)</td>
<td>-20.4 (-29.1)</td>
<td>-19.1 (-28.4)</td>
<td>-4.9 (-20.5)</td>
<td>16.5 (-8.6)</td>
<td>30.8 (-0.7)</td>
<td>34.8 (1.6)</td>
<td>34.1 (1.2)</td>
<td>28.5 (-1.9)</td>
<td>12.6 (-10.8)</td>
<td>-4.8 (-20.4)</td>
<td>-13.8 (-25.4)</td>
<td>6.2 (-14.3)</td>
</tr>
<tr>
<td><strong>Record low</strong></td>
<td>-53 (-47)</td>
<td>-56 (-49)</td>
<td>-52 (-47)</td>
<td>-42 (-41)</td>
<td>-19 (-28)</td>
<td>4 (-18)</td>
<td>22 (-7)</td>
<td>20 (-7)</td>
<td>1 (-17)</td>
<td>-32 (-36)</td>
<td>-40 (-40)</td>
<td>-55 (-48)</td>
<td>-56 (-49)</td>
</tr>
</tbody>
</table>

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How To Generate 20 Watts without Batteries?

- PEM (Proton Exchange Membrane) Fuel Cells
  - Powered by Hydrogen [Gas Canister]
  - Expensive, but Off-the-Shelf
  - E.g. Horizon 20W H2 Fuel Cell

- Ultra-capacitors [Quick Store and Discharge, -40 to 149F Operation]
  - http://batteryuniversity.com/learn/article/whats_the_role_of_the_supercapacitor

- H2 Fuel – Industrial or Innovative H2 Economy [HyCan]

- Solar Cells [Summer Only]

- Wind Power Generation [Extreme Wind Variation]

- Tidal or Hydroelectric [Coastal and USCG Use]

- Diesel Generators and Wind Diesel [State of Practice]

- Other?
Capstone Design

- Feasibility of Year Long Unattended Power [20W] in Arctic Conditions
- Integration of Power Generation, Storage, Management and Distribution
- Power Electronics
- Power Monitoring, Health & Status, Safety
- Demonstration of Proof-of-Concept
- Field Test by U. of Alaska ADAC
Open Reference Design for Distribution by Mentor Graphics and Intel Embedded Education and Research Program

- Exposes Students to High Quality 3D Vision
- Configurable Research Platform for 3D Passive & Active Mapping and Multi-spectral
- Low Cost Arctic Research Platform, No Batteries, Drop-in-Place
- UAV - Battery Powered, Soil Erosion, Vegetation, Animal Surveys, SAR Ops