The Goal

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

Smarter “Go-Pro Like” Instrument for Safety, Security, Resource Monitoring (DHS, USGS, …)
- Drop-in Place on UAV, Marine Vessel, Buoy, Port
- Smarter, Multi-Channel
- Potentially Wearable
- Power Efficient
- Intelligent Uplink

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

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

- Passive 3D Depth Mapping with FPGA Efficiency

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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
LWIR Sensors

- High Resolution – **DRS Tamarisk** NTSC, 640x480, $6K OTS

- Medium Resolution – **SEEK Thermal** XR, USB 2, 206x156, $250 OTS

- Low Resolution – **ATOM80** USB 2, 80x60, $900 OTS

Fully Integrated with NVIDIA Jetson with Visible 640x480 and OpenCV

Integrated with Ubuntu 12.04 LTS, V4L2 Connexant Decoder

False Coloring by SEEK AOS App, Not Yet Integrated

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The Current CP Team

- Sam Siewert – PI at ERAU, Adjunct CU-Boulder
- Dylan Schindler, Matthew Vis, Chris Johnson - ERAU Undergraduates, OpenCV Software on Jetson
- Nicholas Mallott on DE1 FPGA Board
- Randall Myers, Mentor Graphics – TME, PCB design
- Chadi Abdelsamad, CU – PhD Student, HW PCB
- Vivek Angoth, CU – MS Student, Camera Interfaces, OpenCL for FPGA and GP-GPU

Previous Team Members:
- Nilendra Nimbalkar, CU – MS Student, OpenCV Software
- Jeries Shihadeh, CU – Ph.D. Student, CU-Boulder, HW and FPGA FW
- Vitaly Ivanov, UAA – BS Student, UAA, Verification, Lab Content
- Jay Khandhar, CU – MS Student, CU-Boulder, DE2i & Linux
- Sagar Sidhpura, CU – MS Student, CU-Boulder, Linux Real-Time Kernel

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 / Computational Photometry

- 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

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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, Standards Algorithms, Improved Performance

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)
OTS Block Diagram

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

- Analog Camera #1 LEFT (NIR, Visible)
- Analog Camera #2 RIGHT (LWIR, TIR)
- 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)

Sony NTSC Visible

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

Sensor Fusion in the Cloud
Pass through – no intelligence

Analog Camera #1
LEFT
(NIR, Visible)

Analog Camera #2
RIGHT
(LWIR, TIR)

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

2D Hough Transform
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)

Sony NTSC Visible

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

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Concept #1 - FPGA Acceleration

Thermal Map Threat Assessment

Dynamic Hazard Assessment

HD Camera #1 (NIR, Visible)

Vector Processing CVPU (Computer Vision Processing Unit)

HD Camera #N (LWIR, UV)

USB 3.0, GigE Vision Host Channels

Mobile Sensor Network Processor

Cloud Analytics and Machine Learning

2D/3D Spatial Safety Assessment

Flash SD Card (local database)

HD Digital Camera Port (Snapshot history)

Many multi-spectral focal planes ...
Concept #2 – GP-GPU Acceleration

- Thermal Map Threat Assessment
- Dynamic Hazard Assessment

Jetson Tegra X1
With GP-GPU Co-Processing

HD Camera #1
(NIR, Visible)

HD Camera #N
(LWIR, UV)

Flash SD Card
(local database)

Cloud Analytics and Machine Learning

2D/3D Spatial Safety Assessment

Many multi-spectral focal planes …
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
### Why Build a New Camera Interface?

Cost, Open, RT Performance, Battery Power, 2+ Channel, Flexible Optics, Continuous Image Processing


<table>
<thead>
<tr>
<th>Configuration</th>
<th>Cost</th>
<th>Openness</th>
<th>Performance</th>
<th>Efficiency</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<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 Port(^5)</td>
<td>Low (3)</td>
<td>Proprietary HW, Open FW, SW (2)</td>
<td>Variable (1)</td>
<td>High (3)</td>
<td>9</td>
</tr>
<tr>
<td>Analog Camera with PC Frame Grabber</td>
<td>Low (3)</td>
<td>Proprietary HW, Open FW, SW (2)</td>
<td>RT (3)</td>
<td>Low (1)</td>
<td>9</td>
</tr>
<tr>
<td>CameraLink(^4)</td>
<td>High (1)</td>
<td>Proprietary HW, IP FW, Open SW (1.5)</td>
<td>RT (3)</td>
<td>High (3)</td>
<td>8.5</td>
</tr>
<tr>
<td>USB Webcam, GoPro or Active Depth Mapper</td>
<td>Low (3)</td>
<td>Proprietary HW, FW, Open SW (1)</td>
<td>Variable (1)</td>
<td>High (3)</td>
<td>8</td>
</tr>
<tr>
<td>Ethernet CCTV(^6)</td>
<td>Medium (2)</td>
<td>Proprietary HW, FW, Open SW (1)</td>
<td>Predictable (2)</td>
<td>Low (1)</td>
<td>6</td>
</tr>
<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>
<td>5</td>
</tr>
</tbody>
</table>
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

Awareness, Recognition, Security, Safety

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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
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

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)
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

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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

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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 Research Platform, Battery Powered, Drop-in-Place or UAV