CASPR: Autonomous Sensor Processing Experiment for STP-H7

S. Roffe, T. Schwarz, T. Cook, N. Perryman, J. Goodwill, E. Gretok, A. Phillips,
M. Moran, T. Garrett, A. George

University of Pittsburgh

Mission-Critical Computing
NSF CENTER FOR SPACE, HIGH-PERFORMANCE, AND RESILIENT COMPUTING (SHREC)

U.S. NAVAL RESEARCH LABORATORY

PITT SWANSON ENGINEERING ELECTRICAL & COMPUTER

NASA Goddard SPACE FLIGHT CENTER

SATLANTIS

RENESAS

infineon

AIR FORCE RESEARCH LABORATORY

Texas Instruments

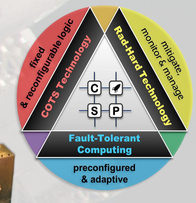
Introduction

Motivation

- Adapt and Evaluate Advanced Sensing and Computing Technologies for Autonomous Sensor Processing in SmallSat Form-Factor

Hybrid Space Computing

- Multifaceted Hybrid Space Computing
  - **Hybrid SoC:** CPU + FPGA
  - **Hybrid Architecture:** COTS + Rad-hard
  - **Robust Design:** Novel mix of COTS, rad-hard, and fault-tolerant computing



STP-H5-CSP

STP-H6-SSIVP

Featured Sensors

- Satlantis iSIM-90
  - Ultra-low ground resolved distance (GRD) at ISS altitude: 3.7 m (1.7 m with super-resolution)
  - Small form-factor for SmallSat earth observation
  - 12-megapixel (3072*4096) Sentech imager
  - Multispectral (NIR, red, green, blue)

- Sysley Neuromorphic Sensor
  - Event-driven high frame-rate capture with low data rate for object tracking
  - Static background ignored by sensor
  - QVGA resolution: (304×240)
  - 50 kfps @ 1000 Lx

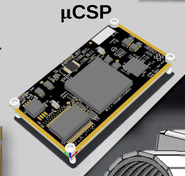
Featured Computing Technologies

- CHREC Space Processor (CSP)
  - Features Zynq-7020 SoC
  - Operational on STP-H5-CSP (Mar'17) and STP-H6-SSIVP (May'19) on-board ISS
- SHREC Space Processor (SSP)
  - Features Zynq-7045 SoC, MGTs, and FPGA-dedicated DDR memory
- µCSP Smart Module
  - Small form-factor Smart Module for thermal management and gimbal control
- Intel's Optane Phase-Change Memory (PCM)
  - Intrinsically rad-tolerant non-volatile memory for large data storage
- AMD G-Series GX-216HC
  - Commercially purchased GPU for ML/CV app acceleration

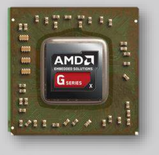
CSP

SSP

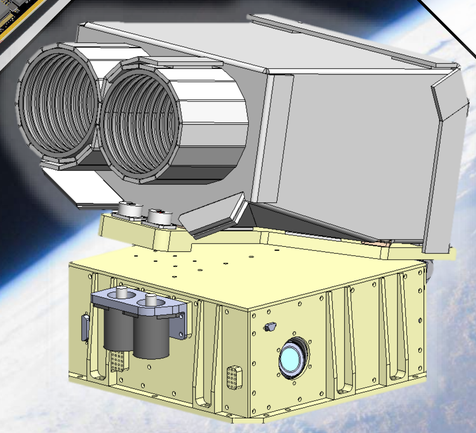
µCSP



GPU

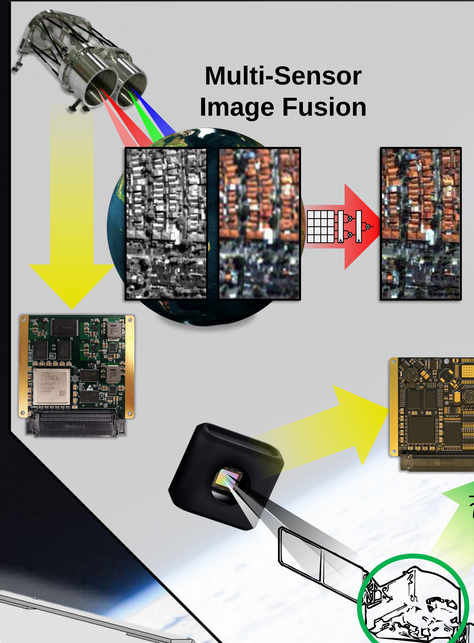


PCM



Experiment Applications

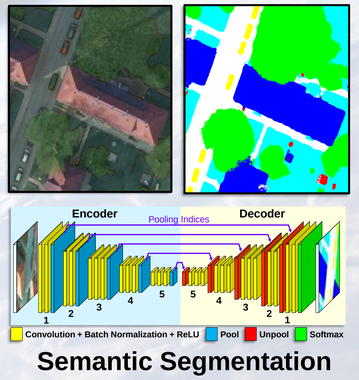
Multi-Sensor Image Fusion



Gaussian-Blob Tracking

Image Super-Resolution

Semantic Segmentation



Super-Resolution

- Upsample pixels to generate image with higher resolution than original image

Image Fusion

- Combine images from multiple distinct sensors to generate one image with more information than the source images

Deep Learning

- Use convolutional neural networks (CNNs) trained to classify and label objects in images (e.g., semantic segmentation)

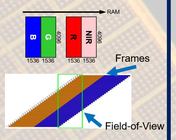
Object Tracking

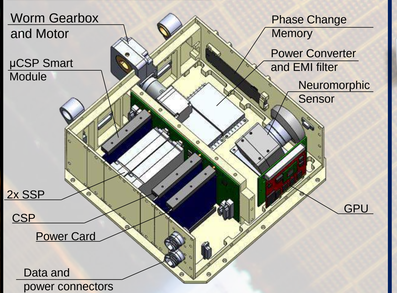
- Leverage high framerate of neuromorphic sensor for object and velocity tracking on the horizon

Mechanical & Power

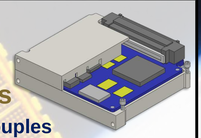
Features

- Gimbal-Actuated Optics
  - Single-DoF system allows for 15° rotation towards starboard
  - Stepper motor with 30:1 gear reduction ratio provides 1/10 FoV pointing accuracy
  - Hinge joint contributes to thermal isolation of optical assembly

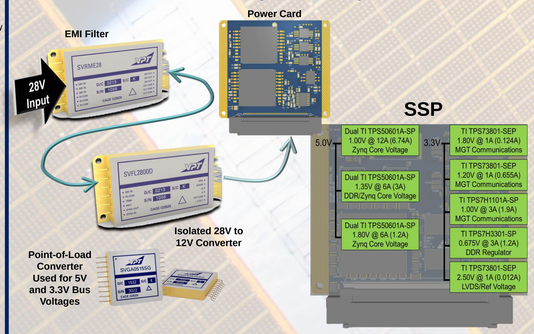




- Active Thermal Management of Optics
  - Six heaters and thermocouples manage temperature of optics
  - System cold biased for all beta angles
  - 15-layer multi-layer insulation ensures stability as orbital conditions vary



- Radiation-Hardened Power Components
  - CASPR uses VPT power converters
  - SSP uses Texas Instruments power devices
  - Enables reliable power to system as a whole



STP-H7-CASPR

Mission

- Adapt & Evaluate Sensing and Computing Technologies for Autonomous Sensor Processing
- Experiment on STP-H7 Pallet

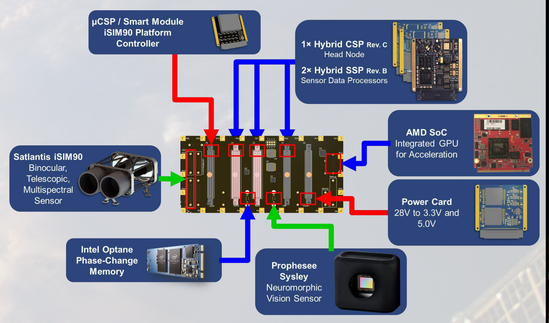
Success Criteria

- SSP
  - Accelerate computing with MGT communications
- iSIM90
  - Perform low-GSD experiments autonomously
- Neuromorphic Sensor
  - Tracking space objects for space situational awareness
- GPU
  - Accelerate Machine Learning and Computer Vision apps
- PCM
  - Long-term storage of data collected from sensors

Electrical & Computing

System Architecture

- Components
  - One CSP *Head Node* (CD&H)
  - Sysley Neuromorphic Sensor
  - Two SSP *Camera Nodes* (sensor-interfacing and compute)
  - iSIM90 binocular optics
  - Smart Module with µCSP (thermal management and gimbal-motor control)
  - One PCM Node (storage)
  - One GPU Node (compute)
  - One Interconnect Backplane
  - One Power Card



Features

- Management
  - Power Management to maximize experimentation
  - µCSP for gimbal control and active thermal management
- Processing Flows
  - Parallel processing over MGTs
  - Data passed from SSP0 to GPU for offloading computation
  - Store raw and processed data in PCM