CRAFT PROSPECT

A Space Engineering Practice

12th December 2018, CEOI Showcase

Onboard Data Autonomy for Next Generation of Earth Observation Nanosatellites

CEOI Pathfinder : Jul 17 – Mar 18

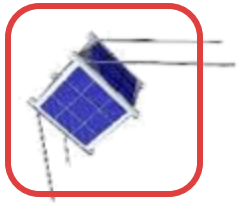
MANCHESTER 1824
The University of Manchester

UCL

bright ascension

Centre for EO Instrumentation

Craft Prospect Today



Mission & System Engineering

Enabling Technologies & Services

Novel Mission Applications

Products
e.g. Forwards Looking Imager

MISSION ARCHITECTING

RESPONSIVE OPERATIONS

Revenue

Enables

KEY AUGMENTATION SERVICE

Throughout all investing in the development of systems engineering and processes

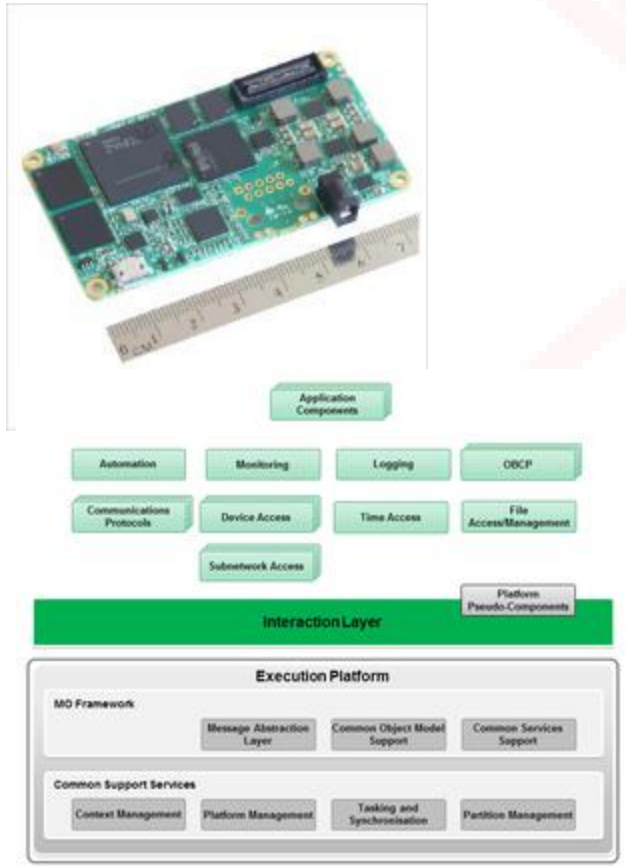
Opportunity

- Growth in **demand for real-time actionable** data from space
- **Resource-constrained small satellites** dominating manifests
- **Intensive applications** like space video and IoT communications
- Need to manage complex **networked concept of operations**
- Existing **operational paradigms outdated**
- Rapidly evolving **consumer-driven autonomy** market

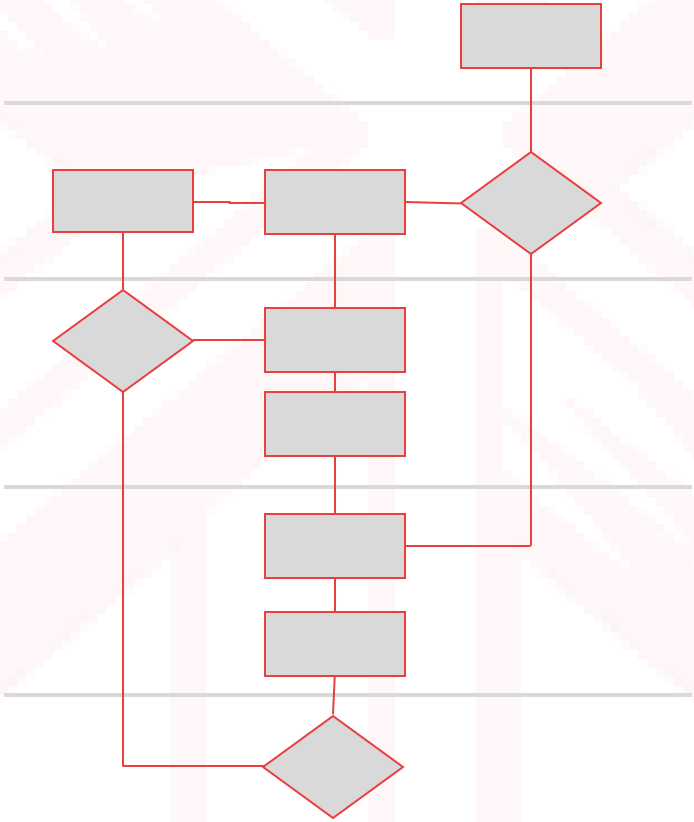
=> Develop common product components to enable more responsive operations

Framework needs

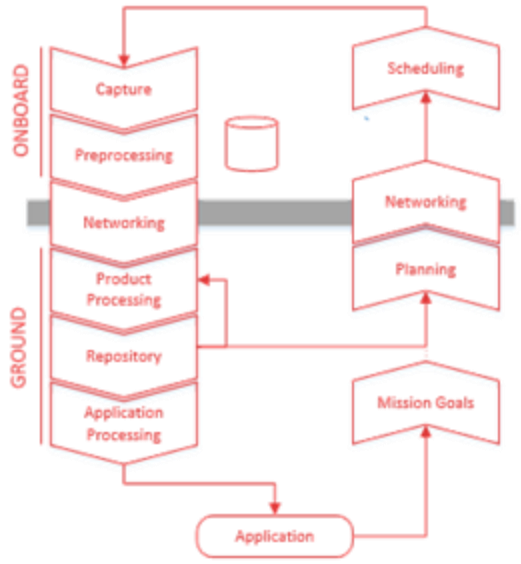
Align to/extends existing approaches

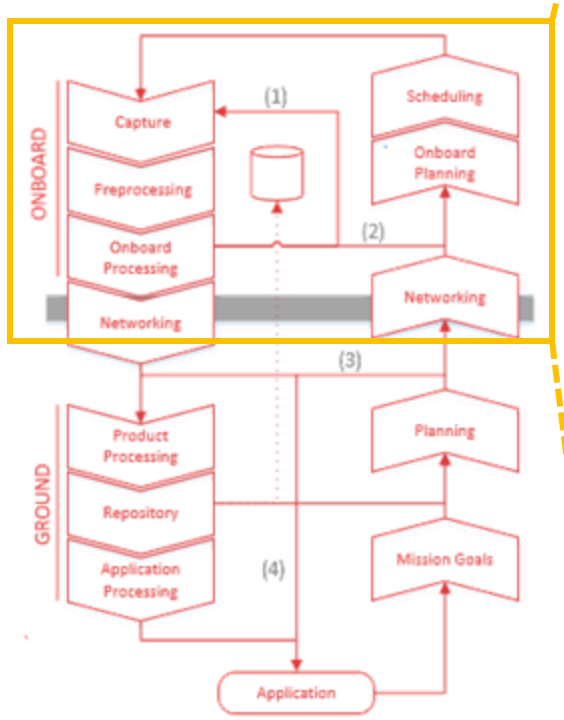


Interfaces to existing software/hardware



Allows robust fault detection, isolation and recovery





Current → Future

Monitoring & Control *
- Event Log
- (Critical) Monitor
- Event-Action

Planning & Scheduling *
- Resource Forecasting
- Goal Planning
- Scheduling

Autonomy Manager
- Autonomy Supervisor

Flight Dynamics *
- Orbit Model

Onboard Control Procedures *
- Scripting

Data Source
- Instrument
- Instrument Manager

Networking
- Comms Stack
- Comms Manager

Data Processing
- Realtime Process
- Offline Process

Archiving *
- Product Summary
- Data Manager
- Data Store

Deployment *
- Component Explorer

bright ascension

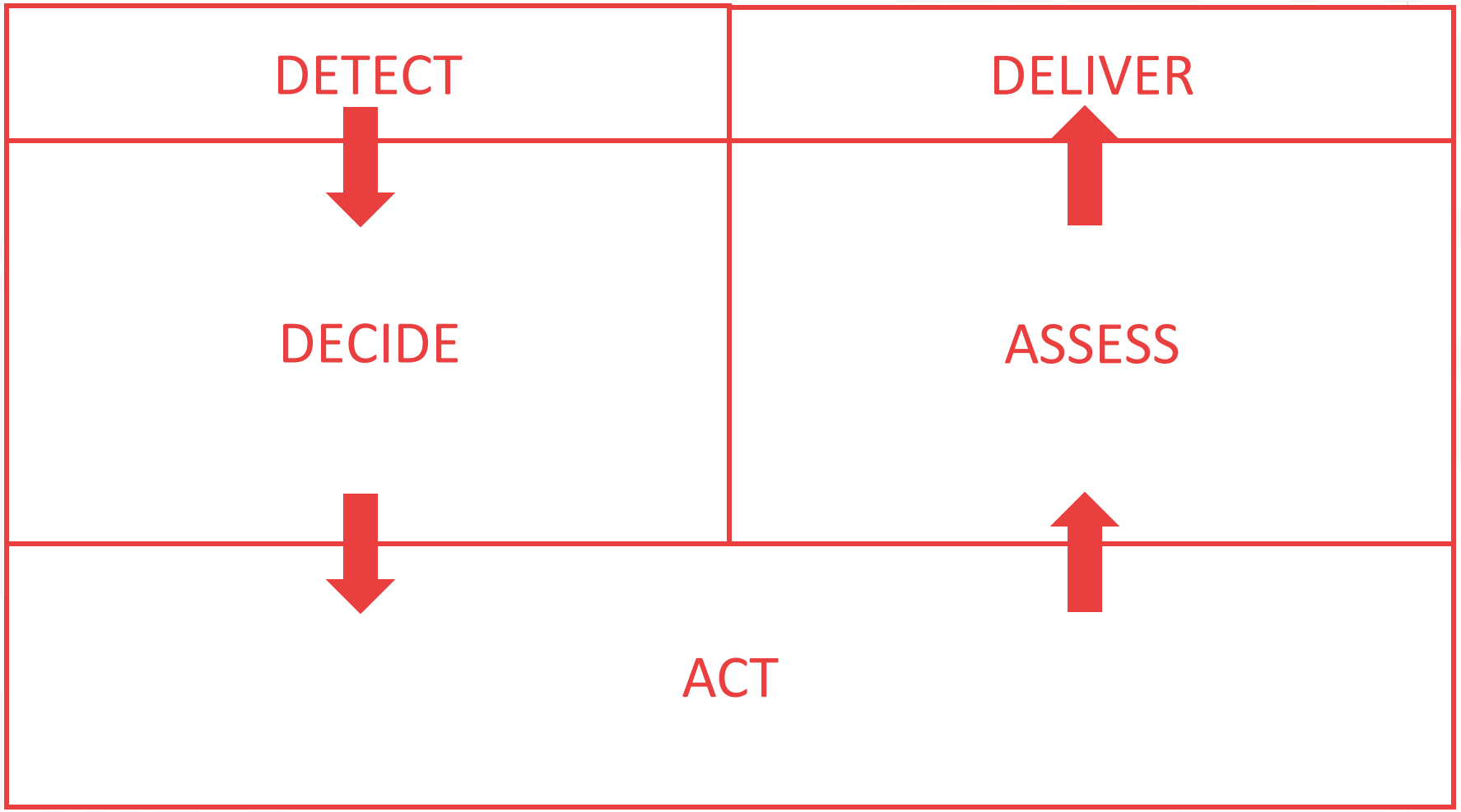
Defined in this work

Gen1 current or planned

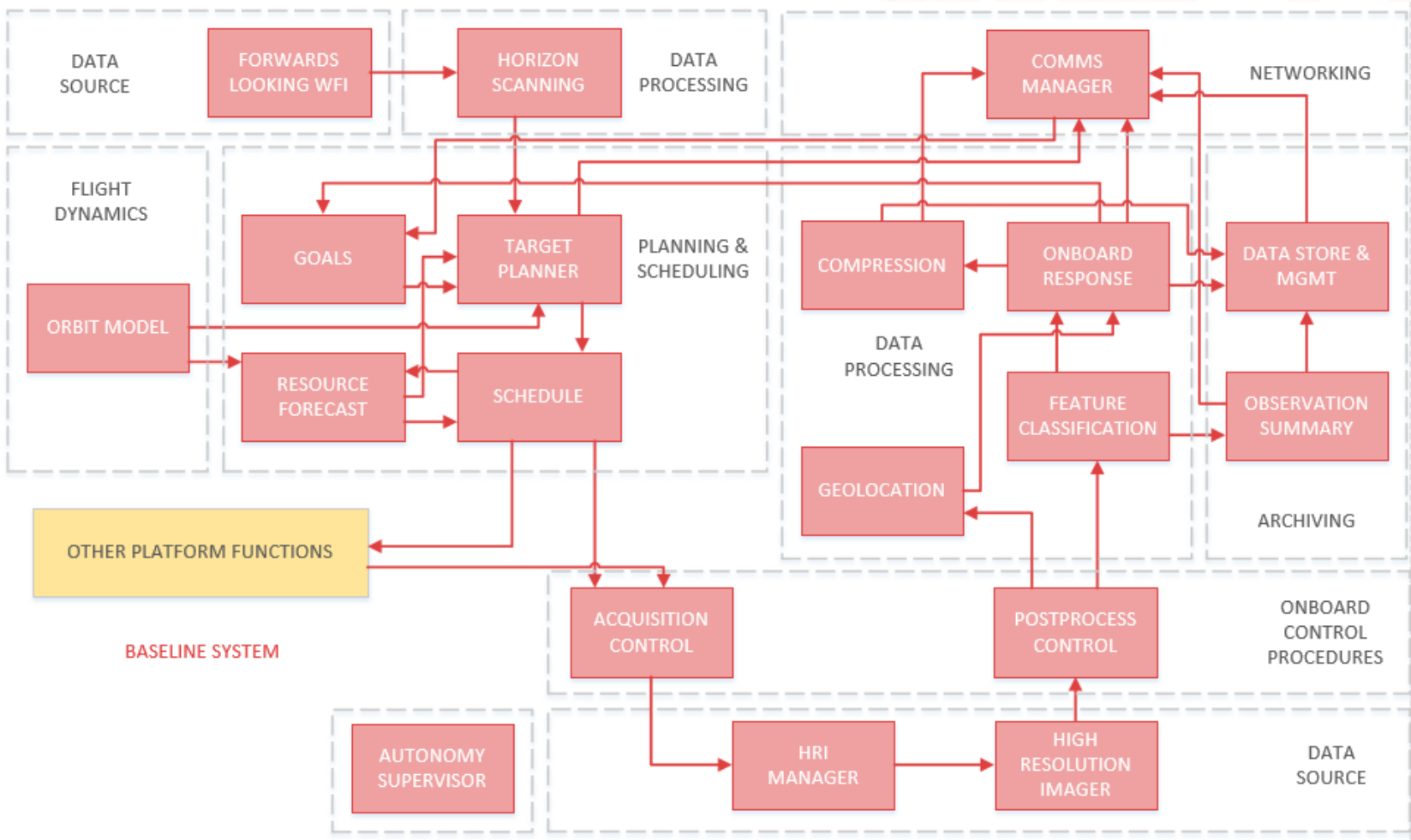
* defined MO service exists

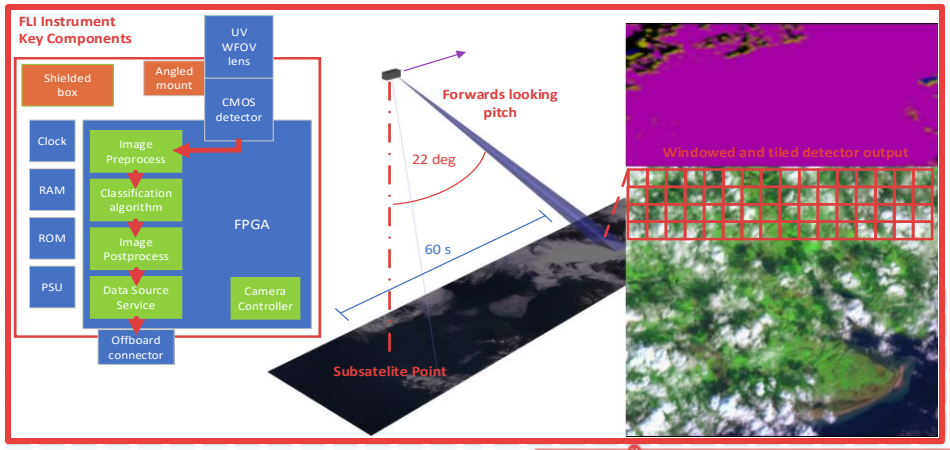

2:57 PM
ATLAS
Monday, May 16, 2016
SX9 SPLIT TRAINING
Body Boost
220
118
29:33
Exercise Name
Reps
Lbs
Form
Dumbbell Thruster
5
35
Dumbbell Thruster
5
40
Dumbbell Thruster
5
35
SUMMARY
CARDIO
FREESTYLE

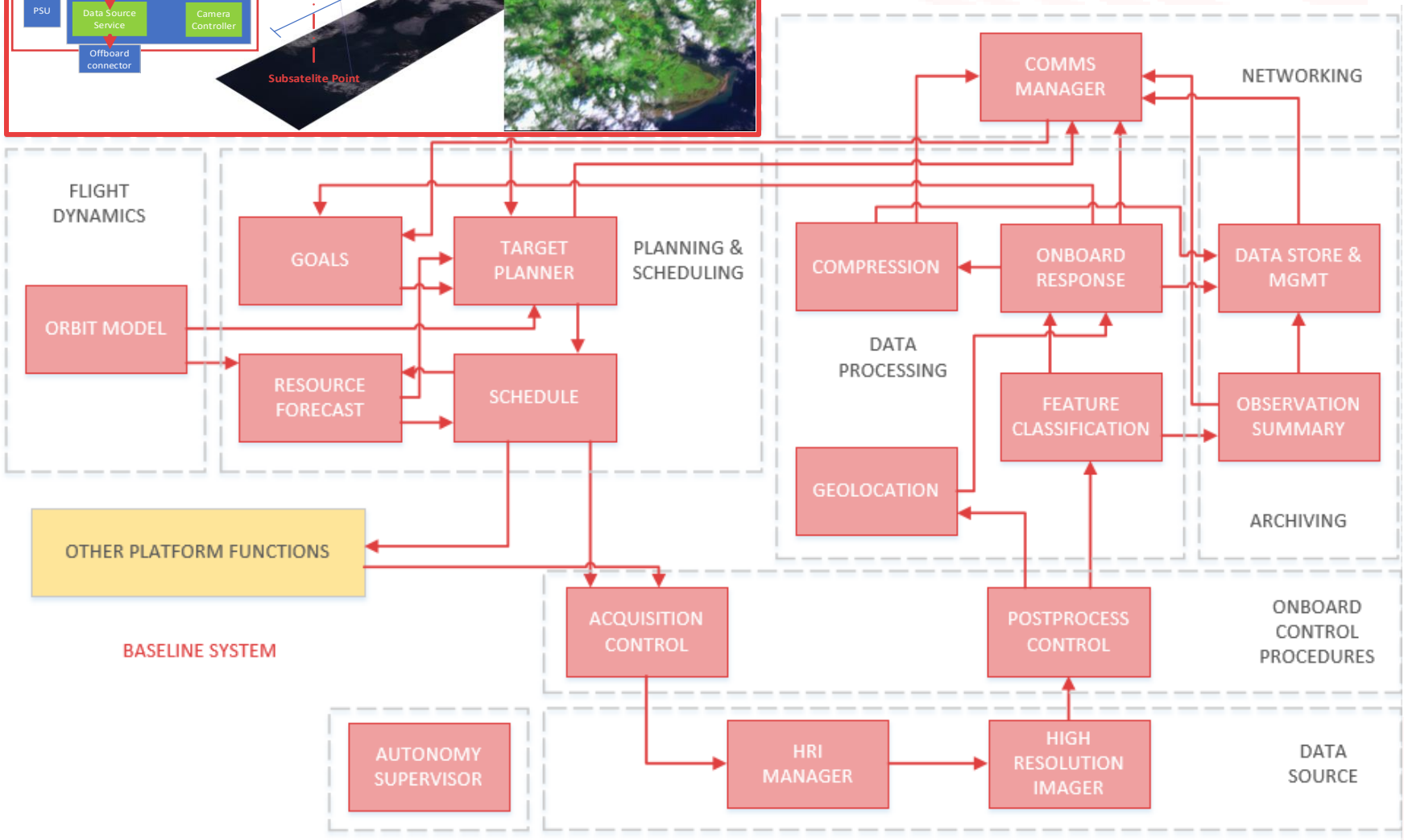
Reference Onboard Architectures



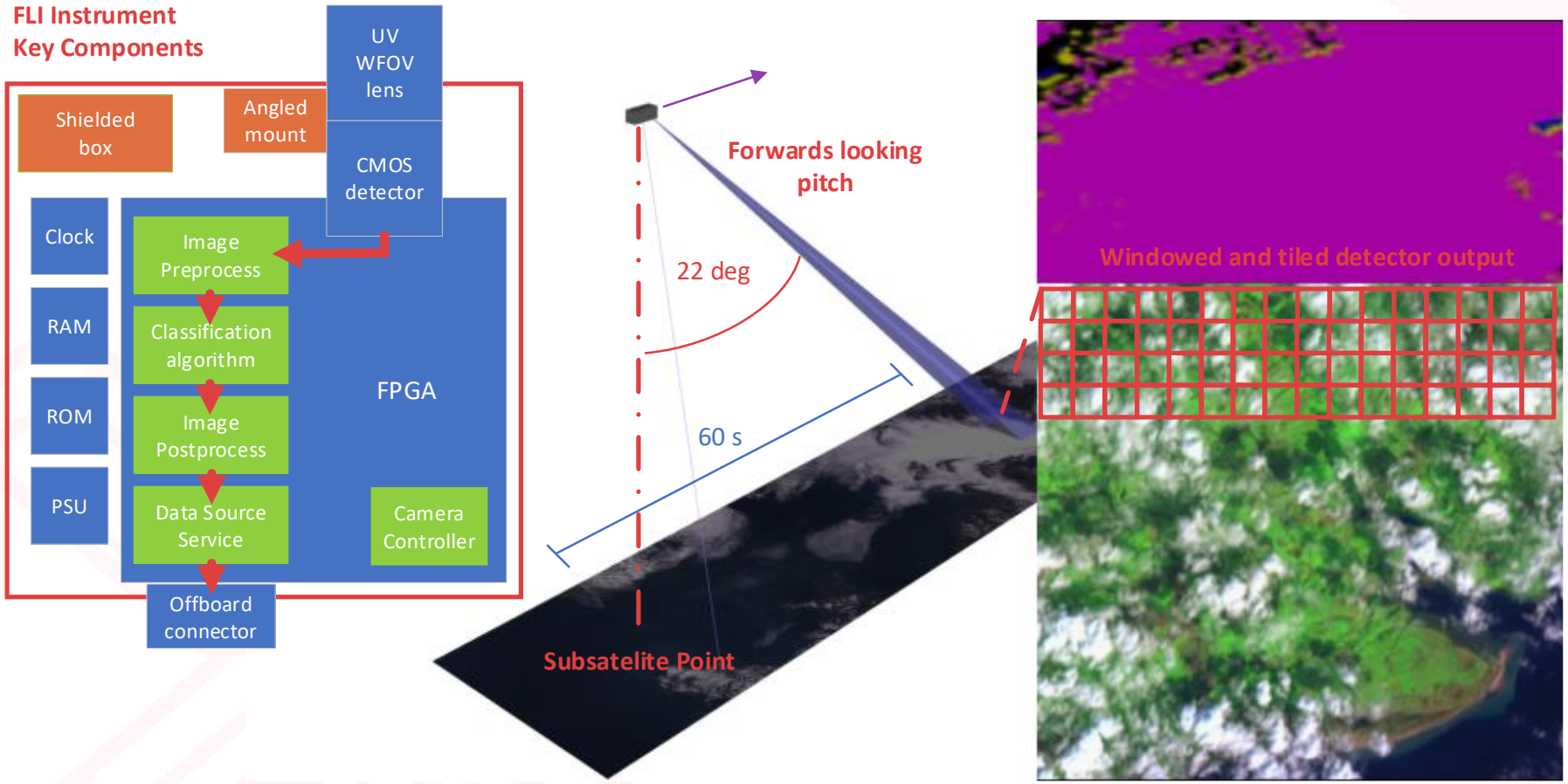
Reference Onboard Architectures




FLI Instrument
Key Components
Shielded box
Angled mount
UV WFOV lens
CMOS detector
Clock
RAM
ROM
PSU
Image Preprocess
Classification algorithm
Image Postprocess
Data Source Service
FPGA
Camera Controller
Offboard connector
Forwards looking pitch
22 deg
60 s
Subsatelite Point
Windowed and tiled detector output

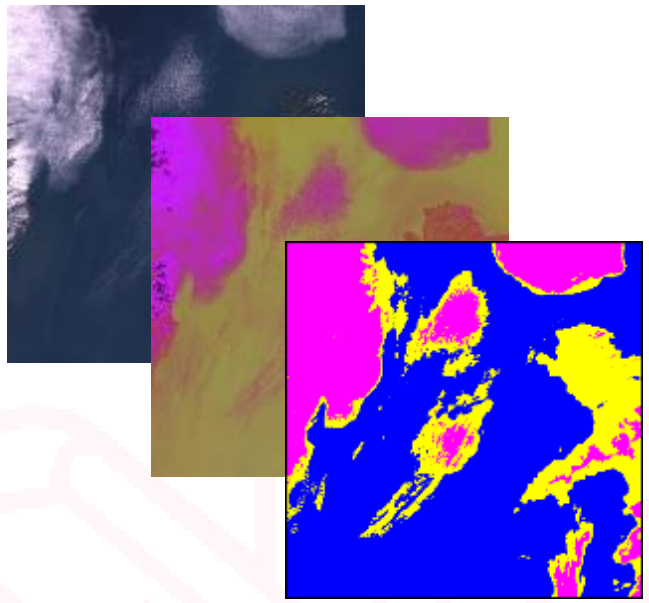

COMMS MANAGER
NETWORKING
FLIGHT DYNAMICS
GOALS
TARGET PLANNER
PLANNING & SCHEDULING
ORBIT MODEL
RESOURCE FORECAST
SCHEDULE
COMPRESSION
ONBOARD RESPONSE
DATA STORE & MGMT
DATA PROCESSING
FEATURE CLASSIFICATION
OBSERVATION SUMMARY
GEOLOCATION
ARCHIVING
OTHER PLATFORM FUNCTIONS
BASELINE SYSTEM
ACQUISITION CONTROL
POSTPROCESS CONTROL
ONBOARD CONTROL PROCEDURES
AUTONOMY SUPERVISOR
HRI MANAGER
HIGH RESOLUTION IMAGER
DATA SOURCE

DETECT: Forwards Looking Imager

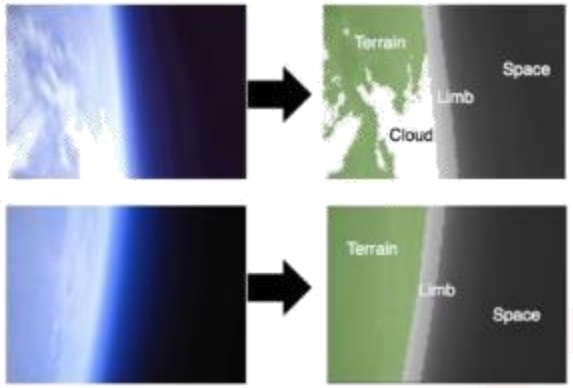


- Target prioritisation
- Resource assignment
- Payload repointing/slew
- Constellation task reassignment

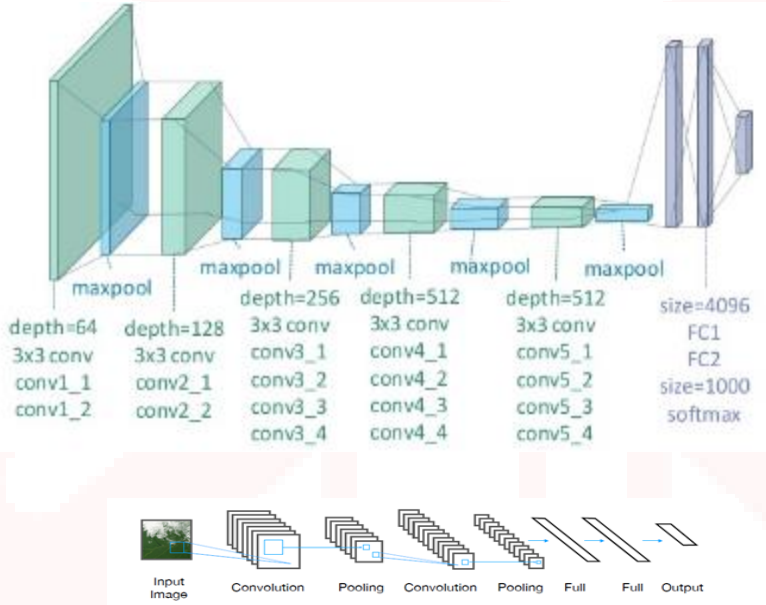
FLI Algorithm Downselect



Fmask



TextureCam

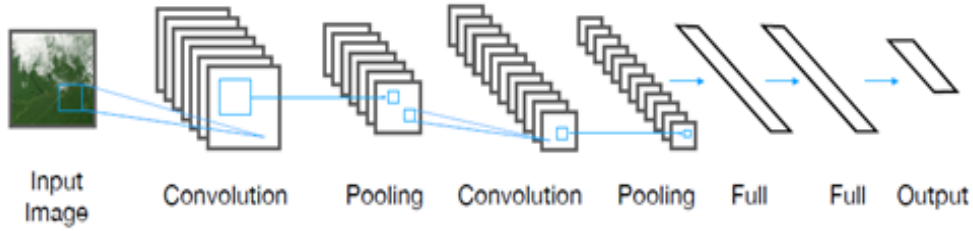


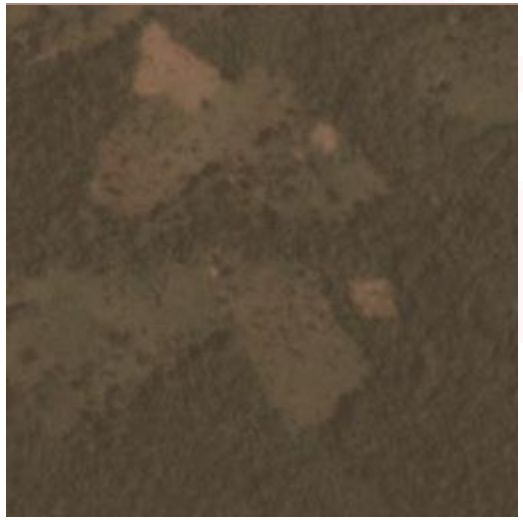
Deep learning

Increasing applicability across domains

Deep learning

- Applied transfer learning to existing CNN
- Modified open source VGG
- Trained using Planet Labs classification tiles
- < 1 hr training
- < 1 s inference





{ ‘agriculture’, ‘cultivation’, ‘habitation’, ‘partly_cloudy’, ‘primary’, ‘road’ }

Simonyam K & Zisserman A, “Very deep convolutional networks for large scale image recognition,” arXiv preprint arXiv:1409.1556, 2014.

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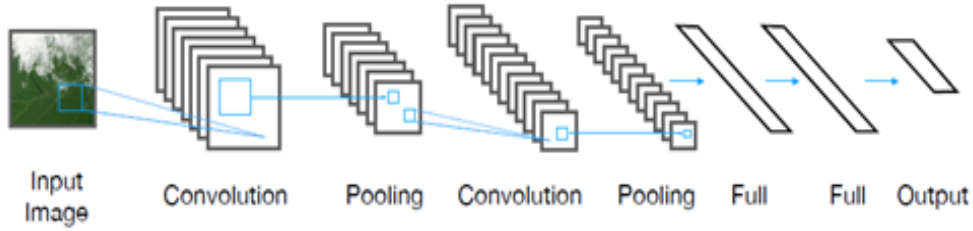

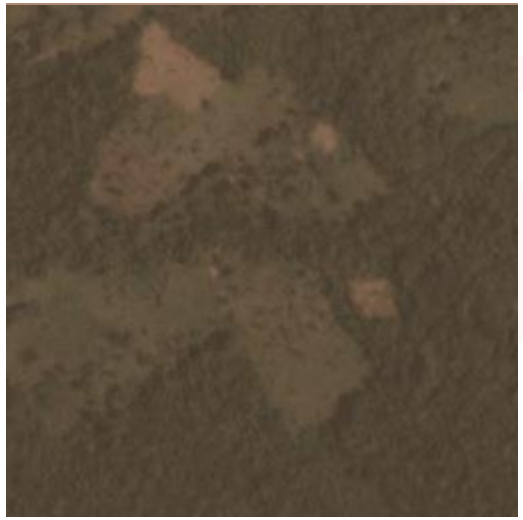

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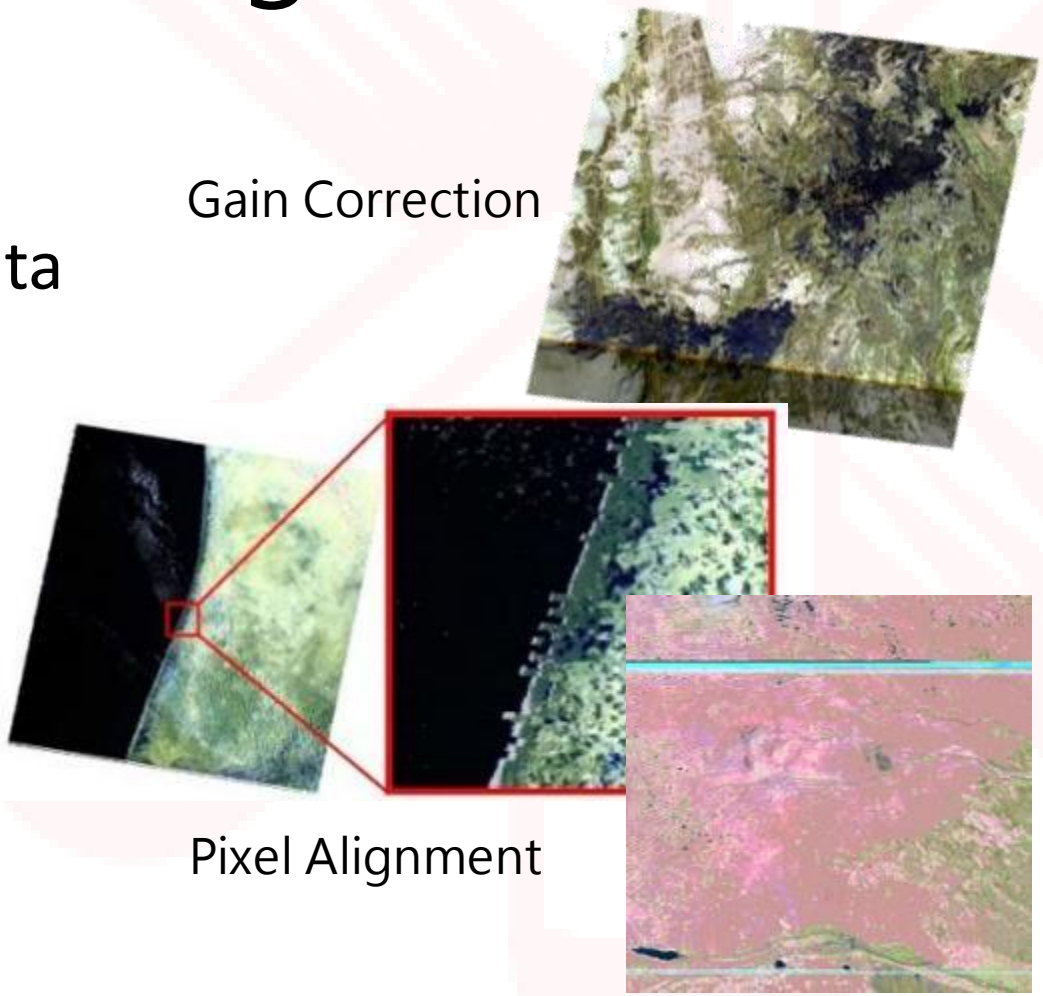
Implementation challenges

- Power and processing constraints
- Access to applicable Level 0 training data
- Ground reference points
- Incorporating anomalies
- Onboard systems interfacing
- Meeting operational regulations
- Demonstrating mission assurance
- Parallax error due to forwards looking



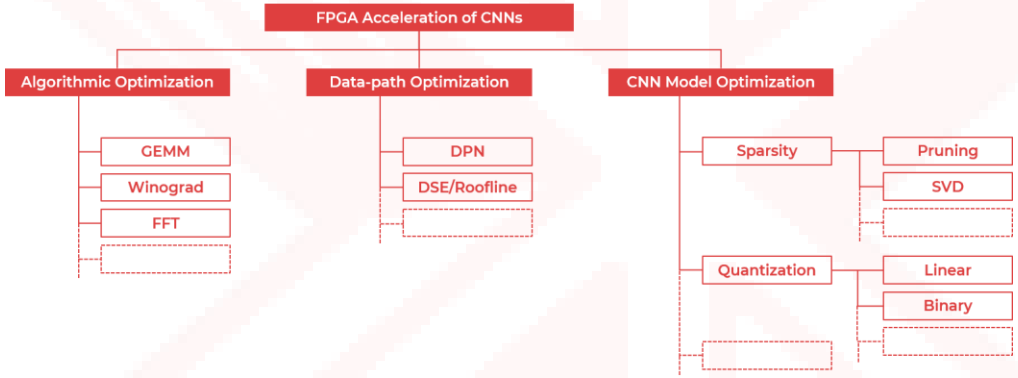
Gain Correction

Pixel Alignment

Sun Glint

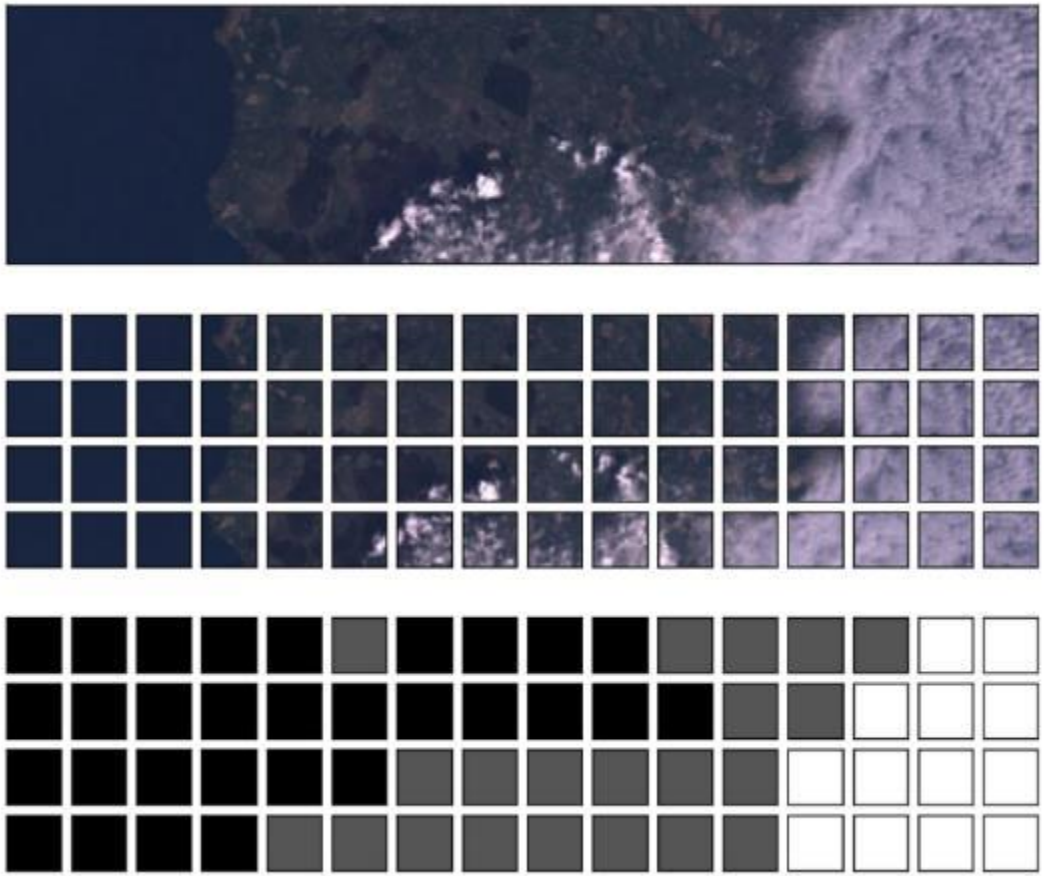
Enabling strategies

- Target FPGA with known flight heritage
- Tools to enable rapid synthesis from high level languages to embedded
- Evaluation of a number of optimization pipelines and approaches
- Adapted existing open source libraries for image processing and deep learning
- Discretisation/quantisation of the convolutional neural network
- Creating a system-in-the-loop test including distortions and anomalies



Name	Interface	Devices	Design Space Exploration	Year
fpgaConvNet	Caffe & Torch	Xilinx SoC	Global Optimiser (Simulated Annealing)	May 2016
DeepBurning	Caffe	Xilinx SoC	Heuristic	Jun 2016
Angel-Eye	Caffe	Xilinx SoC	Heuristic with Analytical Model	Jul 2016
ALAMO	Caffe	Intel SoC & Standalone	Heuristic	Aug 2016
Haddoc2	Caffe	Xilinx & Intel Standalone	Deterministic	Sep 2016
DnnWeaver	Caffe	Xilinx & Intel	Custom Search Algorithm	Oct 2016
Caffeine	Caffe	Xilinx Standalone	Exhaustive over Roofline Model	Nov 2016
AutoCodeGen	Proprietary	Xilinx Standalone	Heuristic with Analytical Model	Dec 2016
FINN	Theano	Xilinx SoC & Standalone	Heuristic	Feb 2017
FP-DNN	TensorFlow	Intel Standalone	Algorithmic	May 2017
Snowflake	Torch	Xilinx SoC	Heuristic	May 2017
SysArrayAccel	C	Intel Standalone	Exhaustive over Analytical Model	Jun 2017
FFTCodeGen	Proprietary	Intel HARP	Roofline and Analytical Models	Dec 2017

Test case

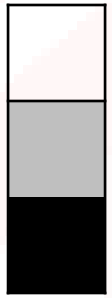


- Image is split into tiles
- Cloud detection payload classifies each segment with a single label:

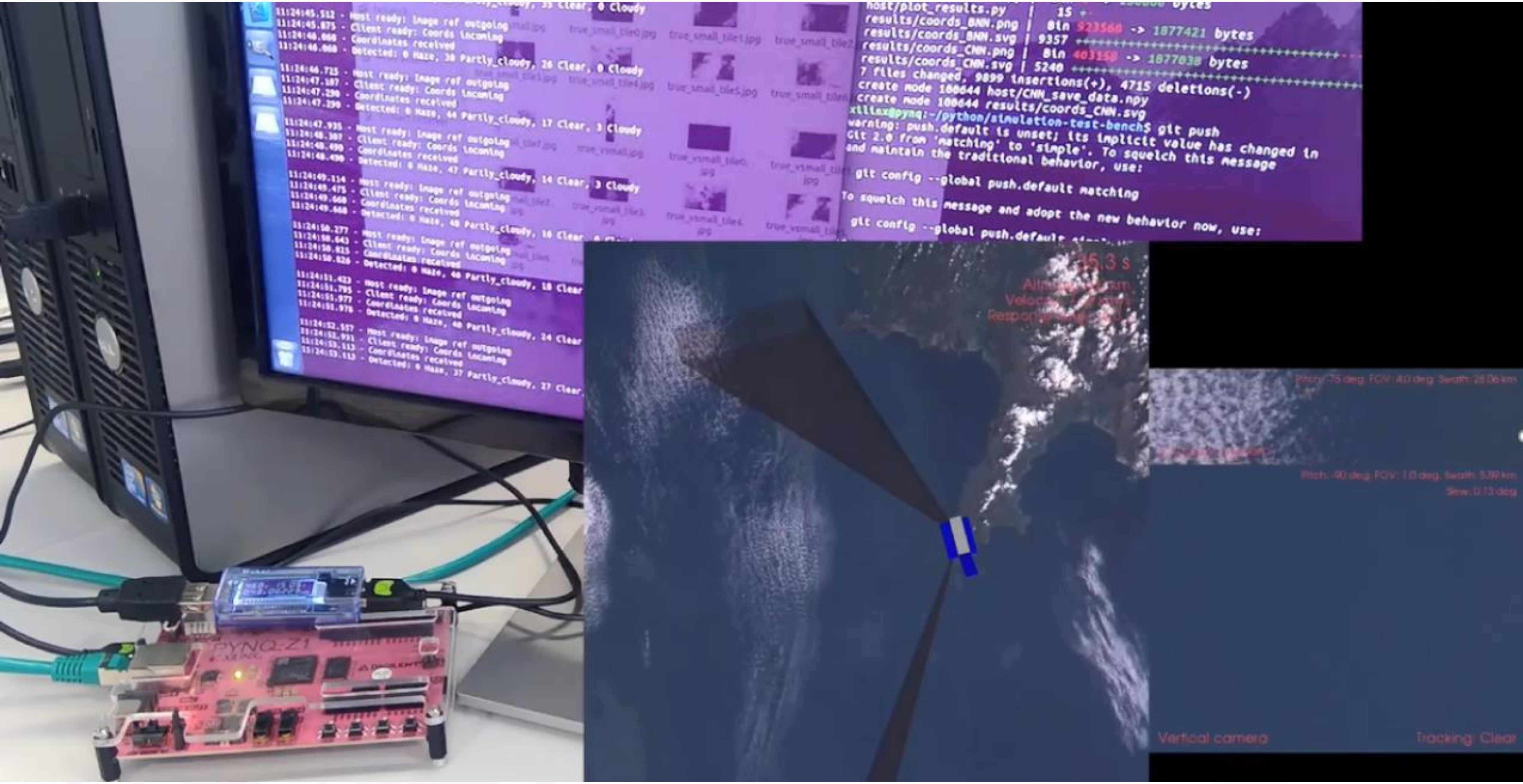
  Clear

  Partly cloudy

  Cloudy



- Payload pointing controller avoids cloudy regions and targets clear regions


results/coords_BNN.png | Bin 923560 -> 1877421 bytes
results/coords_CNN.png | Bin 403158 -> 1877038 bytes
7 files changed, 9899 insertions(+), 4715 deletions(-)
create mode 100644 host/CNN_save_data.npy
create mode 100644 results/coords_CNN.svg
git push
warning: push.default is unset; its implicit value has changed in
Git 2.0 from 'matching' to 'simple'. To squelch this message
and maintain the traditional behavior, use:
git config --global push.default matching
To squelch this message and adopt the new behavior now, use:
Host ready: Image ref outgoing
Client ready: Coords incoming
Coordinates received
Detected: 0 Haze, 44 Partly_cloudy, 17 Clear, 3 Cloudy
Detected: 0 Haze, 47 Partly_cloudy, 14 Clear, 3 Cloudy
PYNQ-Z1
Vertical camera
Tracking: Clear

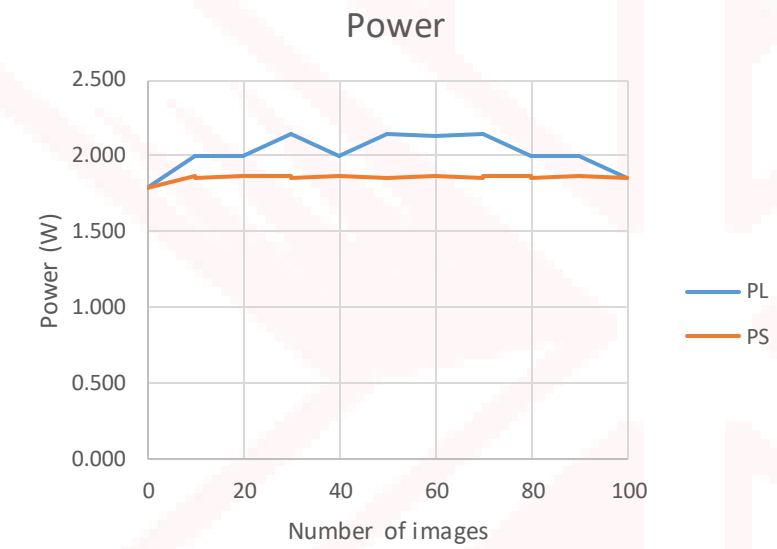
Results

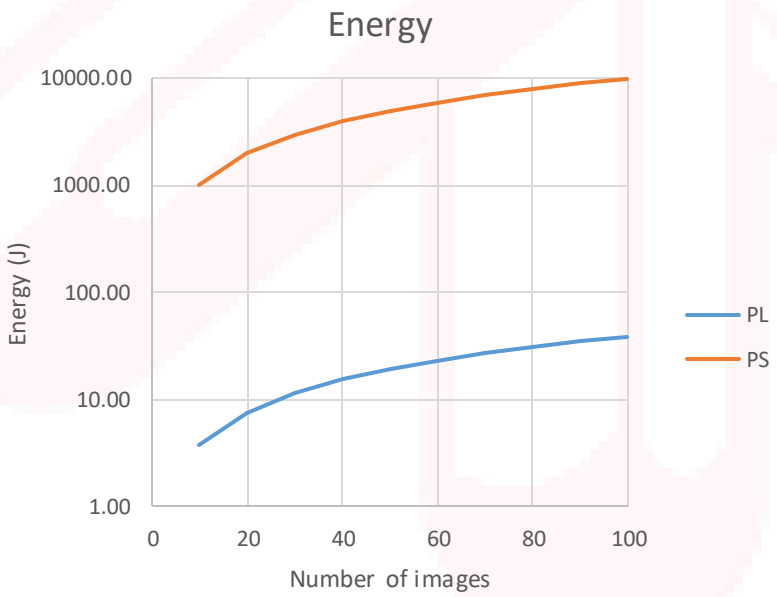
Model	Initialisation[1]	Inference[2]
Pre-optimal	7.06 s	3.63 s
Pre-acceleration (PS)	0.36 s	52.9 s
Accelerated (PS+PL)	0.36 s	0.19 s

(1) Initialisation is always in PS. Involves loading neural network libraries and creating NN object.

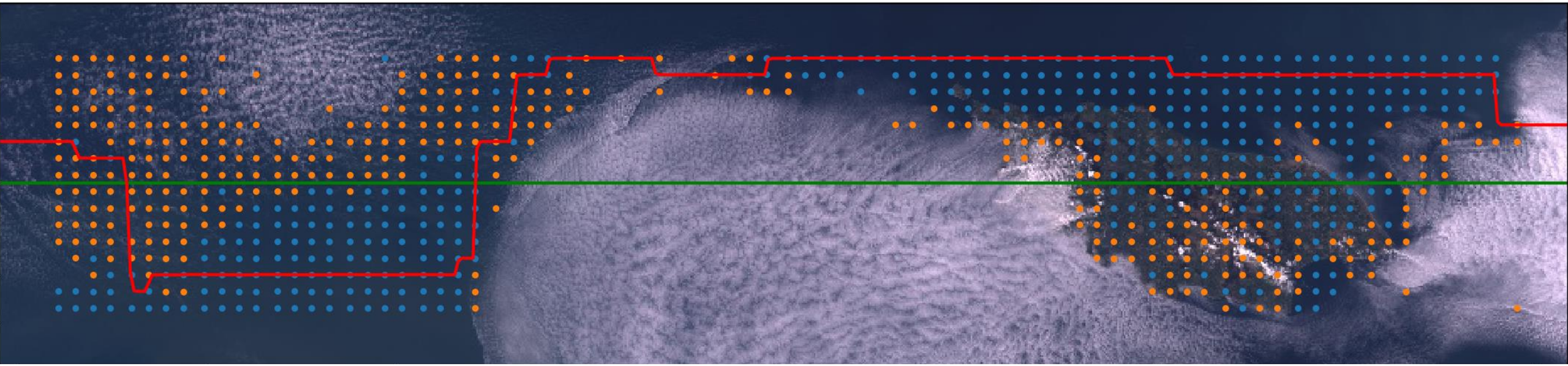
(2) Inference performed on single image split into tile segments and batch classified

Accuracy of 97% achieved against human evaluated tiles, now being formally benchmarked





Payload cloud avoidance



- Inference model is deployed on FPGA, allowing real-time cloud detection
- At the area access rate in LEO we can extract features at 60% max loading
- < 2 W, < 5 s from capture through to planning output

Initial benefits

Technical

- Component based standards for autonomous flight software
- Identification of autonomy enabling algorithms and applications
- Application of deep learning neural networks for target classification
- Toolchain from high level language through to accelerated firmware
- Techniques to allow low power real-time data processing onboard

Non-technical

- Interfacing with various university departments
- Running successful R&D projects within a small business and team
- Managing work across university and industry project partners
- Possibility of and demand for mission in UK across SME/academia
- Application of more formal gateway design review (RID) process

Ongoing since April

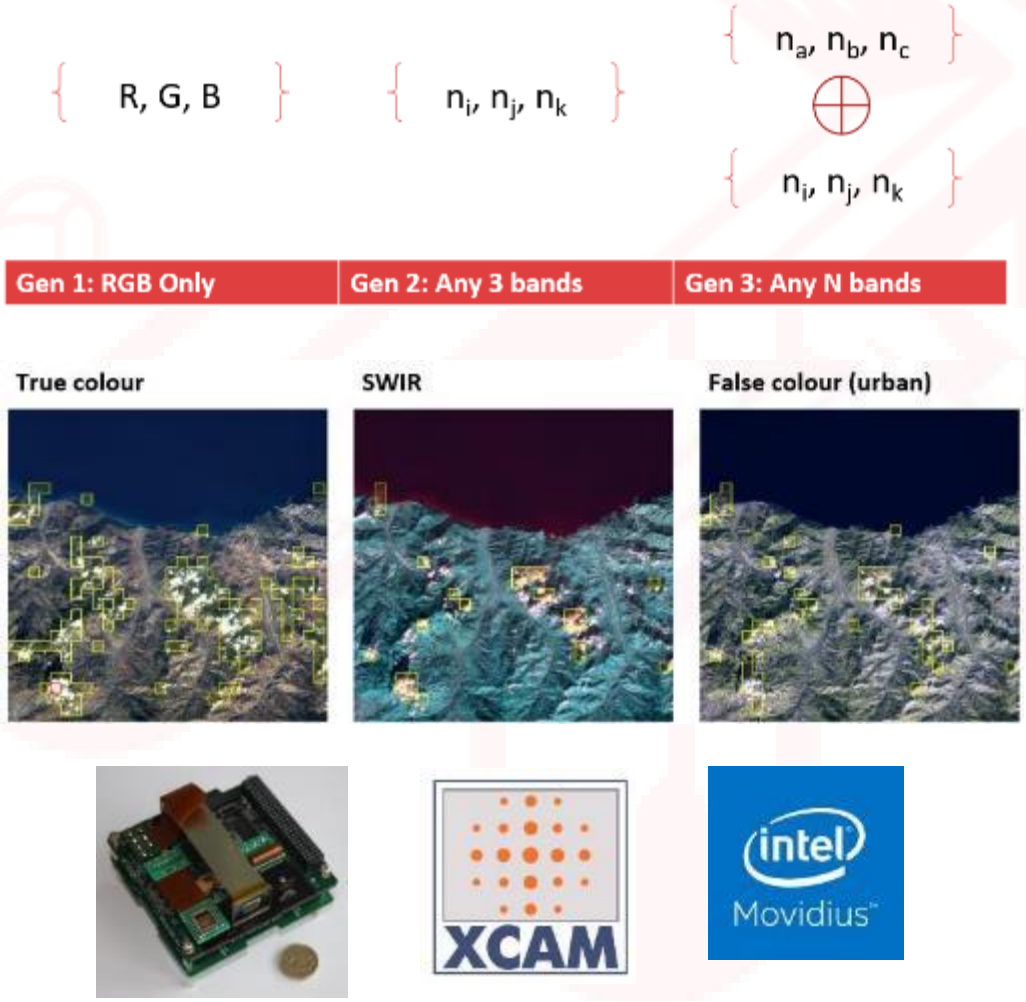
MVP

- Craft Prospect has created a MVP EM product for CubeSats and small systems
- Delivered to first customers for third party performance benchmarking and interface testing
- FPGA-based (2W), but extendable with Myriad units for additional low power neural networks
- Reconfigurable for real-time ops
  - Tile-size, sensor input, resamples, field of view, responsive time
- Internal or external camera sources

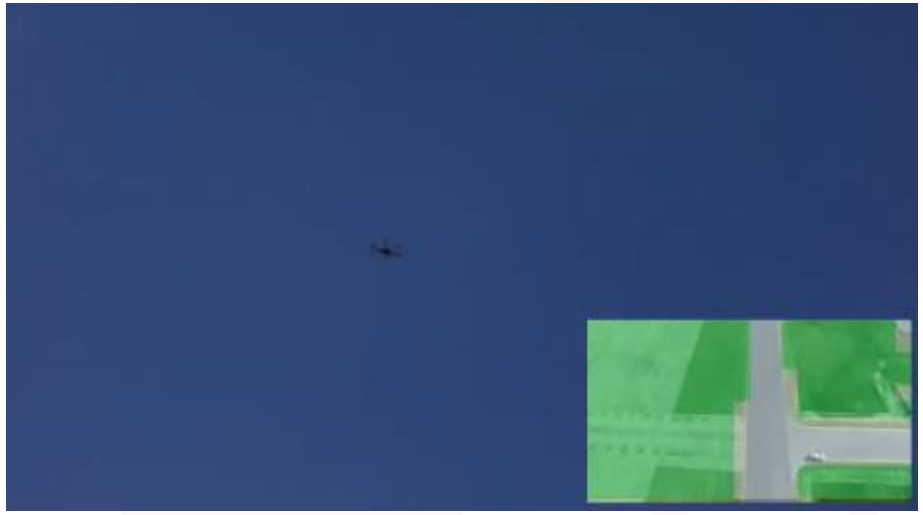
Higgs Centre for Innovation
Science & Technology Facilities Council

Current developments

- Extended NN to include any bands and any combinations/number
- Trained with own data and existing: Planet, Sentinel, LandSat, drone
- Tools to rapidly classify new data sets using transfer learning
- Tools to create and extend sparse data sets for training
- Utilised and benchmarked performance between FPGAs and VPUs
- Integration with existing third party camera systems



Drone testing



The University of Manchester

Seed contracts delivered

AI4EO

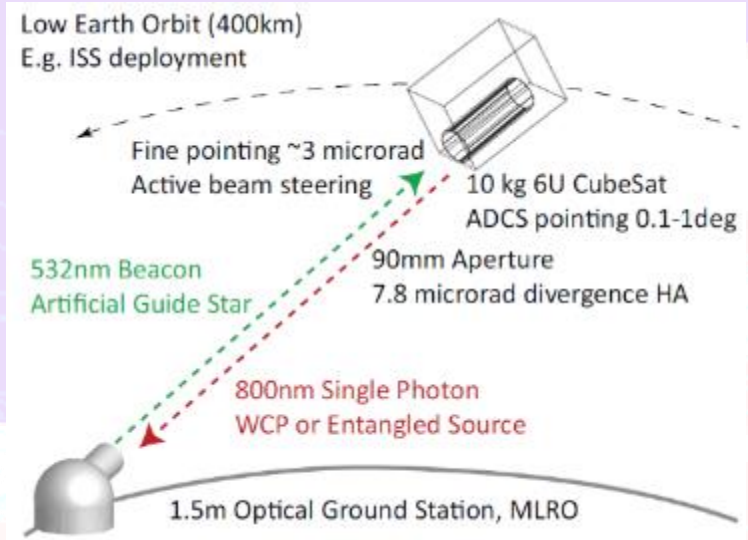
Asset Maintenance

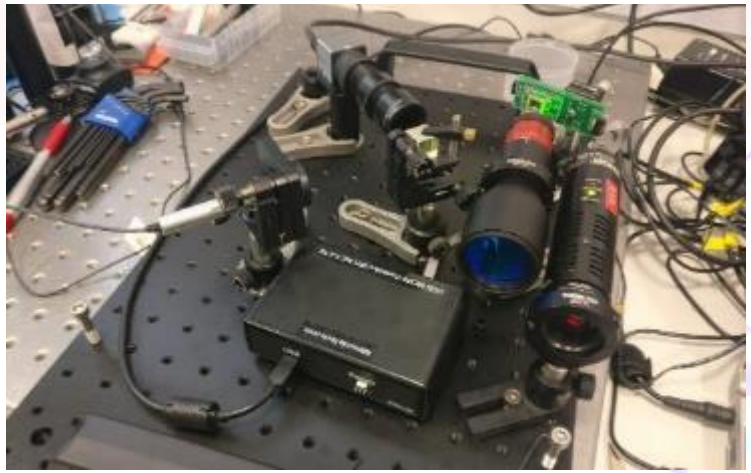
Attitude Control Testbed

- Looking to partner with others interested in onboard data processing with AI or autonomy for different data sets / use cases

Responsive Operations for Key Services

- Onboard ML to support real-time planning and signal identification EO + Telecom
- Maximise utility of high power and bandwidth Quantum Key Distribution (QKD) payload
- In-Orbit Demonstration opportunity for FLI and autonomy framework
- Towards delivery of secret keys for securing BT telecoms infrastructure





BT

Innovate UK

Summary

- Overall **framework for autonomy** and enabling algorithms presented for small/nanosatellites
- **Forwards looking imager** EM on flight representative hardware, with 1-2 min look-ahead
- Engaged with **14 potential customers** for the technology to understand requirements
- Acceleration of enabling algorithms embedded into FPGA **300x faster** (PS vs PS+PL) [and VPUs]
- Toolchain to rapidly develop and test from **high level languages to embedded** prototyped
- **Real time feature detection** for the area access rates in LEO demonstrated at < 2 W
- Application and training optimisation of deep learning for **cloud detection** case
- **System-in-the-loop** simulation developed to allow end to end testing of the imaging system
- Plans/opportunity to progress key technology elements in **flight demonstration 2019**
- Towards full flight opportunity in the **Responsive Operations for Key Services** IOD

Acknowledgements

“Onboard Data Autonomy for Next Generation of EO Nanosatellites”

Forwards Looking Imager Product Development

thanks

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