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Boresight Calibration of the WASP Airborne Mapping Camera System

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Presentation objective

- Give an overview of the Wildfire Airborne Sensor Program, WASP
- Show the importance of the boresight calibration method for aerial photography in general and for the WASP
- How WASP is handling the boresight calibration

Overview about the Wildfire Airborne Sensor Program

- WASP's objective
  - improve current methods used to detect fire in forest areas
- How to attain
  - set of cameras connected to a GPS and computer
  - mount equipment on small size plane and fly over forest
  - cameras are shot every 4 or less seconds
  - images are processed in real time on the plane

WASP Accomplishments

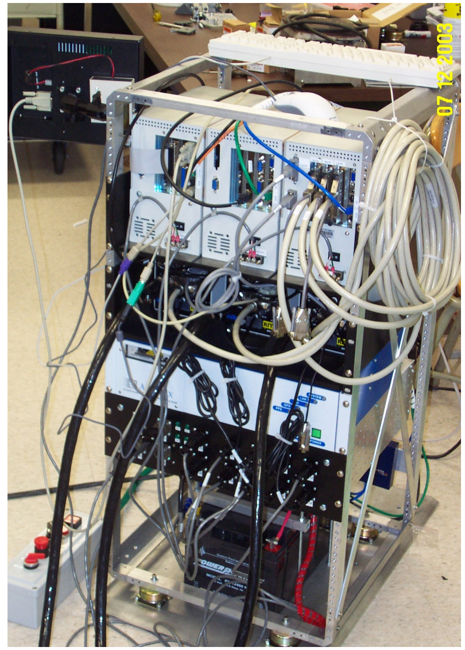
- Test flights over RIT

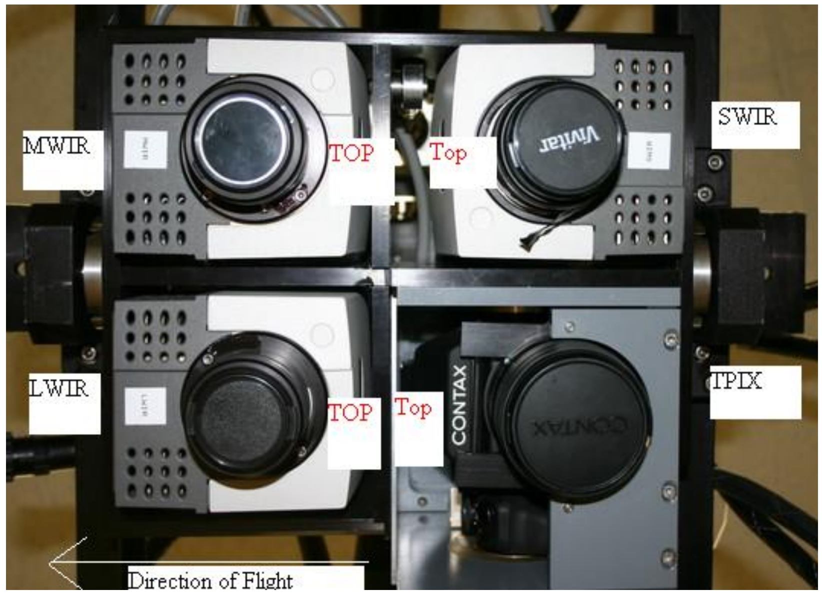
- Flight over controlled burn in Ohio
  - fire propagation model
  - high resolution DEM, digital elevation model

- Rewriting the acquisition system and plug to
  - image-to-image registration
  - georeference
  - mosaicing modules
  - fire detection

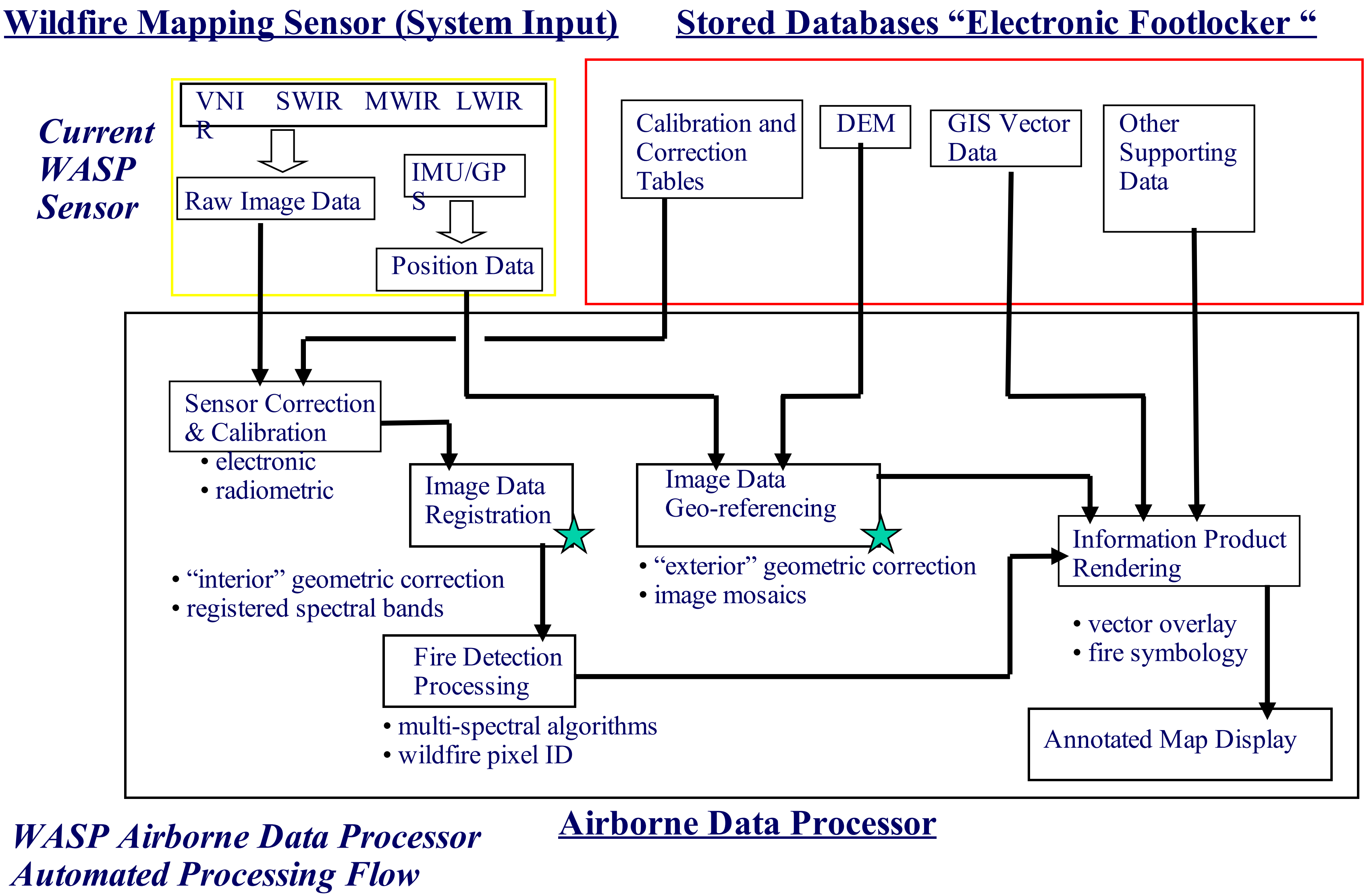
WASP Hardware

- GPS and IMU or Inertial Measurement Unit
  give cameras position and orientation
- Gimbal - swing about 60 degrees to increase swath
- Airborne Data Processor or ADP
- 16 mega pixel visible camera – region overview
- Three infrared cameras - core fire detection
  - short wave 0.9 to 1.7μm
  - medium wave 3.0 to 5.0 μm
  - long wave 8.0 to 9.2 μm





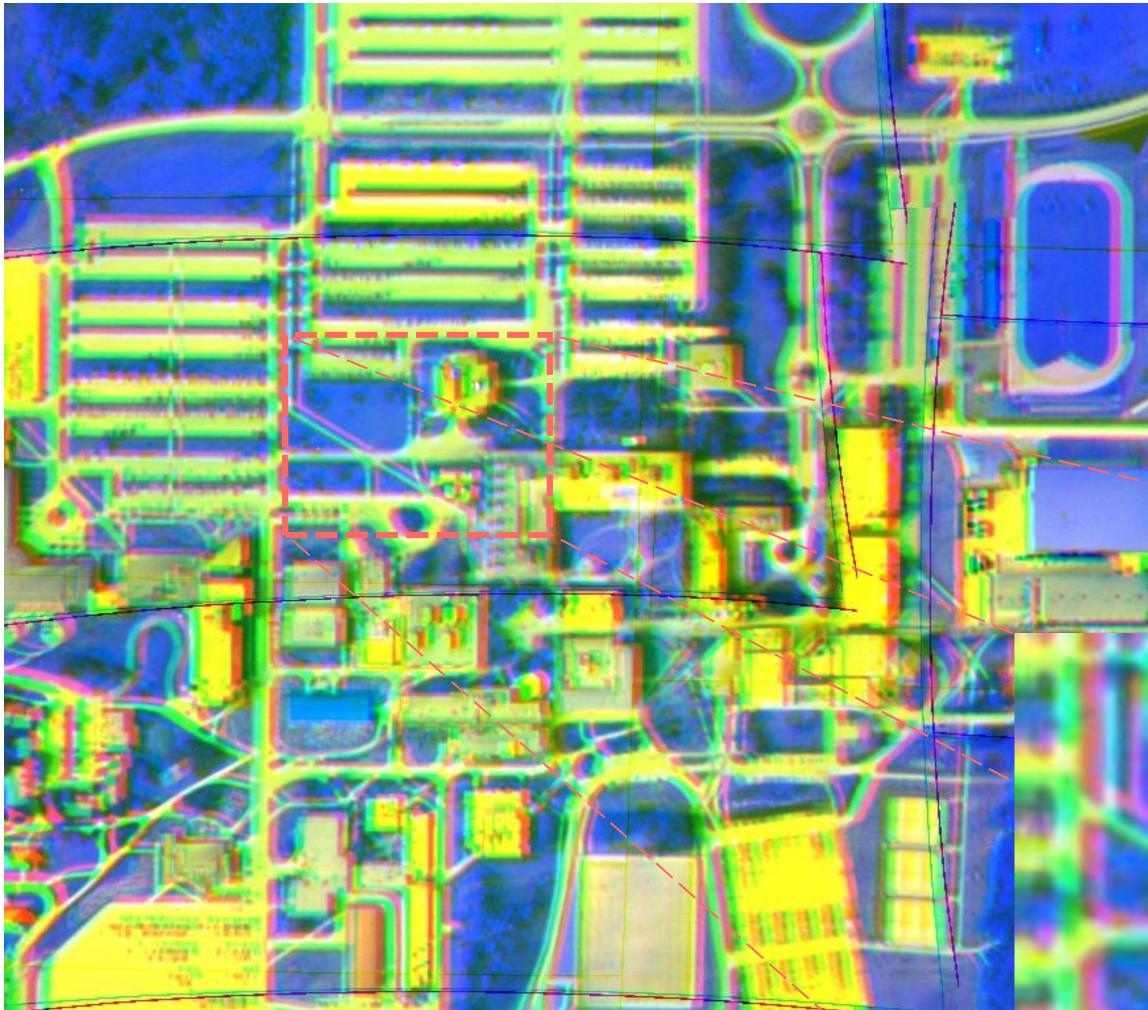
Overview of capturing process

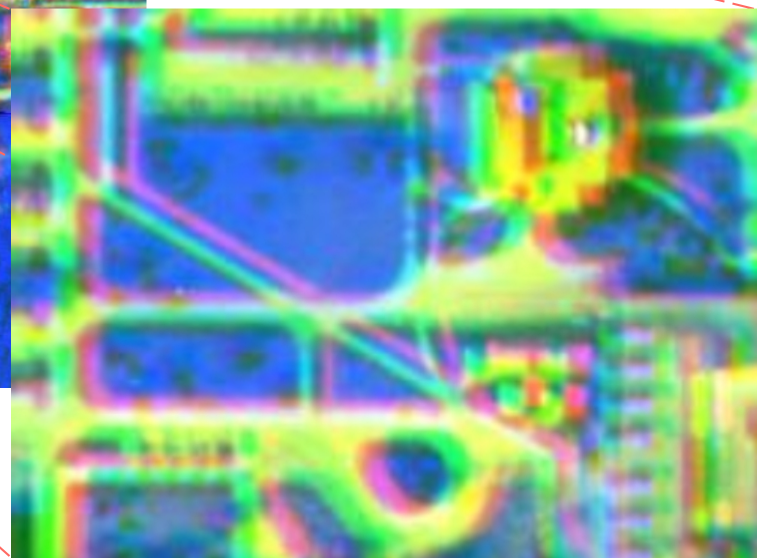


Why boresight

- Boresight is the relation between camera and Inertial Measurement Unit, IMU
- Boresight is a crucial for image to image registration. The images need to stack on top of each other so their pixels represent the same ground feature
- Boresight allows the creation of high resolution image-maps to locate burn areas

Band to Band Registration without Boresight



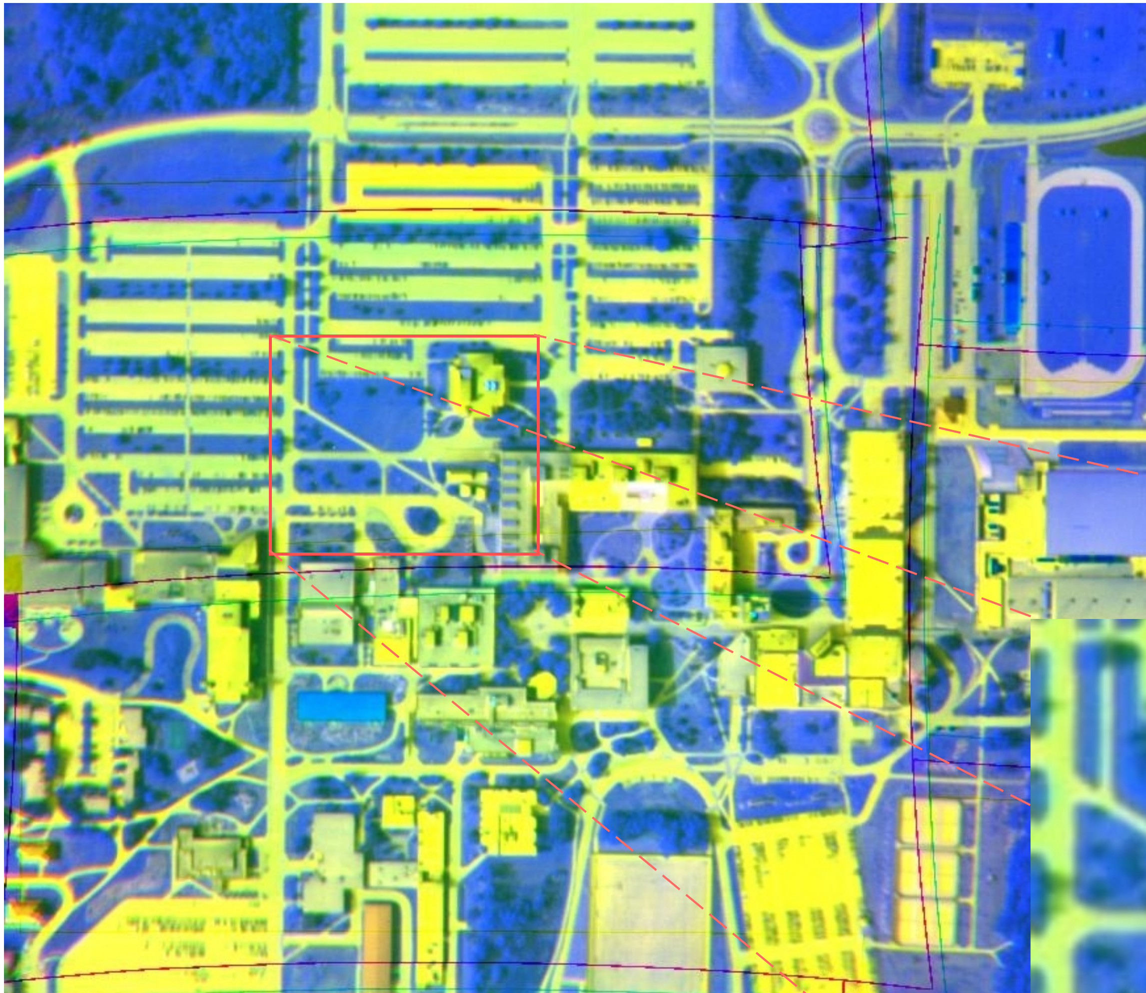


Band Assignment

LWIR (long wave infrared) RED
MWIR (mid wave infrared) GREEN
SWIR (short wave infrared) BLUE

- 640 by 512 pixels
- 25 micro meter pixel size
- 16 bit images

Band to Band Registration with Boresight



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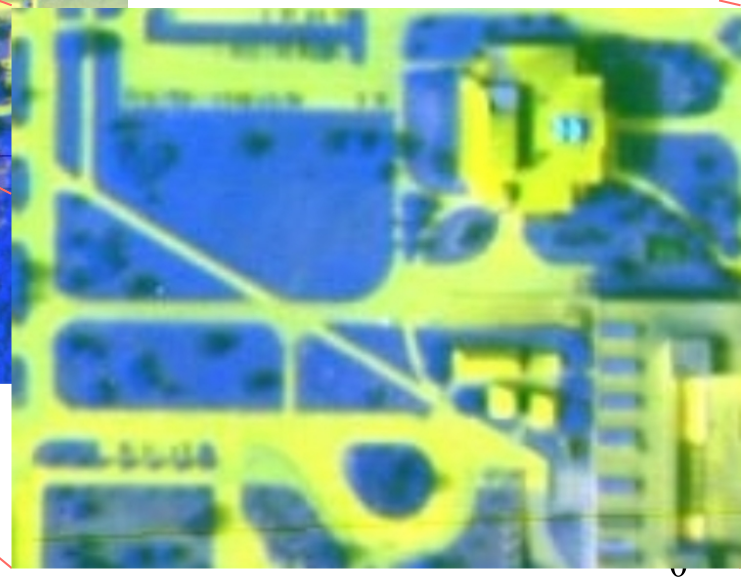
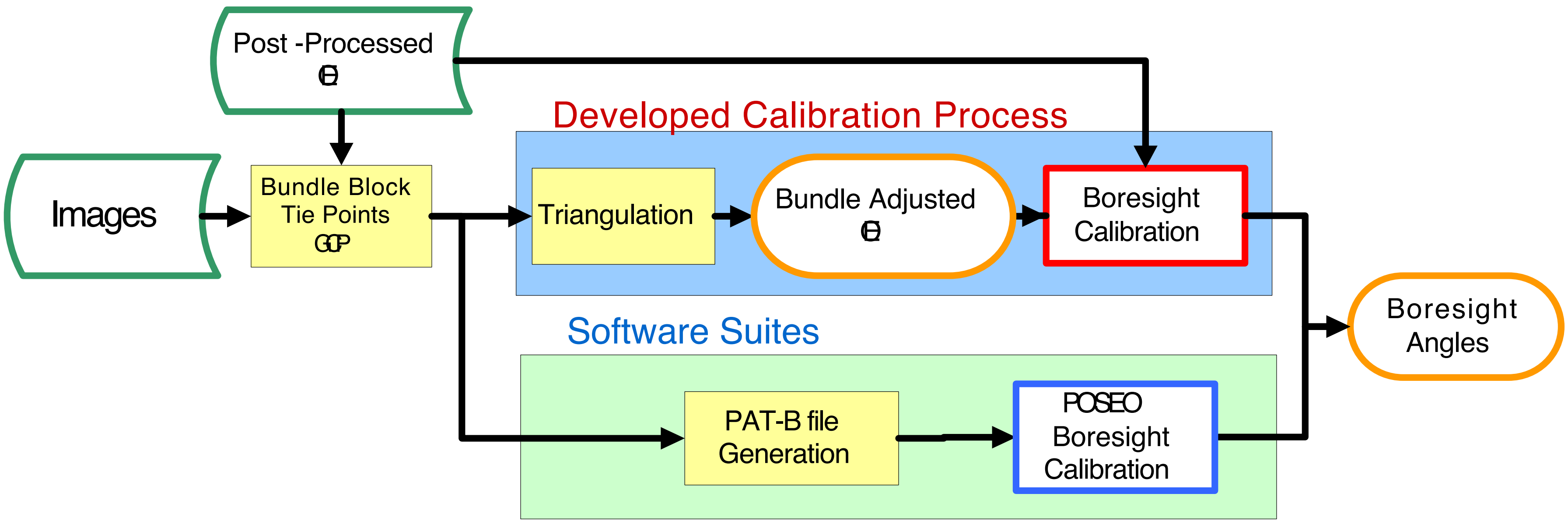
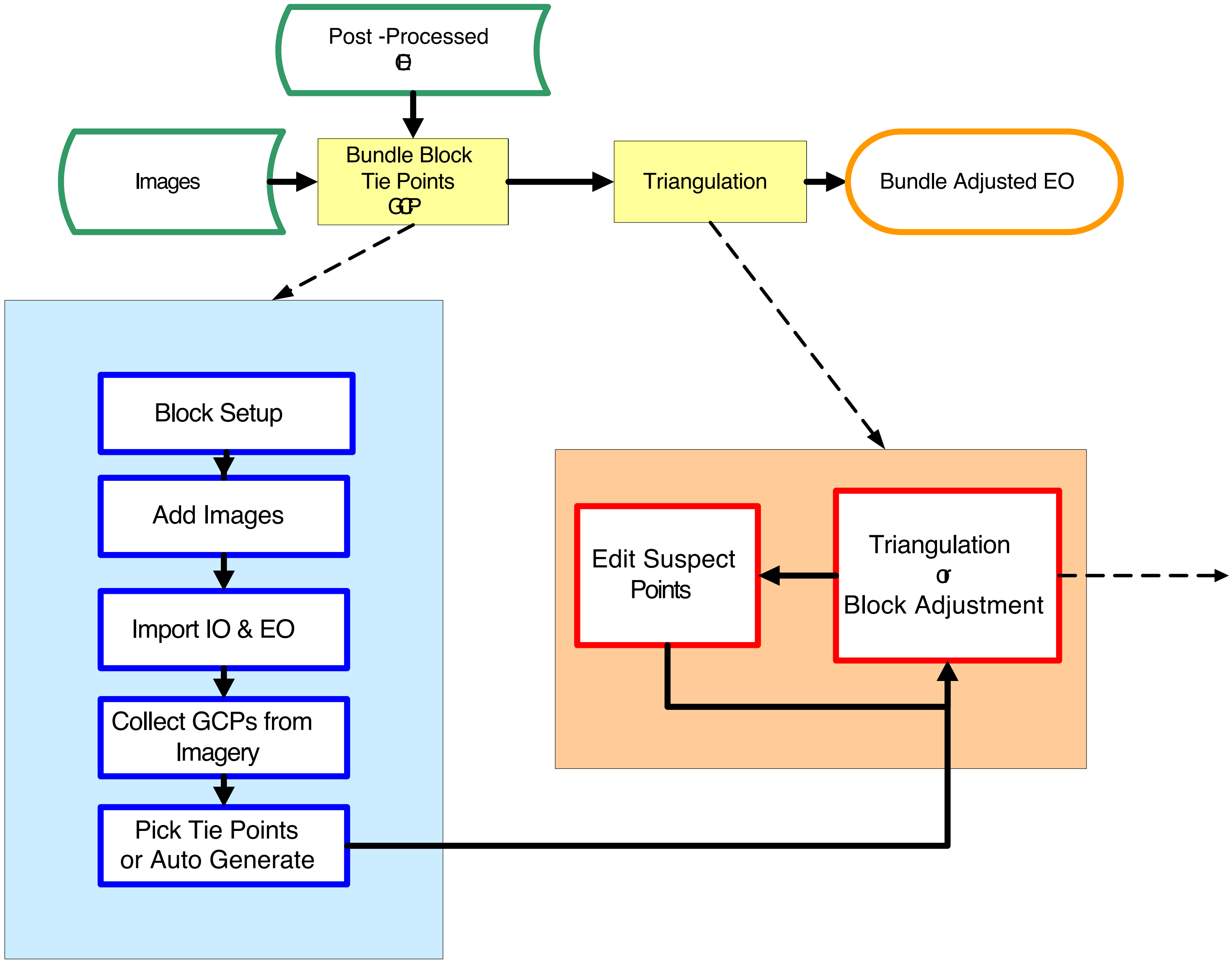


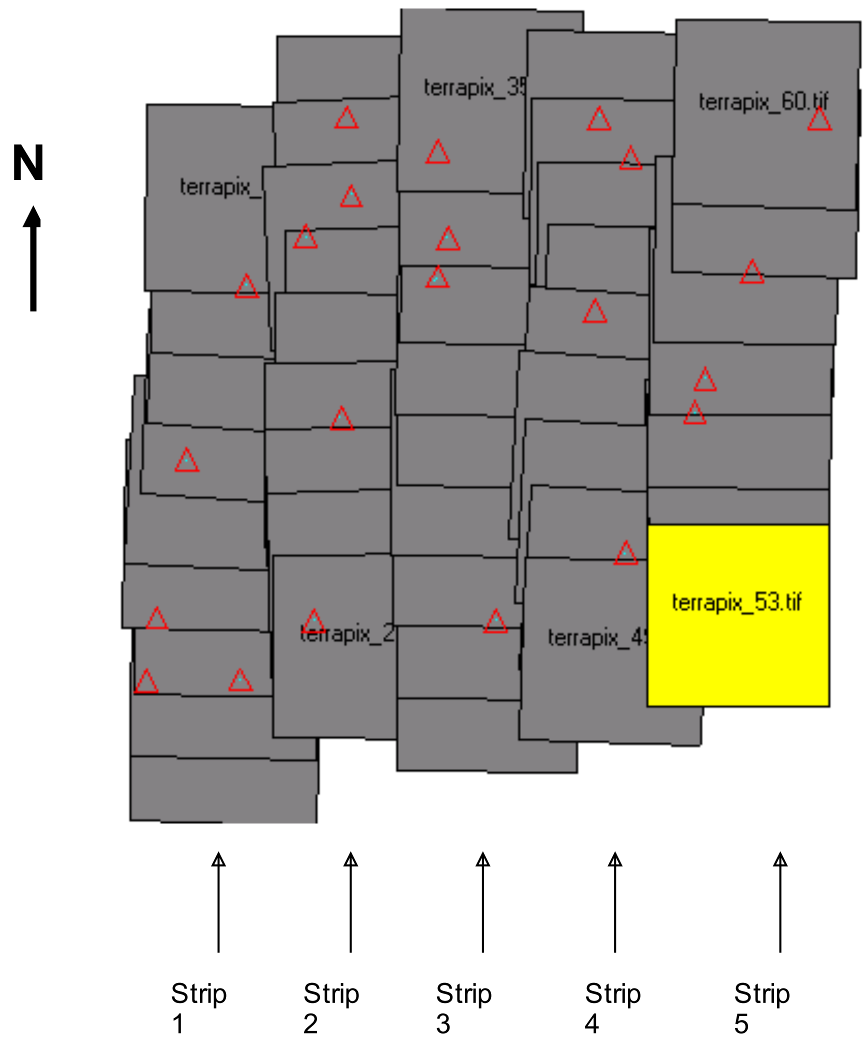
Deriving the boresight



Triangulation – [M]AT



Block Diagram with GCP

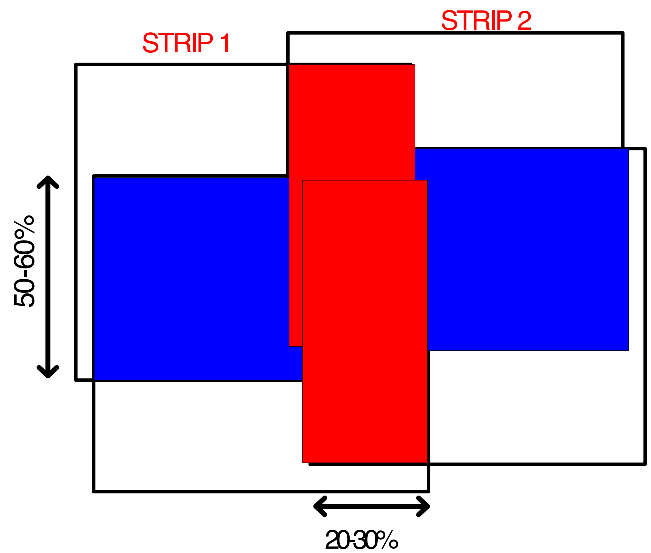


△ **GCP [Ground Control Points]**

- **22 GCPs**
- **43 Images in 5 strips**

Requirements

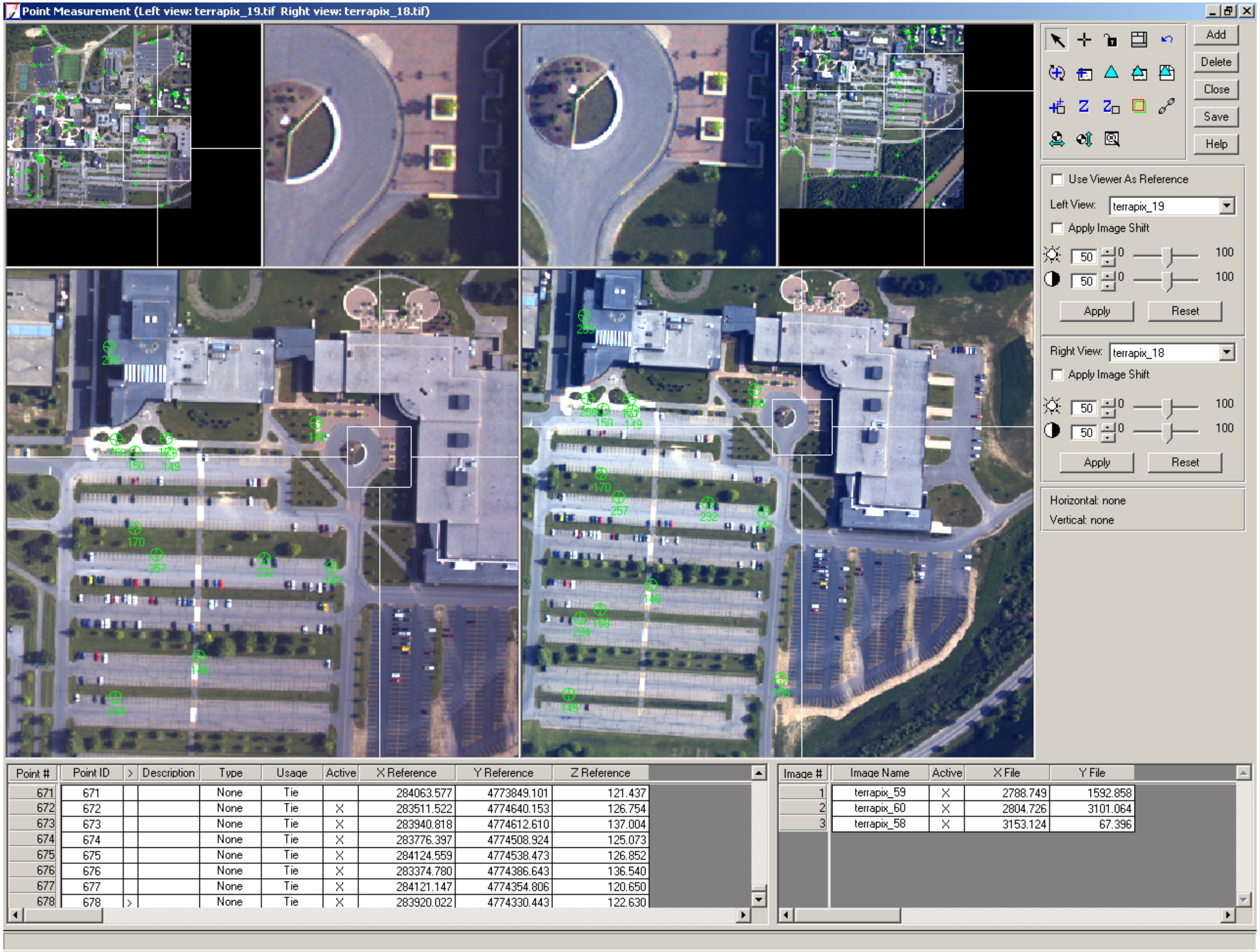
- **GCP in beginning and end of strip**
- **Opposite flying directions**
- **Minimum of two strips**



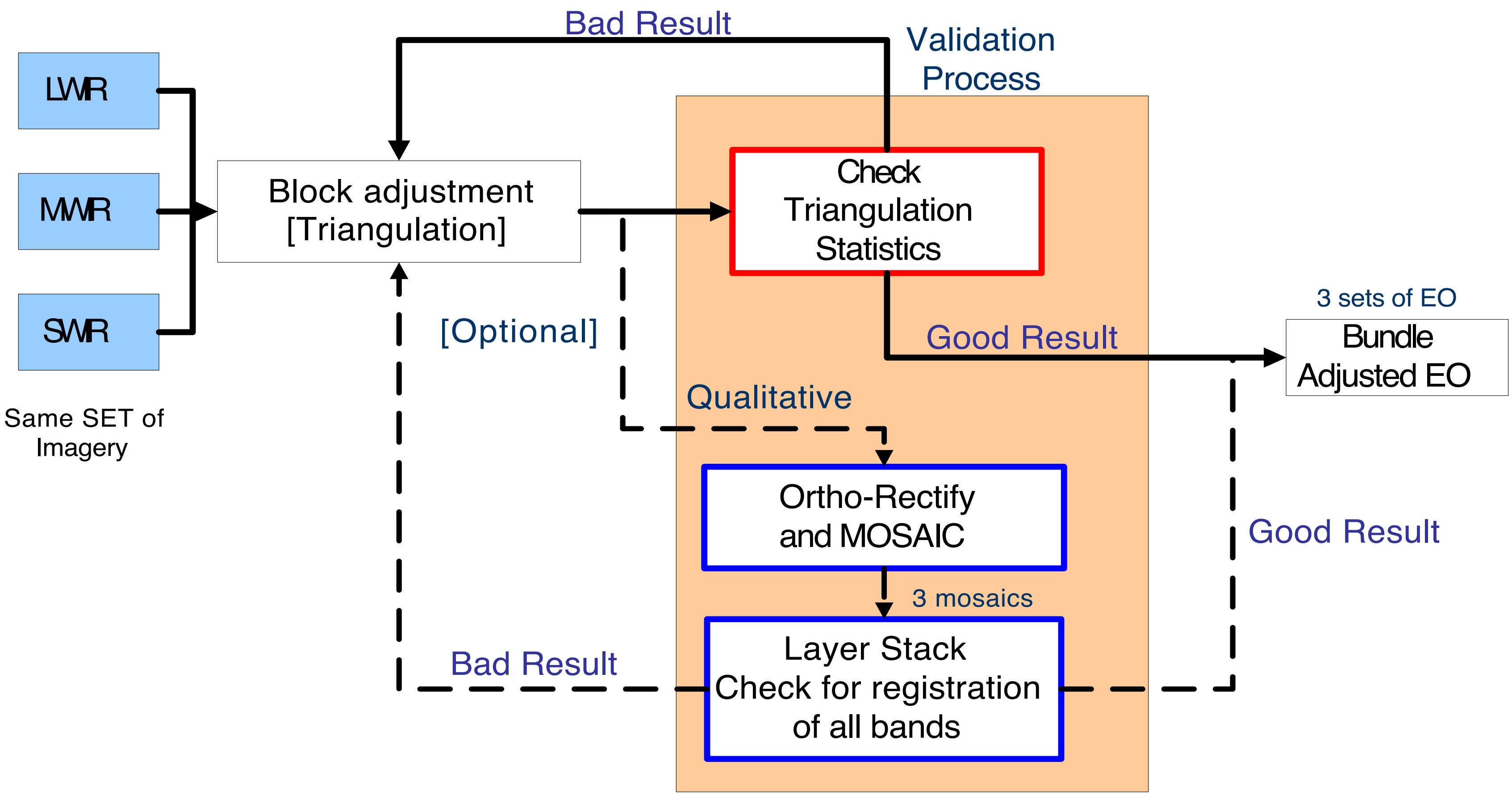
IO and EO

- Interior Orientation or IO
  - Focal length
  - Radial lens distortion (K0, K1 and K2)
  - Pixel size
- Exterior Orientation or EO
  - $(x, y, z, \omega, \varphi, \kappa)$

Adding Points



Bundle Adjusted EO Validation



Deriving the angles from the orientation matrix

The orientation matrix M is derived from Mω, MΦ and MK, which are the rotation matrices with respect to x, y and z axis:

$$M = M_\omega M_\phi M_\kappa$$

$$M = \begin{bmatrix} \cos\Phi\cos K & \cos\omega\sin K + \sin\omega\sin\Phi\cos K & \sin\omega\sin K - \cos\omega\sin\Phi\cos K \\ -\cos\Phi\sin K & \cos\omega\cos K - \sin\omega\sin\Phi\sin K & \sin\omega\cos K + \cos\omega\sin\Phi\sin K \\ \sin\Phi & -\sin\omega\cos\Phi & \cos\omega\cos\Phi \end{bmatrix}$$

Omega (roll), phi (pitch) and kappa (yaw) are derived from the following relationships:

$$\sin\Phi = m_{31}$$

$$-\tan\omega = \frac{-\sin\omega\cos\Phi}{\cos\omega\cos\Phi} = \frac{m_{32}}{m_{33}}$$

$$-\tan K = \frac{-\cos\Phi\sin K}{\cos\Phi\cos K} = \frac{m_{21}}{m_{11}}$$

Deriving the boresight matrix [ΔM]

Transformation to be applied to post processed exterior orientation (IMU attitude with differential GPS) that will yield the orientation of each camera

This transformation is a matrix multiplication of the unknown boresight matrix (ΔM) matrix and the known IMU attitude

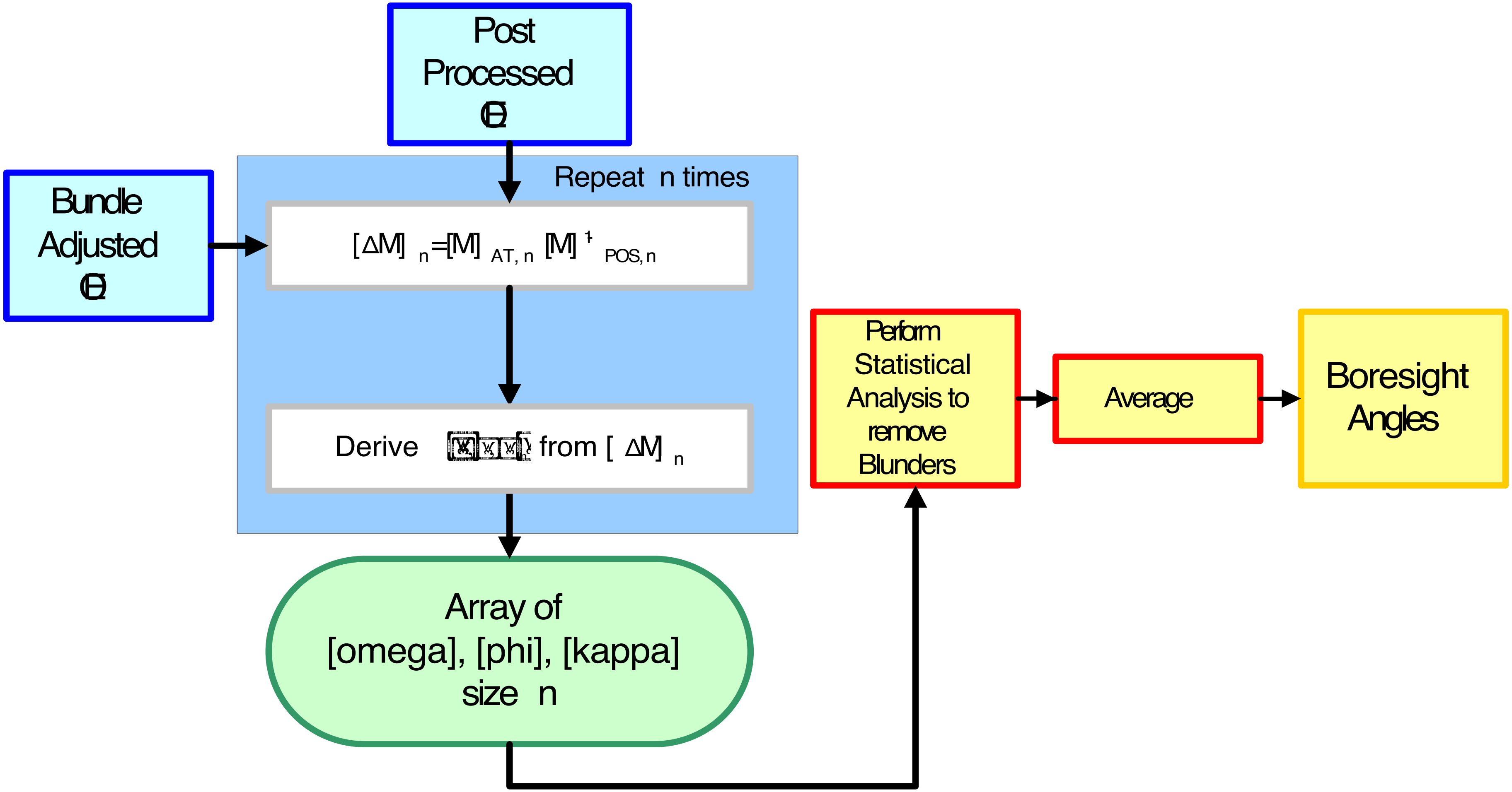
$$[M]AT = [\Delta M][M]POS$$

Multiplying both sides by [M]POS-1 yields

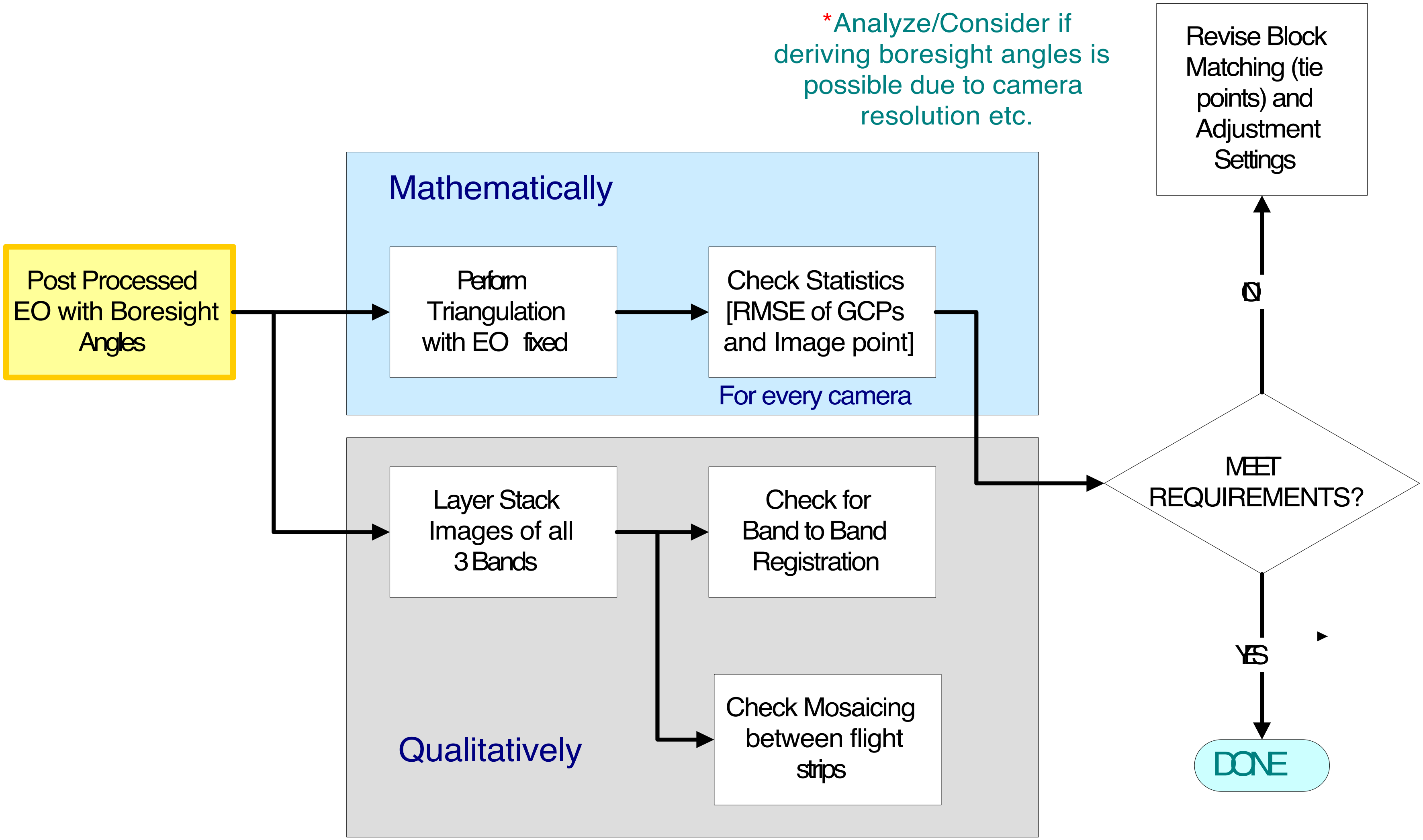
$$[\Delta M] = [M]AT \times [M]POS\text{-}1$$

- [M]AT is the orientation matrix from Aerial Triangulation
- [ΔM] is the transformation matrix
- [M]POS is the IMU's attitude

Deriving the Boresight Angles



Validating the Derived Boresight Angles



What is next

Limitations and areas for improvement:

- How to take GPS accuracy deterioration high altitudes into account.
- Not accounting for lever arm between IMU and cameras
- There are other more robust triangulation software
- Picking tie points in IR imagery is error prone (distortion and low resolution)
- Hard to keep consistency when terms and signs are defined differently among the literature and software vendors

Future steps:

- Use data sets over other regions to validate boresight
- Assess fire detection algorithm's performance using boresight corrected imagery
  - Real time GPS data (without differential correction)
  - Vary flying height (4k to 10k)
- Resort to other registration techniques if boresight correction doesn't produce adequate results

Who is involved

Chester F. Carlson Center for Imaging Science

Funded by

US Forest Service as potential user

Corporations

Local companies

- Pictometry, Pixel Physics, LightForce Technology Inc, Landcare Aviation

Consultant

- Don Light

Educational institutions

- University at Buffalo, State University of New York,
  Cayuga Community College

Questions?

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Thank you!