# Geometric Calibration of the CAMIS Sensor


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# Presentation Outline

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# 1.1 Research Objectives

- CAMIS sensor has been used in multispectral imaging and mapping purposes by mounting it in an airplane with GPS and INS systems.
- These auxiliary sensors provide very good position and attitude data for stabilizing the subsequent bundle block adjustment.
- The aim of this work was to make a laboratory calibration for the geometric parameters of the CAMIS sensor.

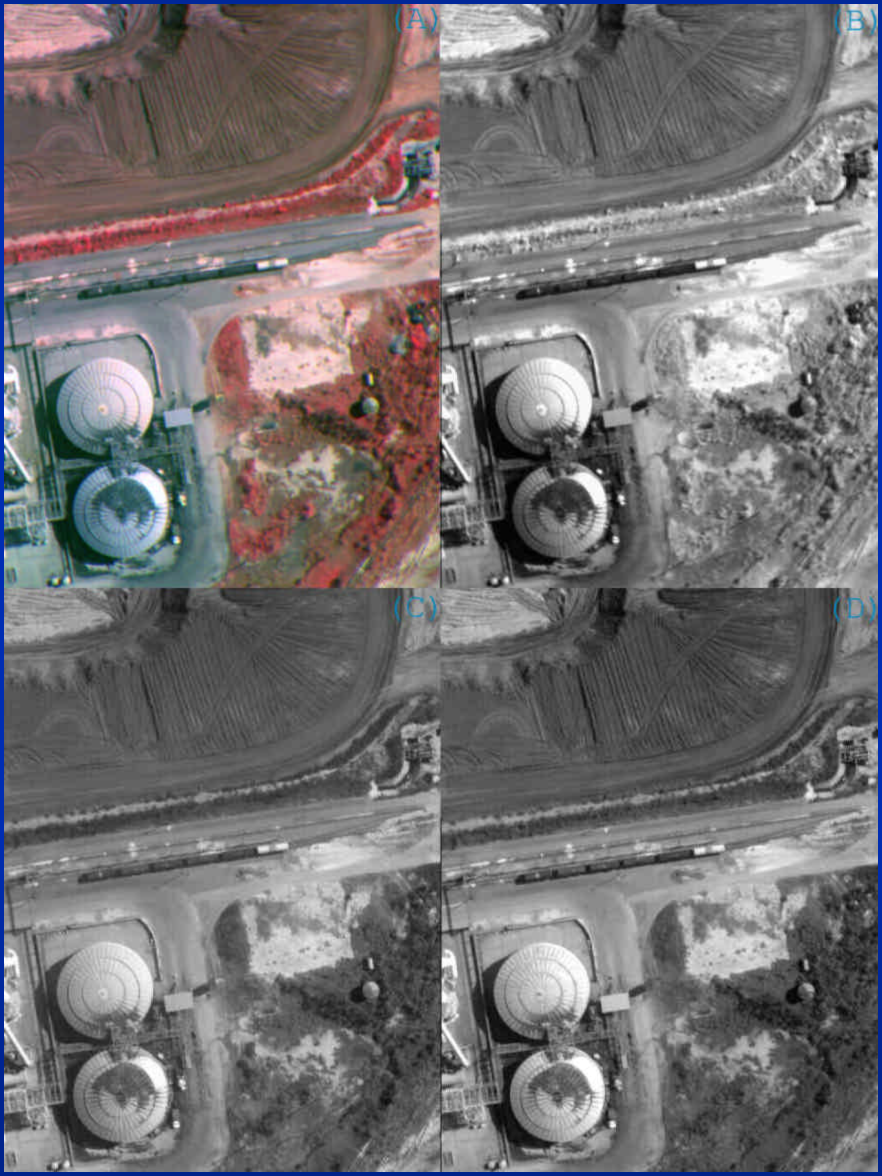
# 1.2 Sensor Description

- CAMIS stands for Computerized Airborne Multicamera Imaging System.
- CAMIS is a system for airborne remote sensing and is designed to utilize modern solid-state imaging and data acquisition technology.
- It consists of four co-boresighted area-CCD cameras with band pass filters: blue, green, red, and near infrared.
- Each sensor has its own optics and obtains its own image independently from the others at the same time.
- The sensor is operated by Topographic Engineering Center and we have worked with Mr. Mitch Pierson to obtain the required data.

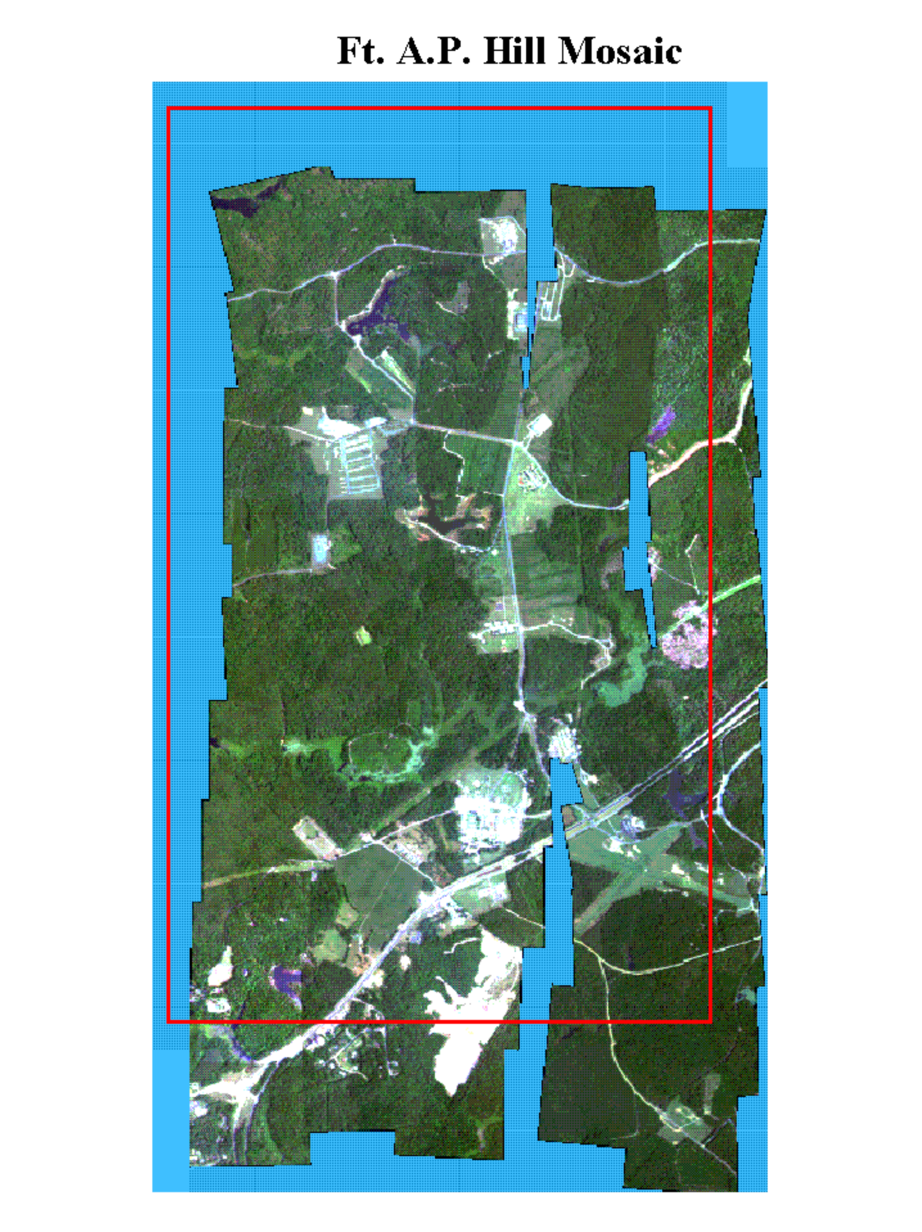

CAMIS, the four cameras

# CAMIS in Aircraft with Image Display

# CAMIS 3 Bands and Color Composite



# Mosaic from CAMIS Strips



# 2) Site work

## 2.1) Calibration site preparation:

- Targets layout
  - Target design
    - cross shape
      - » So their centers positions will be read easily.
  - Targets layout
    - "X" pattern
      - » This layout allows us to recover the needed geometric parameters and systematic errors
  - Exposure stations
    - The sensor was mounted on a leveled plate fixed on a survey tripod which is about 8m from targets (far enough to use infinity focus position)

Enlargement showing 5 targets

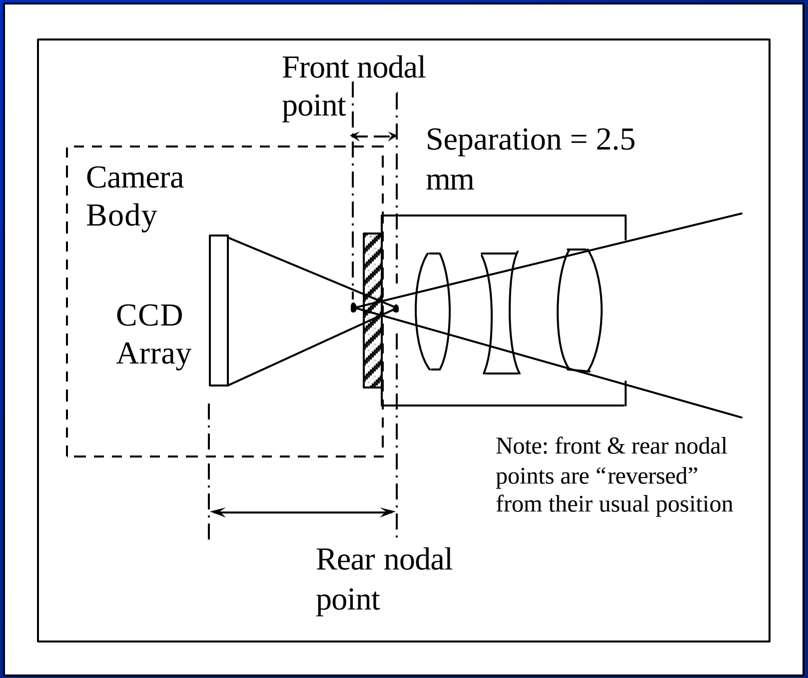
Targets layout

# 2) Site work steps cont'd

## 2.2) Measurements and adjustment in object space:

- Laboratory measurements
  - Two 3 arc-second accuracy theodolites were stationed and referenced to measure directions.
    - target centers
    - theodolite locations
    - camera case monuments
  - Steel tape and machinist calipers to measure distances
  - Optical bench to determine the locations of the nodal points

Measurements in the calibration site




cross section of one camera showing the lenses, rear and front nodal points

# 2) Site work steps cont’d

## 2.2) Measurements and adjustment in object space cont’d

- Network adjustment
  - Having all these observations, we end up with an over determined system of equations.
  - A bundle adjustment program was developed to adjust those coordinates of the targets and the instrument stations.
  - As a result of that, we determined precisely all our targets and stations in the object space which is a necessity for the calibration purpose.

## 2.3) Capturing Images

- This step was operated by a team from TEC and observed by the Purdue team
- We tried to simulate the real working conditions by setting the lenses to the “working” infinity focus position
- Images were viewed at the site to make sure that as many as possible of the targets were exposed.

# 3) Target Locations in Image Space

## 3.1) Cross Correlation Matching (CCM)

- A cross correlation matching program was used to get rough approximation of target positions in the image space to within a pixel.
- This was done by computing the similarity between a window patch containing the ideal target and the another window from the captured image.
- Despite the fact that, the CCM results showed that we are only away from the exact position by a pixel or less, we needed more accurate and precise methods to define the exact location within a hundredth of a pixel or so.

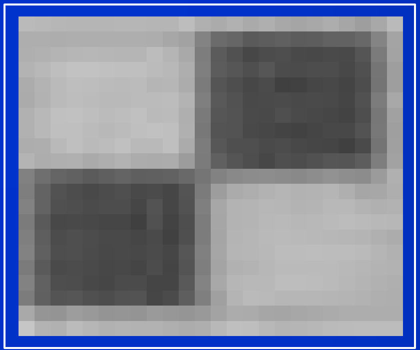
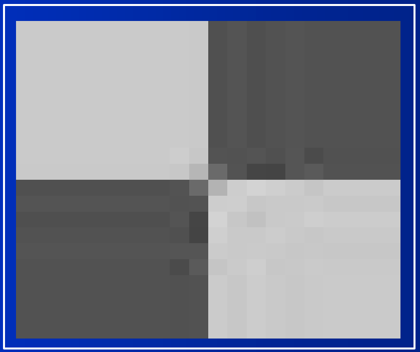
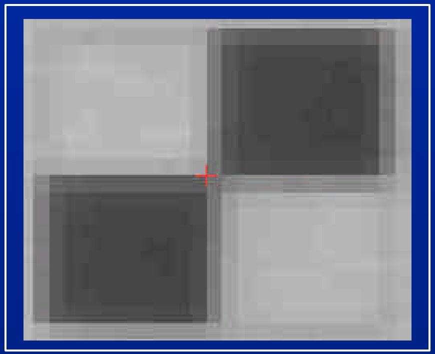


image patch (v)



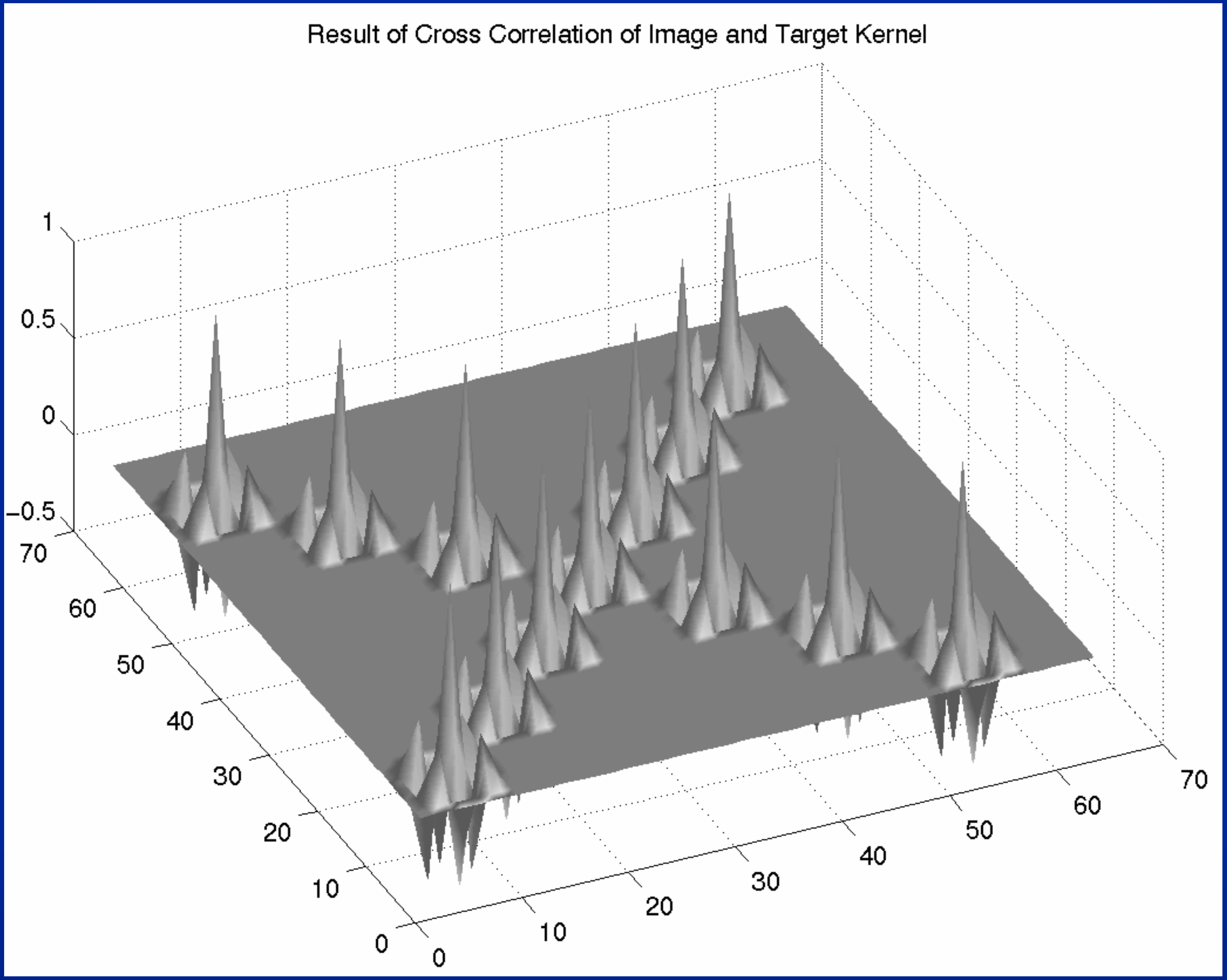
ideal template (u)

$$C_{uv} = \frac{\sum_{i=1}^{N} (u_i - \bar{u})(v_i - \bar{v})}{\left[ \sum_{i=1}^{N} (u_i - \bar{u}) \sum_{i=1}^{N} (v_i - \bar{v}) \right]^{1/2}}$$



CCM Match

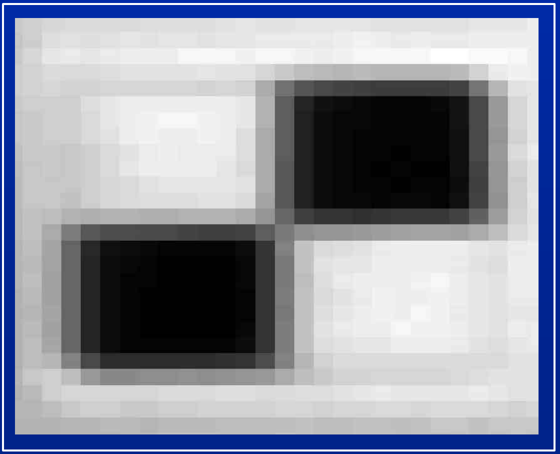
# Response to Coarse Alignment via Template Matching



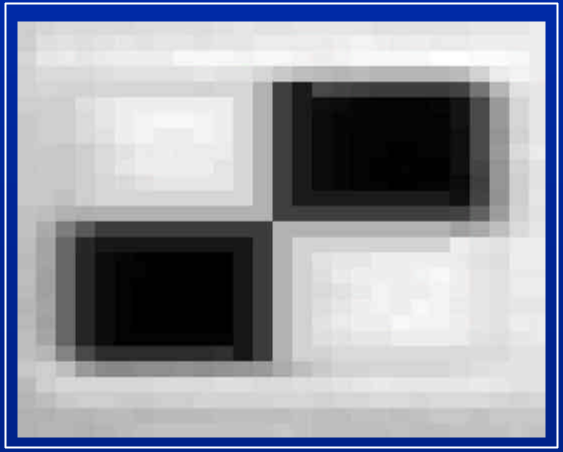
# 3) Target Locations in Image Space cont’d

## 3.2) Least squares matching (LSQM)

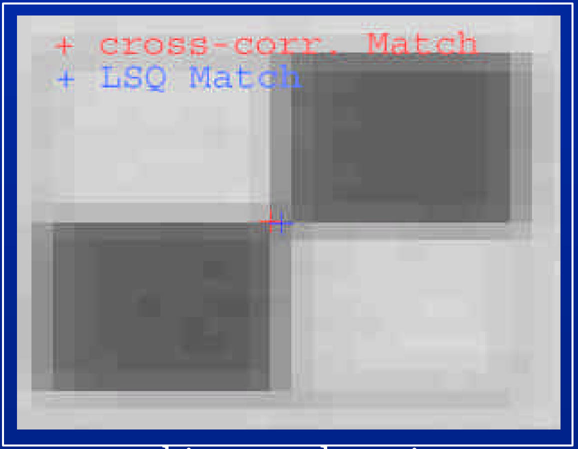
- LSQM utilizes the first derivative of the intensity in both x and y directions to refine the best correspondence and the exact matching can be reached by moving one window with respect to the other one while minimizing some of squares of differences of intensity values.
- The similarity between the two spots was only geometrically modeled since the radiometric effect was eliminated.
  - Get the approximate location of the imaged target using the first matching approach. Those locations should be within a few pixels of the exact location.
  - A window around that location from the image with adequate size will be extracted.
  - The ideal or template target is retrieved at this point. Similarity in the intensity is enforced between the two windows.



the target in Image patch



the extracted target




matching results using two methods in succession

# 4) Math Model and Solution Method

## 4.1) Math Model

- The mathematical model was chosen carefully in order to recover all significant sources of geometric errors and estimate all significant correction parameters for those errors.

$$x - x_o = x' - x_o + \Delta x \quad = -f \, \frac{r_{11}(X - X_c) + r_{12}(Y - Y_c) + r_{13}(Z - Z_c)}{r_{31}(X - X_c) + r_{32}(Y - Y_c) + r_{33}(Z - Z_c)}$$

$$y - y_o = y' - y_o + \Delta y \quad = -f \, \frac{r_{21}(X - X_c) + r_{22}(Y - Y_c) + r_{23}(Z - Z_c)}{r_{31}(X - X_c) + r_{32}(Y - Y_c) + r_{33}(Z - Z_c)}$$

- Samtaney (1999) explored this model in detail.
  - It was derived from the fundamental collinearity equations. It maps the coordinates from the object space into the image space through some parameters.
    - Exterior parameters which include the location and orientation parameters
    - Interior parameters, lens distortion and focal length are examples of the second type.

# 4) Math Model cont'd

– The model specifically covers and takes into account the lens distortion through some parameters that model radial, decentering, and affinity distortion.

$$\Delta x = \bar{x}(k_1 r^2 + k_2 r^4 + k_3 r^6) + p_1(r^2 + 2\bar{x}^2) + 2 p_2 \bar{x}\ \bar{y}$$

$$\Delta y = \bar{y}(k_1 r^2 + k_2 r^4 + k_3 r^6) + 2 p_1 \bar{x}\ \bar{y} + p_2(r^2 + 2\bar{y}^2) + a_1 \bar{x} + a_2 \bar{y}$$

where: $r^2 = \bar{x}^2 - \bar{y}^2, \quad \bar{x} = x' - x_o, \quad \bar{y} = y' - y_o$

$k_i, \ p_i, \ a_i$ : radial , decentering, affinity distortion coefficients

# 4) Math Model cont'd

$$F_x = \bar{x} + \bar{x}(k_1 r^2 + k_2 r^4 + k_3 r^6) + p_1(r^2 + 2\bar{x}^2) + 2p_2\overline{xy}$$

$$+ f\,\frac{r_{11}(X - X_c) + r_{12}(Y - Y_c) + r_{13}(Z - Z_c)}{r_{31}(X - X_c) + r_{32}(Y - Y_c) + r_{33}(Z - Z_c)} = 0$$

$$F_y = \bar{y} + \bar{y}(k_1 r^2 + k_2 r^4 + k_3 r^6) + 2p_1\overline{xy} + p_2(r^2 + 2\bar{y}^2) +$$

$$a_1\bar{x} + a_2\bar{y} + f\,\frac{r_{21}(X - X_c) + r_{22}(Y - Y_c) + r_{23}(Z - Z_c)}{r_{31}(X - X_c) + r_{32}(Y - Y_c) + r_{33}(Z - Z_c)} = 0$$

- Each target observation will generate two equations. Consequently, the number of equations will be twice the number of targets in the image for each camera.

# 4) Math Model cont'd

## 4.2) Solution Method

- In a calibration process like this we want the number of equations to exceed the minimum requirement in order to have an *overdetermined* system. Such a system enhances the reliability and precision of the result. In this problem, 13 parameters were estimated and the number of targets that were used was 20 and 21 in some cases. So, the redundancy we had during the procedure was 27.

- The Unified least squares approach was used to solve this system since some *a priori* knowledge is available for a number of parameters. This a priori knowledge is utilized to give those parameters initial values and weights.

- In this sense, some of the parameters were treated as observations with low precision by assigned large variances to them. Since the system is non-linear, the parameter values will be updated iteratively until convergence by adding the correction vector

# 5) Distortion Analysis

- After determining the camera parameters including distortion parameters, distortion curves were drawn for visual and computational analysis.

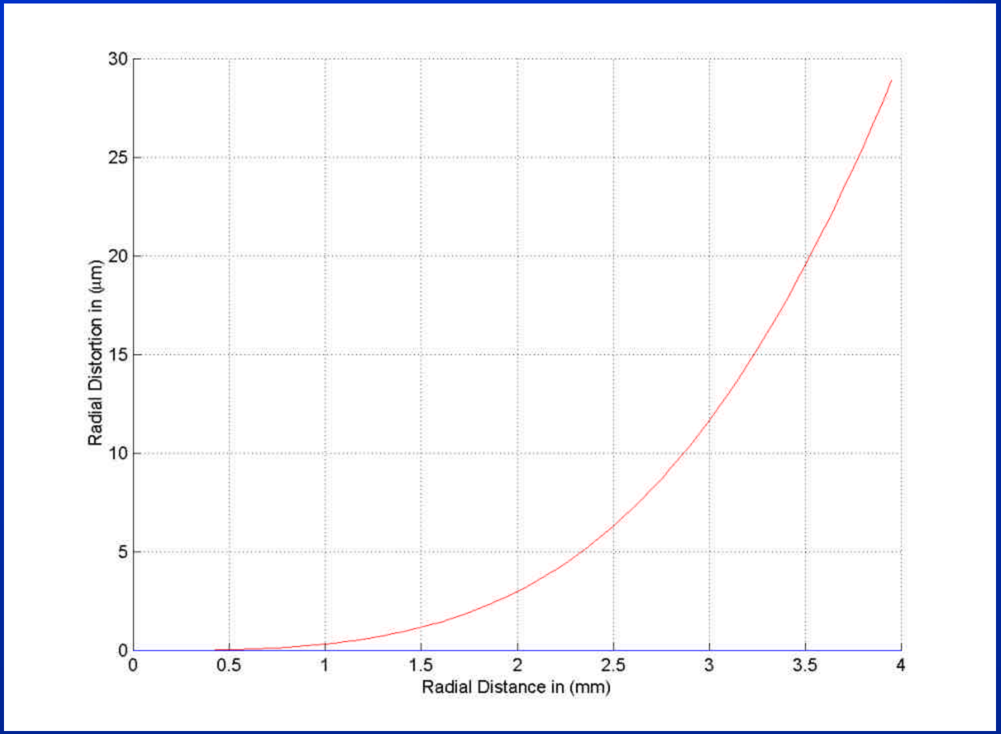
## 5.1) Radial Distortion

It is the displacement of an imaged object radially either towards or away from the principle point

$$\Delta r = k_1 r^3 + k_2 r^5 + k_3 r^7$$

$$d_x = \Delta r * \bar{x} / r \quad d_y = \Delta r * \bar{y} / r$$

The resulting curves were obtained for all four cameras and the maximum radial distortion was less than 40 micrometers.




Radial distortion curve of the blue camera

# 5) Distortion Analysis cont'd

- Radial distortion curve equalization

- The following step was done to level or balance the curve based on equalizing the maximum and the minimum distortion values. This step has no effect on the final results of the corrected coordinates; it is just cosmetic but accepted professional practice.

- Mathematically, balancing the curve leads to a change in the radial distortion parameters and consequently the focal length and other related camera parameters. So this procedure was done iteratively and the parameters were updated.

- CFL: Calibrated focal length.

$$r_{max} - CFL \times \tan(a_{max}) + r_{min} - CFL \times \tan(a_{min}) = 0$$

$$CFL = \frac{r_{max} + r_{min}}{\tan(a_{max}) + \tan(a_{min})}$$

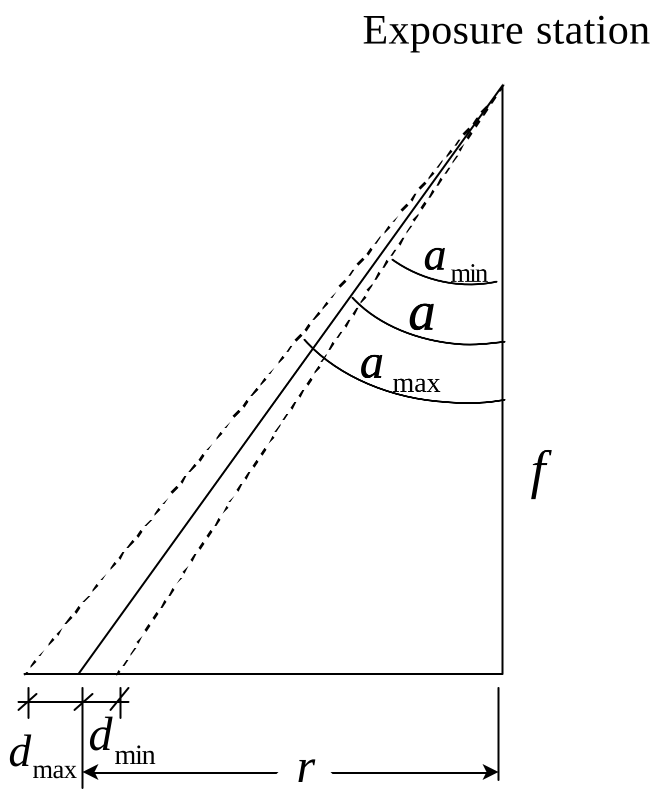
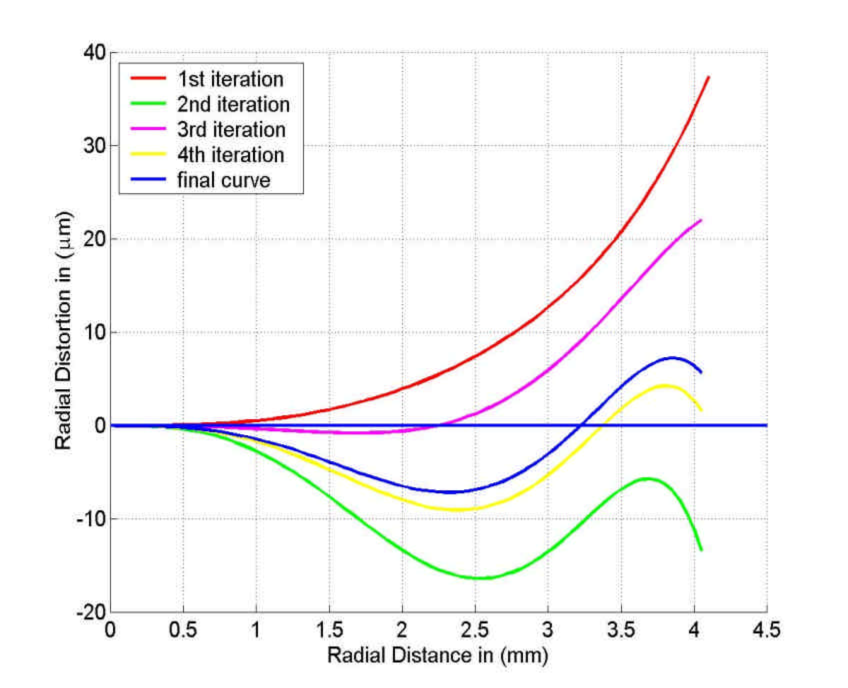



image plane cross section

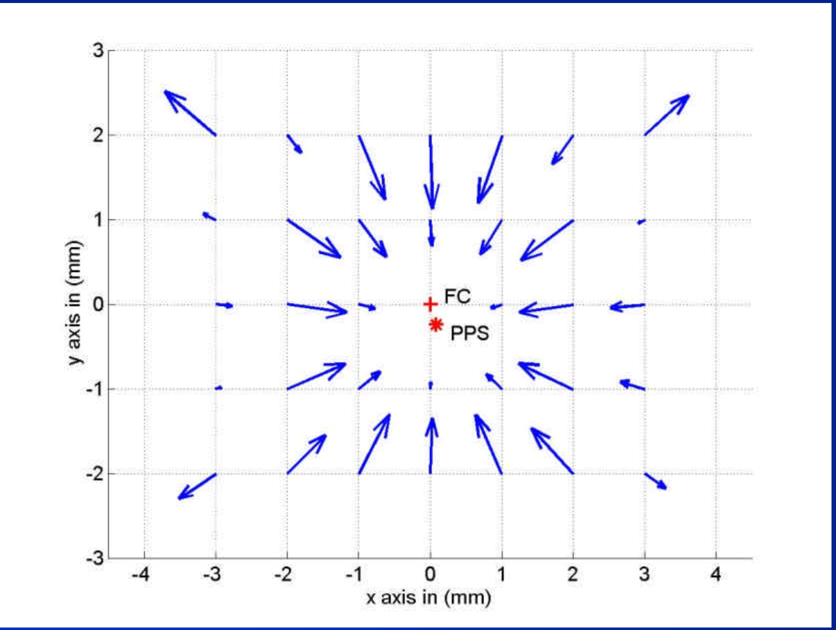
We want dmax and dmin to have approximately the same magnitude.

# 5) Distortion Analysis cont'd

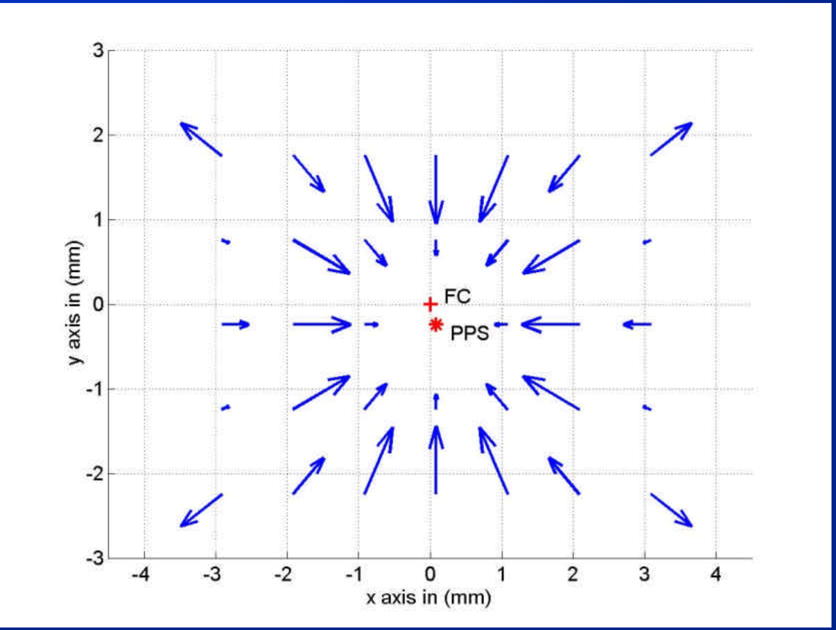
Radial distortion (RD) resulting curves




Radial distortion (Equalization iteration for the Blue camera)




Scaled RD centered at FC for the Blue camera




Scaled RD centered at PPS for the Blue camera

FC: fiducial center.

PPS: principal point of best symmetry.

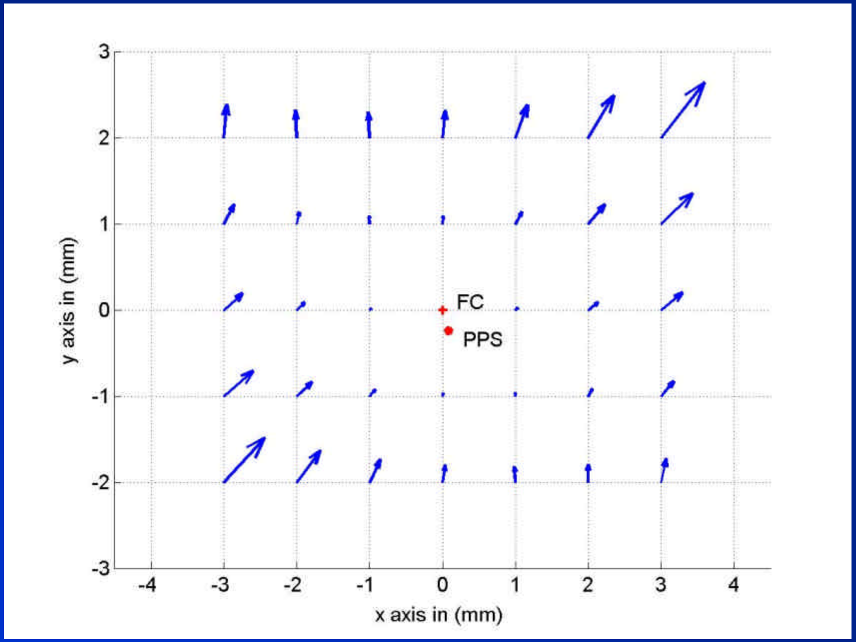
# 5) Distortion Analysis cont'd

## 5.2) Decentering Distortion (DD)

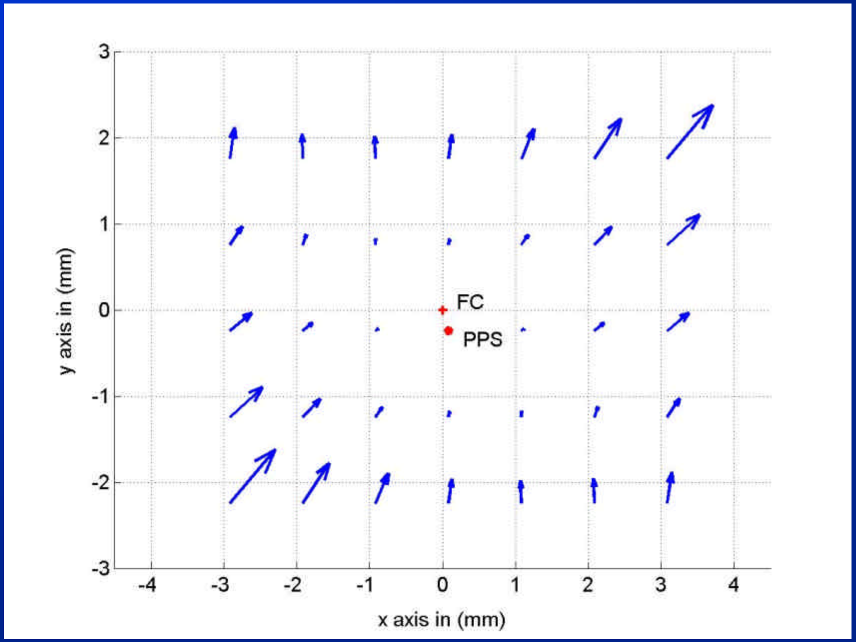
- The misalignment between lens components will lead to systematic image displacement errors which is called Decentering Distortion.

$$d_x = p_1[r^2 + 2(x - x_o)^2] + 2p_2(x - x_o)(y - y_o)$$

$$d_y = p_2[r^2 + 2(y - y_o)^2] + 2p_1(x - x_o)(y - y_o)$$




Scaled DD centered at PPS for the Blue camera




Scaled DD centered at FC for the Blue camera

# 6) Results and Discussion

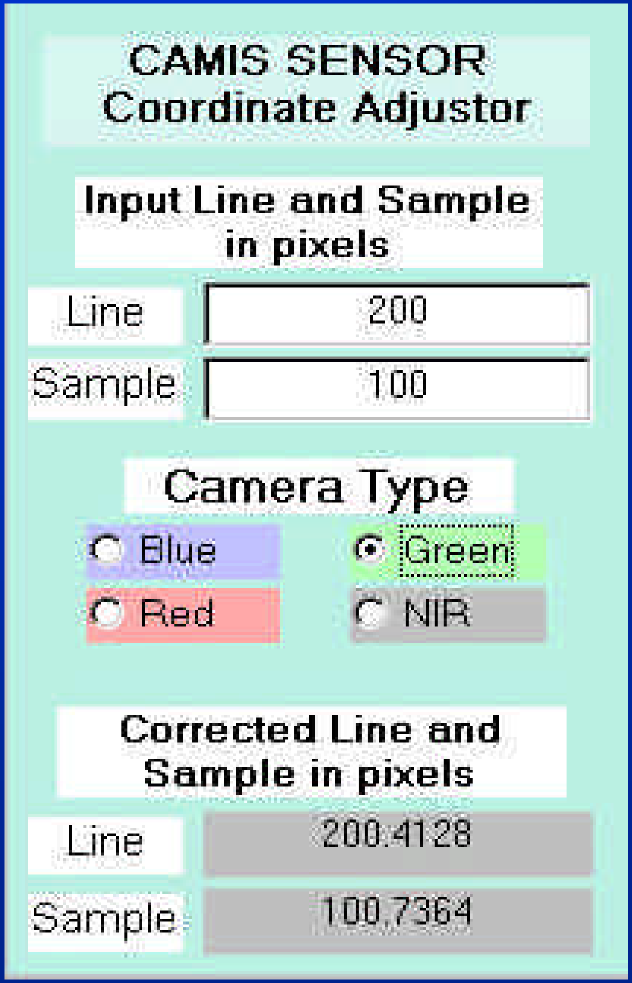
| Parameter | Blue Camera (Working band 450nm) | Green Camera (Working band 550nm) | Red Camera (Working band 650nm) | IR Camera (Working band 800nm) |
|---|---|---|---|---|
| $f$ | 16.168 $mm$ | 16.154 $mm$ | 16.177 $mm$ | 16.174 $mm$ |
| $x_o$ | 0.084357 $mm$ | -0.024693 $mm$ | -0.253464 $mm$ | -0.014537 $mm$ |
| $y_o$ | -0.239466 $mm$ | - 0.213401 $mm$ | - 0.109878 $mm$ | -0.158923 $mm$ |
| $k_1$ | -1.696019 $*10^{-3}$ | -1.709735 $*10^{-3}$ | -2.011666 $*10^{-3}$ | -1.712994 $*10^{-3}$ |
| $k_2$ | 0.257710 $*10^{-3}$ | 0.274246 $*10^{-3}$ | 0.337008 $*10^{-3}$ | 0.260639 $*10^{-3}$ |
| $k_3$ | -0.009089 $*10^{-3}$ | -0.010202 $*10^{-3}$ | -0.013096 $*10^{-3}$ | -0.009190 $*10^{-3}$ |
| $p_1$ | 0.053187 $*10^{-3}$ | 0.036416 $*10^{-3}$ | -0.134155 $*10^{-3}$ | -0.009700 $*10^{-3}$ |
| $p_2$ | 0.113262 $*10^{-3}$ | 0.036419 $*10^{-3}$ | 0.066029 $*10^{-3}$ | 0.014206 $*10^{-3}$ |
| $a_1$ | 1.162203 $*10^{-3}$ | 0.279185 $*10^{-3}$ | -0.059959 $*10^{-3}$ | 0.130802 $*10^{-3}$ |
| $a_2$ | 0.059299 $*10^{-3}$ | -0.663338 $*10^{-3}$ | -0.637141 $*10^{-3}$ | 0.278204 $*10^{-3}$ |

Estimated parameters of the four sensors.

# 6) Results and discussion cont'd

- For simplicity, the graphical user interface feature in MATLAB was used to create a small user-friendly program to show the results and compute refined image coordinates on a single point basis.

- The parameters of each camera were stored in the file and by inserting the value of the measured line and sample and specifying the corresponding camera, the corrected line and sample will be calculated and printed in the window for the user.



# The interesting contributions of this research

- We tried during this work to automate the calibration process as much as possible.
- The setup and measurements of the targets and the cameras.
- The automation of the target locations in the images, and their subsequent refinement.
- The automatic process for balancing the radial lens distortion in the presence of other correlated parameters.


- ACKNOWLEDGEMENT
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