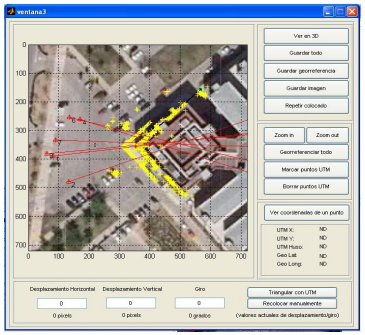
Telecommunications Engineering Thesis

Validating a Structure from Motion Tool for use on Videos recorded from an Unmanned Aerial Vehicle (UAV)



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Spanish National Institute for Aerospace Technology)

Contents

Introduction

- Aims of the thesis
  - Evaluation of SfM software for videos recorded from UAVs
    - Using a state of the art SfM application: Bundler
  - Validation and georeference of results
    - Developing a validation prototype in Matlab: Orto3D

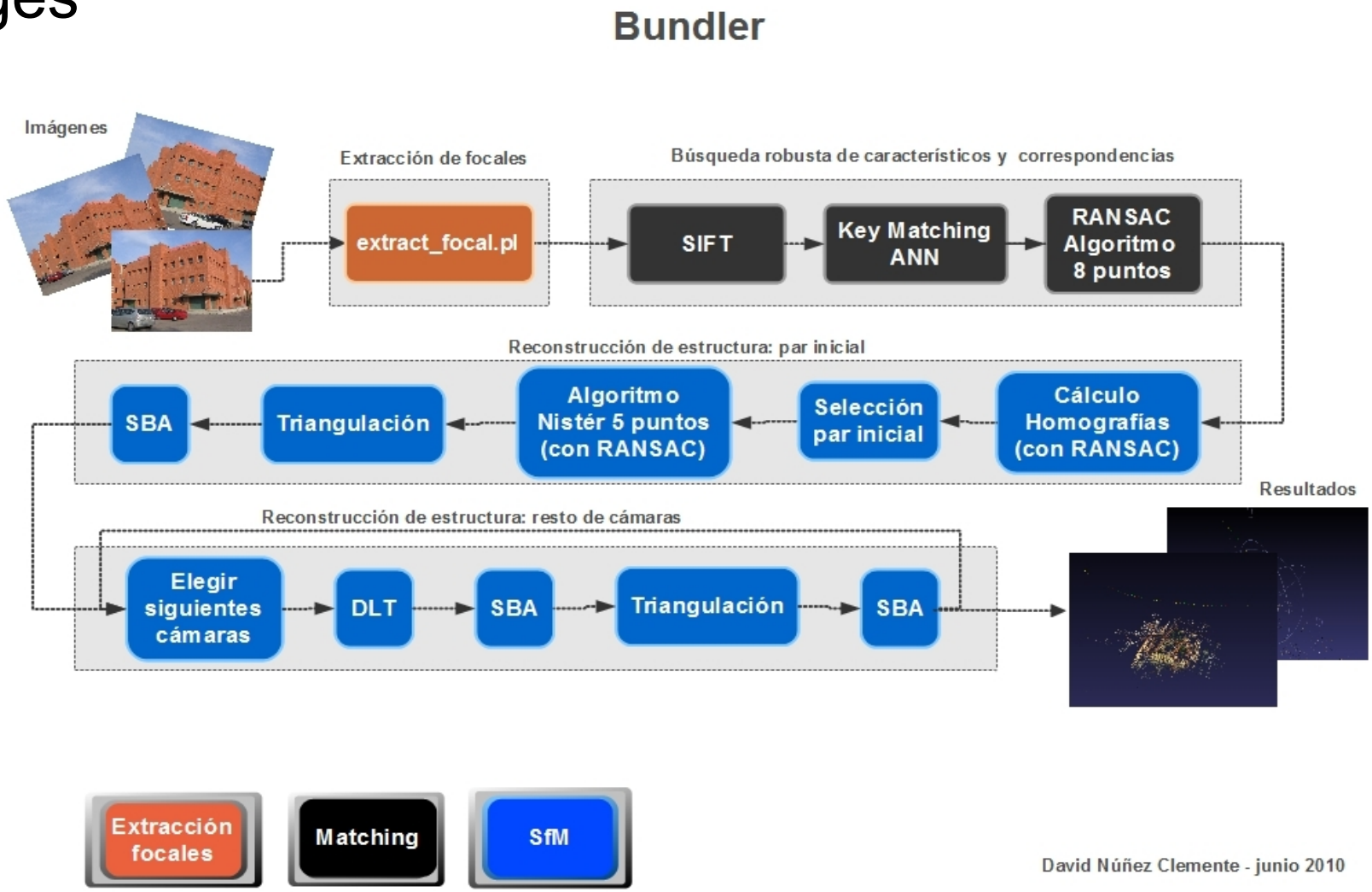
Bundler

- What is Bundler?
  - A SfM software by Noah Snavely
  - Open source code in C/C++
  - Designed for SfM from pictures on the Internet
    - e.g. Flicker or Picasa
  - Divided in stages
  - Software related to:
    - PhotoTourism (UW)
    - PhotoCity (UW & Cornell)
    - Microsoft Photosynth

Figures source: http://phototour.cs.washington.edu/bundler/

Bundler

- Stages



Bundler

- Structure from Motion
  - ***How is SfM implemented in Bundler?***

- First pair of cameras
  - Nister Method
    - Calibrated Cameras
      - » Focal length in EXIF tags
      - » By default f=532 pixels
- Rest of the cameras
  - Focal length estimated with DLT
    - It also relies on EXIF tags

Orto3D

- What is Orto3D?
  - Prototype in Matlab
  - Goal:
    - Evaluation of scenarios and camera parameters.
  - Functionality
    - Read Bundler's output data
    - Select keypoints manually
    - Georeference Bundler reconstructions
    - Validate Bundler results

Orto3D

- Selection of keypoints manually
  - Using 3 cameras
  - Triangulating matching keypoints for
    - Lines (Z axis, georeference and measurements)
    - Quadrilaterals (walls, roofs)
    - Point (height reference)

Orto3D

- Georeference
  - Fairly easy when working with buildings or structures (urban scenarios)

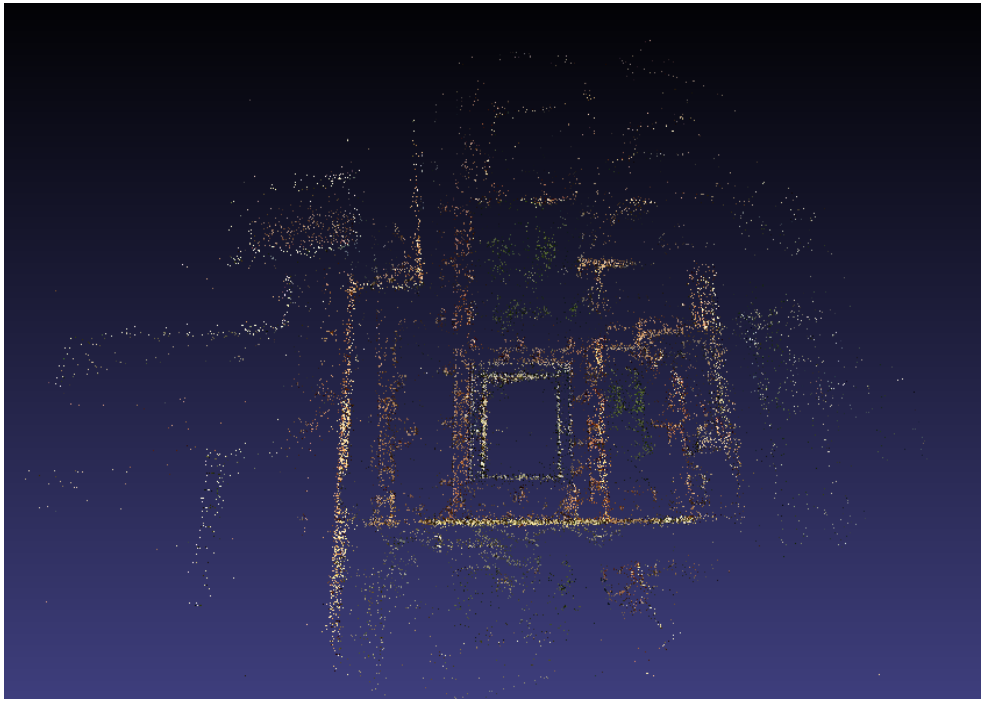


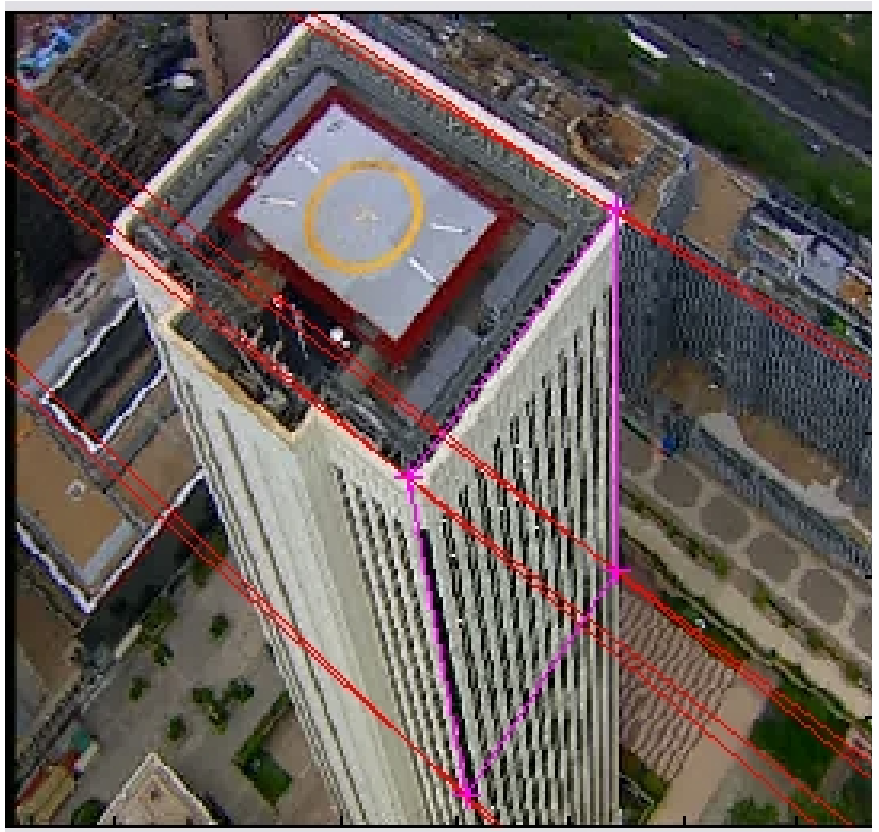
Image source: SIGPAC http://sigpac.mapa.es/fega/visor/

Orto3D

- Validation
  - Problems
    - No real flight data, no camera calibration
      - Accurate results impossible → only approximate results
  - How to evaluate them?
    - Epipolar lines
    - Triangulation
    - Camera positions
    - Measurements

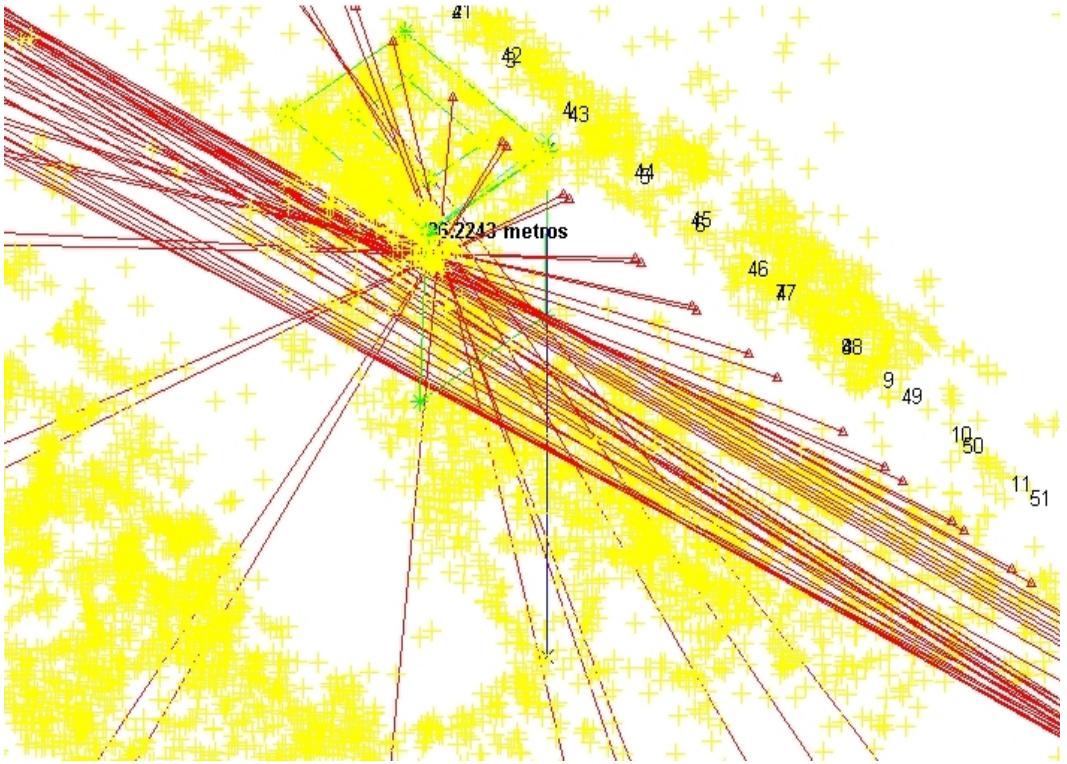
Orto3D

- Epipolar Lines
  - If valid epipolar lines
    - Camera estimated parameters accepted
  - Easy to recognize incorrect results



Orto3D

- Triangulation
  - 3D Points position after triangulation
  - Levenberg – Marquardt with 3 cameras
  - Without using SBA
    - Parameters estimated by Bundler assumed to be correct.



Orto3D

- Camera Positions
  - Show flight path
  - Camera centers
    - Position
  - Principal Axis
    - View direction

Orto3D

- Measurements
  - For comparing with real results

3D Reconstruction Results

- Images
  - Video frames from SIVA
  - Photos from a digital camera
  - Aerial video shootings for TV

3D Reconstruction Results

- SIVA
  - Problems
    - Characters on the frames
    - Low resolution

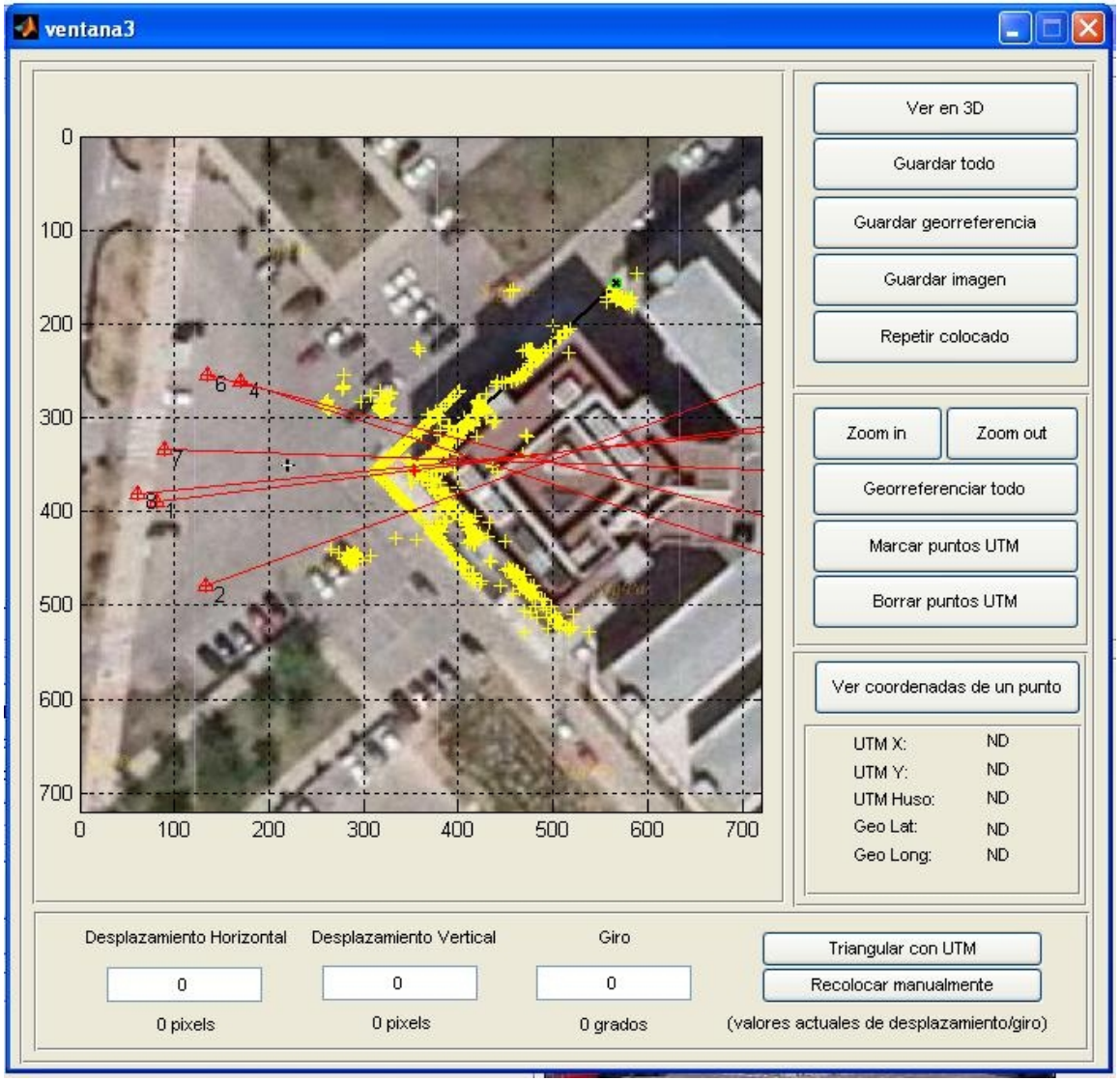
      (352x288) or (720x576) pix.

3D Reconstruction Results

- SIVA
  - Followed approach:
    - Adding a keypoints filter
      - Aim: discard erroneous keypoint matches
      - Method: distance between keypoint matches between frames
    - Results
      - Discards incorrect points by defining a threshold
    - Problem: very limited results due to resolution and compression

3D Reconstruction Results

- Digital Camera
  - Prototype Development
  - Good Resolution (2272x1780 pixels)
  - Square building



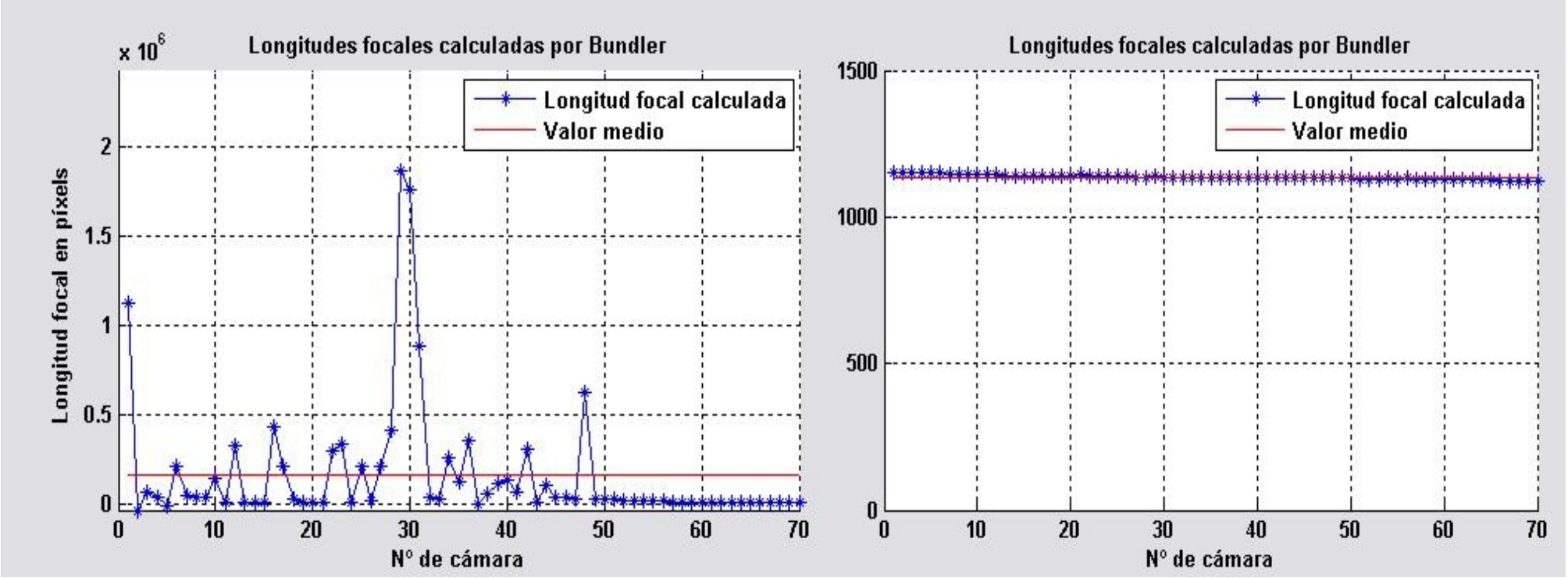
3D Reconstruction Results

- TV shootings
  - Aim:
    - Test 3D results with better resolution images.
  - Many aerial videos at low cost.
  - Good resolution
  - Image Stabilization



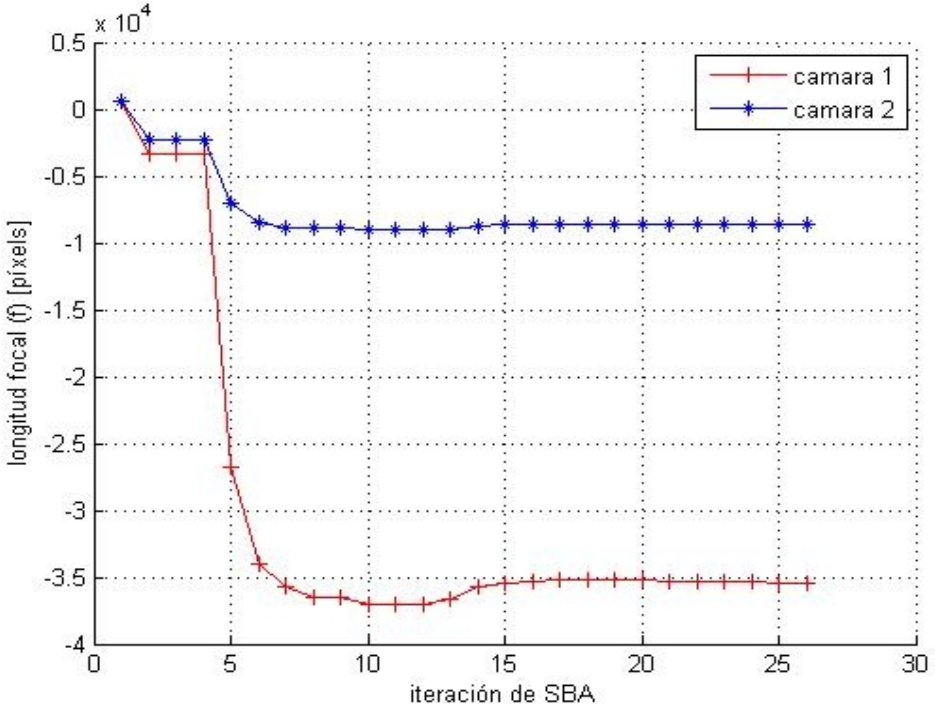

3D Reconstruction Results

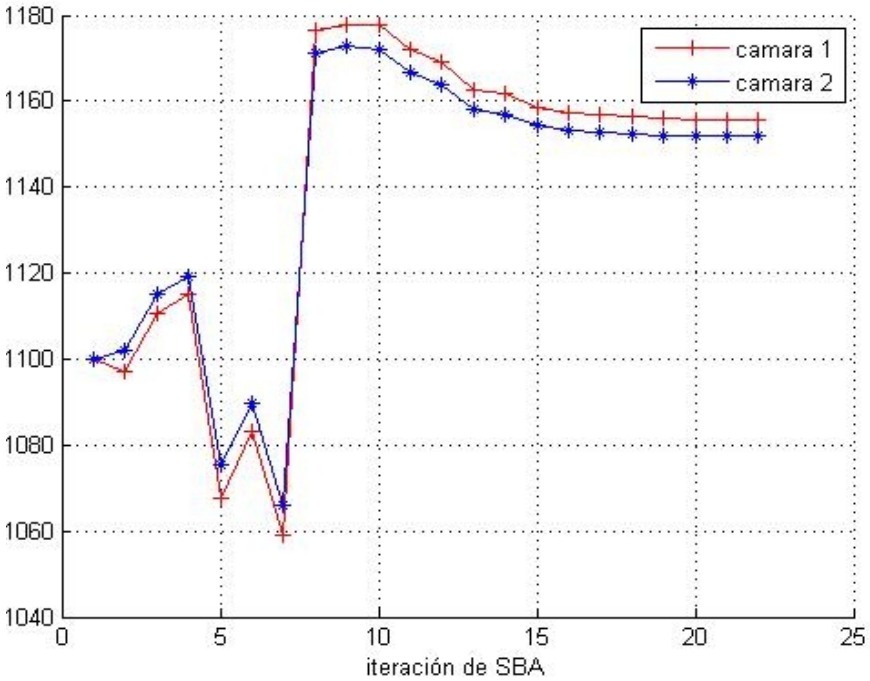
- Focal length estimation
  - Scenario: MECO_3 | MECO_3_MOD_1



3D Reconstruction Results

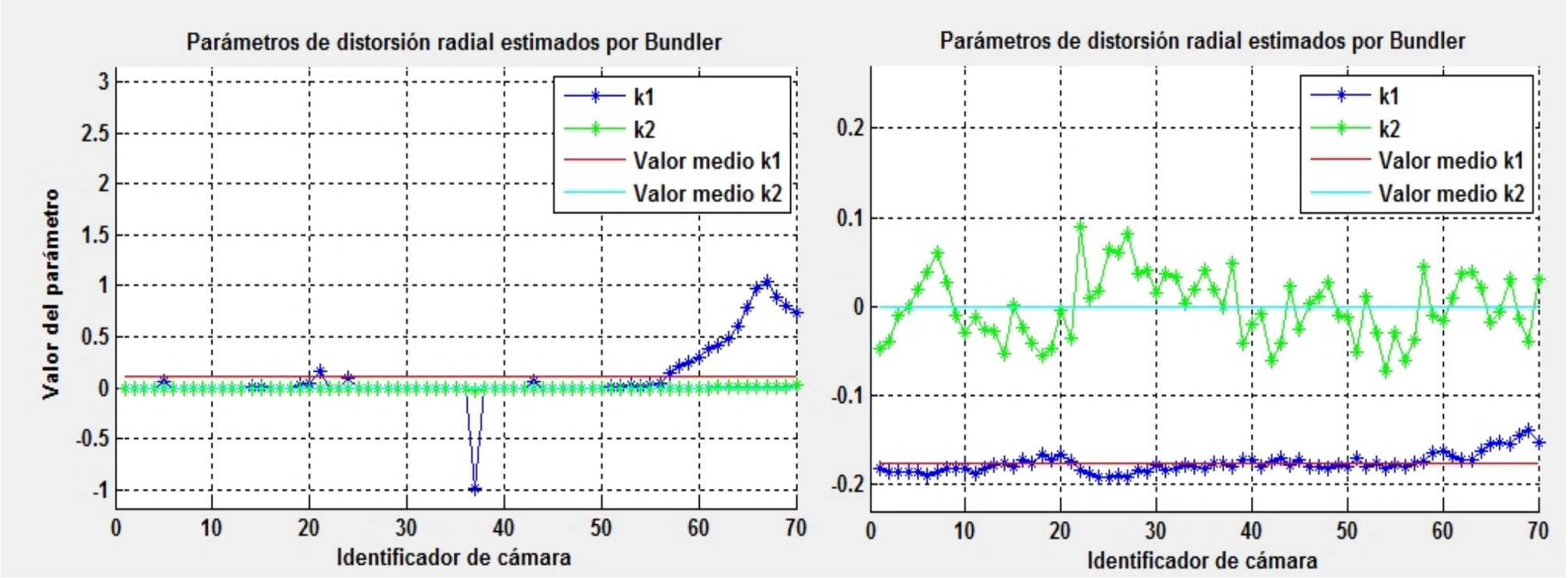
- Focal length estimation
  - Scenario: MECO_3 | MECO_3_MOD_1 (SBA estimations)





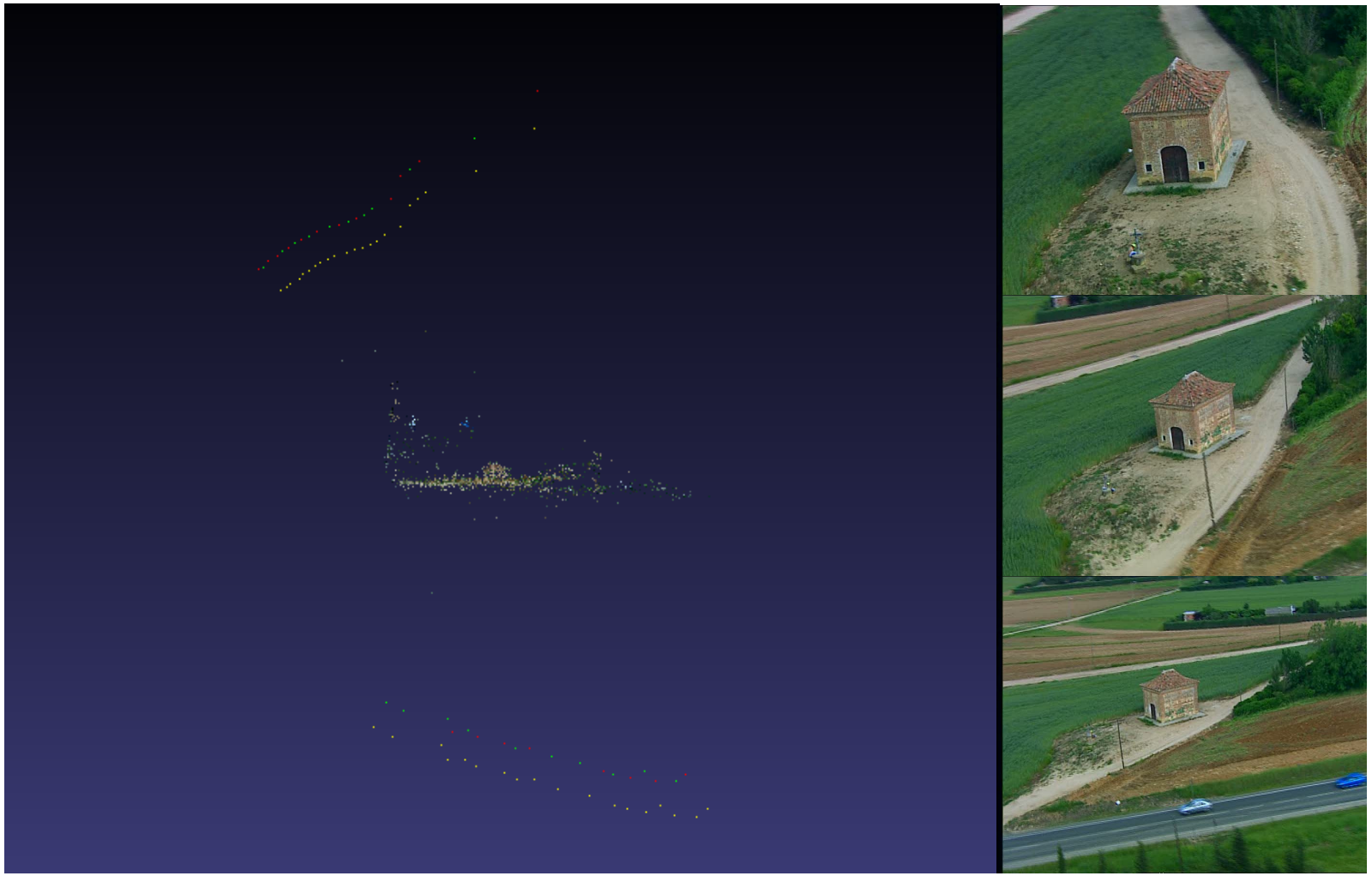
3D Reconstruction Results

- Radial Distortion Estimation
  - Scenario: MECO_3 | MECO_3_MOD_1



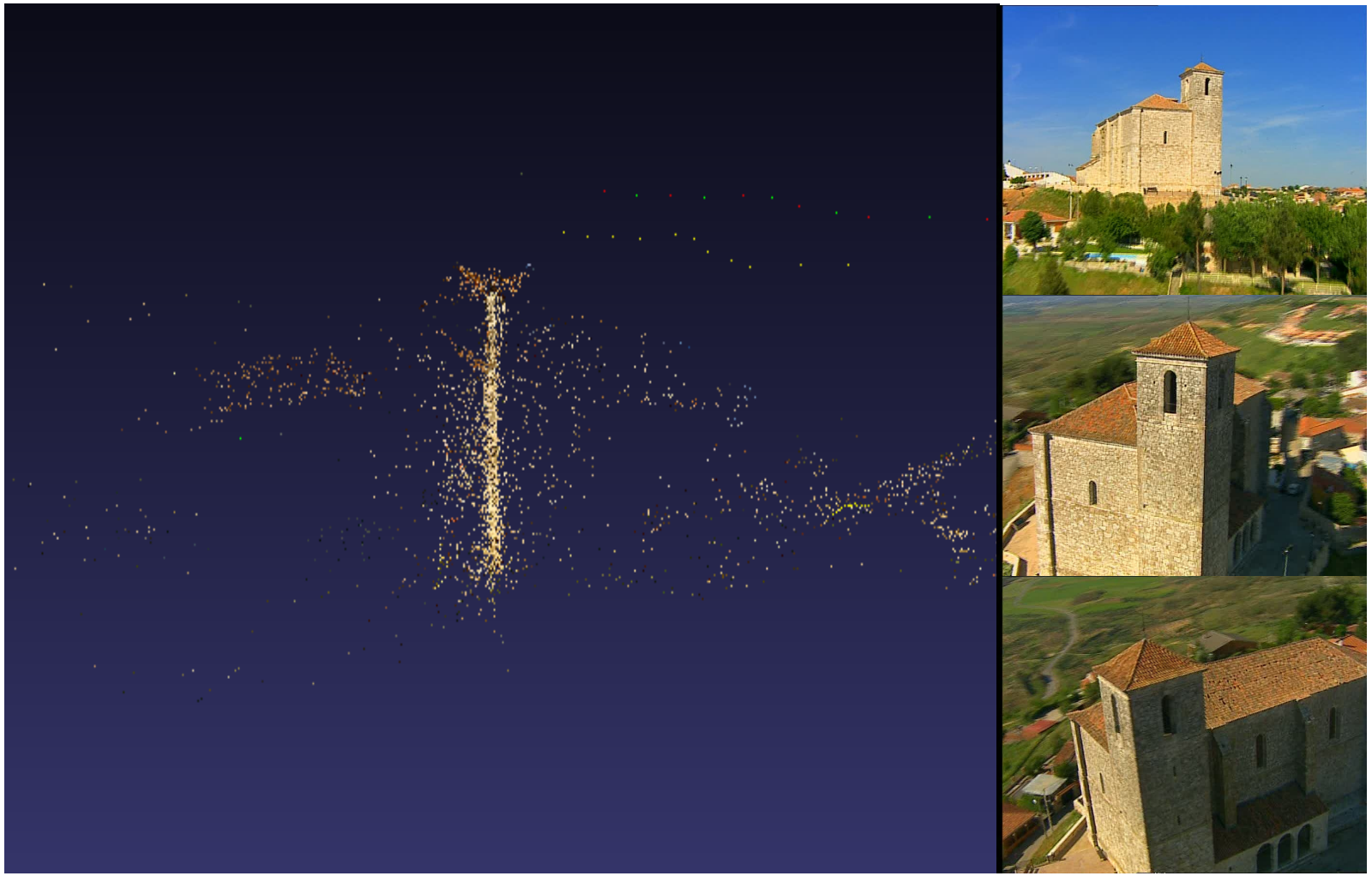
3D Reconstruction Results

- SfM errors: Necker reversal



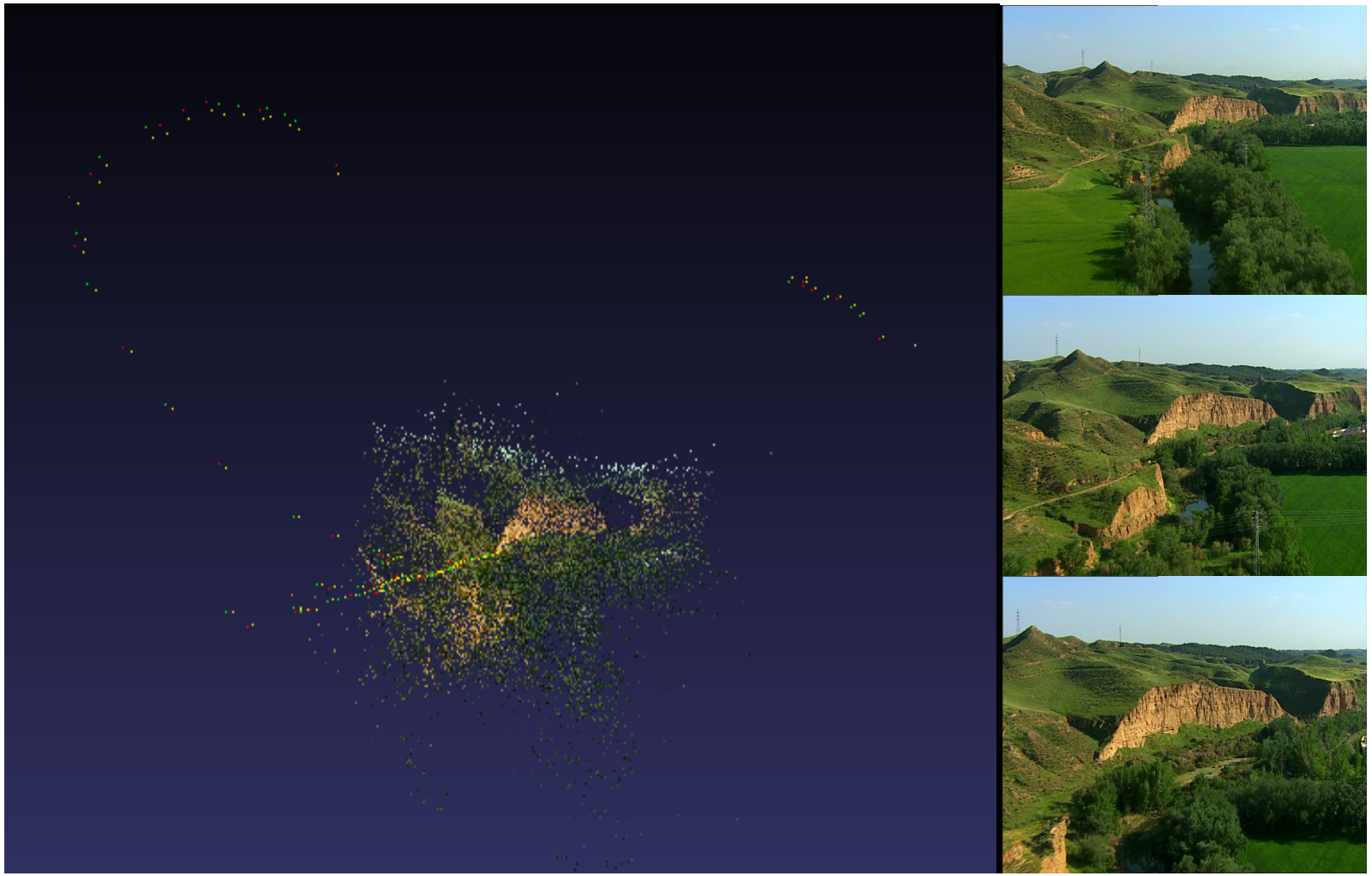
3D Reconstruction Results

- SfM errors: bad initialization



3D Reconstruction Results

- SfM errors: bad initialization



Conclusions

- Bundler
  - Powerful and robust SfM tool
    - *But...* → *Under certain conditions*. Problems if no focal available.
    - Heavy in computing terms
    - Can be used with PMVS or CMVS
  - Problems with overwritten data on frames
    - Avoided with a filter or by defining ROIs
  - Camera calibration dependent
    - No reliabilty without EXIF tags or by enforcing focal values
    - Check other methods for non-calibrated cameras
      - Other estimation methods or autocalibration

Conclusions

- Orto3D
  - Useful for georeference
    - No similar open source application for handling Bundler results.
    - Can be continued, improved and optimized.
    - Good results considering accuracy problems.

Conclusions

- Images
  - Good shooting sequences must be used
    - Enough frames
    - Adequate flight paths (*forward, lateral*)
  - Better if position and focals are known (GPS, telemetry)
    - Increase of robustness and accuracy.

Conclusions

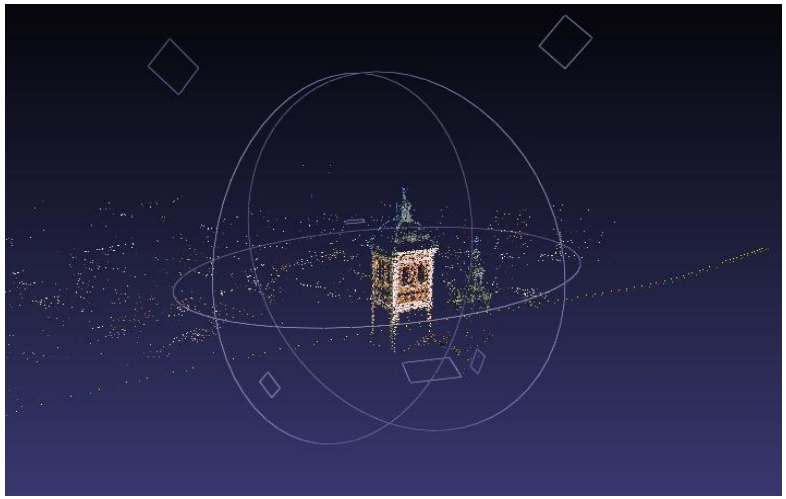
- Thesis contributions
  - Application to the UAV sector
    - Using open source SfM for postprocessing
  - Knowledge adquired in computer vision
  - Defines an interesting work line to be continued

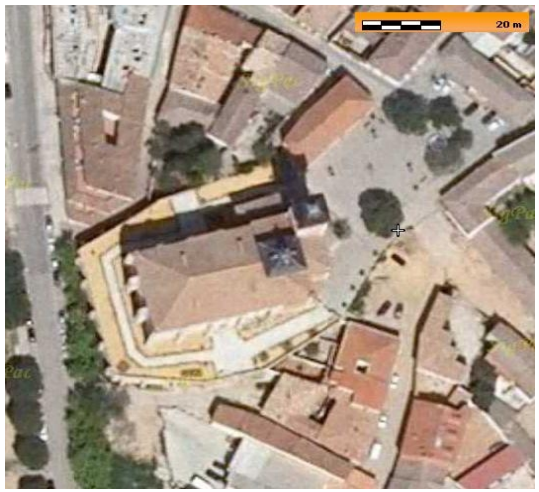
Future Work

- Several options for continuity
  - Documentation of Bundler with Doxygen
  - Modifications of Bundler
  - Improvement of Orto3D
  - Tests of video resolution and compression
  - Exploitation of Image results
  - Real time applications (using other techniques)

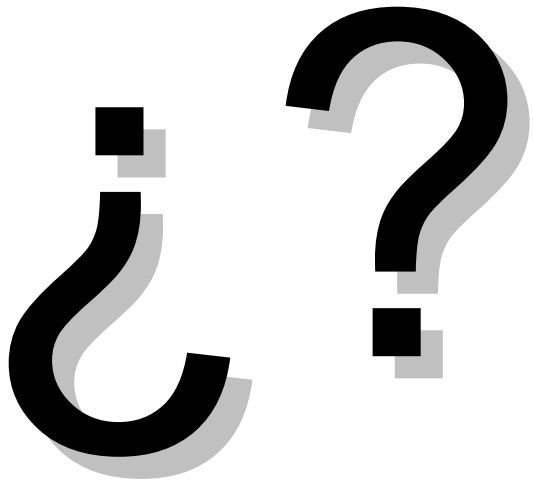
Orto3D Demo

- Orto3D demo with an aerial video
  - Scenario: MECO_3_MOD_1
  - Place: Meco (Madrid, Spain)
  - Description: Bell tower
  - Cameras (frames): 70





Questions



Annex

- Acronyms

ANN: Aproximative Nearest Neighbour

CMVS: Clustering views for Multi-View Stereo

DLT: Direct Linear Transform

EXIF: EXchangeable Image File Format

GPS: Global Positioning System

INTA: Instituto Nacional de Técnica Aeroespacial

LMA: Levenberg-Marquardt Algorithm

MVS: Multi-View Stereo

PMVS: Patch-based Multi-View Stereo

RANSAC: RANdom Sample Consensus

SBA: Sparse Bundler Adjustment

SfM: Structure from Motion

SIFT: Scale Invariant Feature Transform

SIVA: Sistema Integrado de Vigilancia Aérea

SLAM: Simultaneous Location And Mapping

SURF: Speed-Up Robust Features

SW: Software

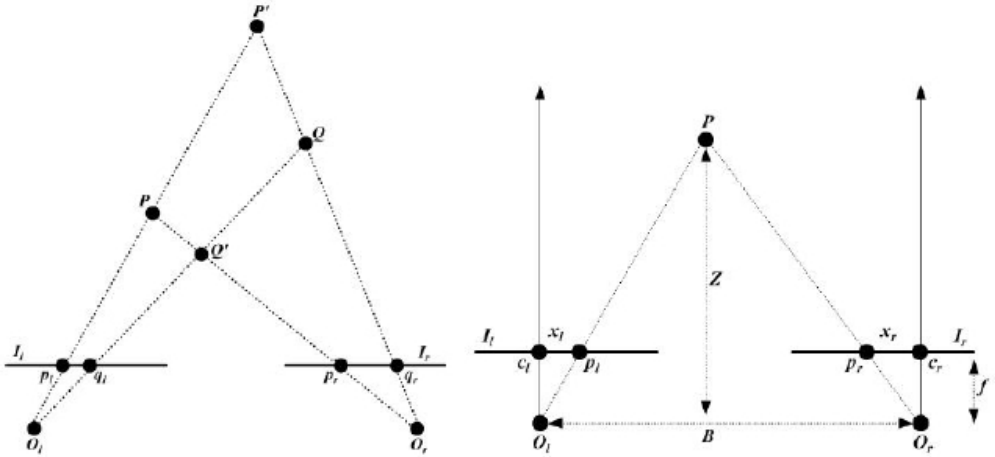
TV: Televisión

UAV: Unmanned Aerial Vehicle

UTM: Universal Transverse Mercator

Annex

- Bundler – Baseline



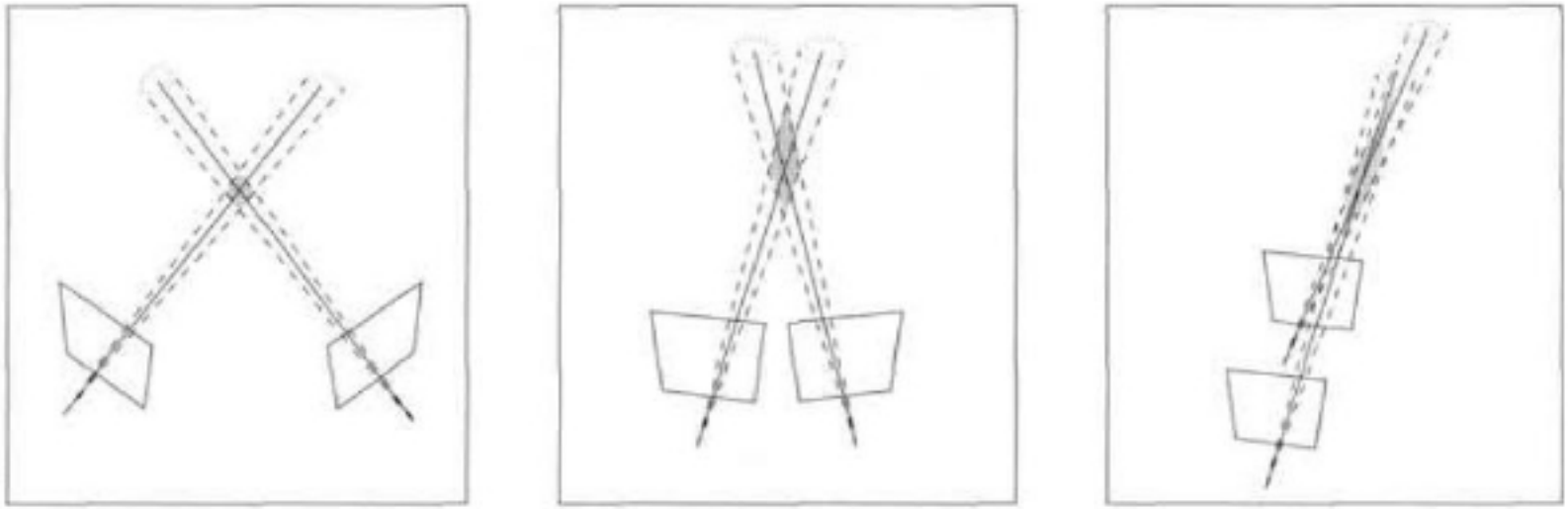
$$Z = f\frac{B}{d}$$

$$\Delta Z_i = Z_i - Z_{i-1} = f_x B(\frac{1}{d_{ui} - 1} - \frac{1}{d_{ui}}) = f_x B \frac{1}{d_{ui}^2 - d_{ui}}$$

Z máxima $Z = f_x B$

Annex

- Bundler – Baseline
  - Vehicle movement vs. depth



Annex

- Bundler – Focal length (Canon Powershot A520)

$$f_{mm} = 5{,}8mm \qquad f_{mm} = 23{,}2mm \qquad ancho\_CCD_{mm} = 5{,}76mm$$

$$f_{pixels} = res_x(\frac{f_{mm}}{ancho\_CCD_{mm}})$$

$$(1{,}006944445res_x, 4{,}027777778res_x)$$

$$f_{pix} = 1{,}2res_x$$

$$f_{mm} = 1{,}2 * 5{,}76 = 6{,}912mm$$

Annex

- Bundler – Running time

Etapa de la ejecución	Tiempo		Porcentaje
Característicos SIFT	$7m$	$4{,}818s$	19,23 %
Correspondencias	$16m$	$34{,}967s$	45,05 %
Reconstrucción SfM	$13m$	$8{,}812s$	35,70 %
Total	$36m$	$48{,}597s$	100,00 %

Tabla 5.1: Tiempo de ejecución para MECO_3_MOD_1

Etapa de la ejecución	Tiempo		Porcentaje
Característicos SIFT	$8m$	$5{,}057s$	21,50 %
Correspondencias	$18m$	$32{,}119s$	49,29 %
Reconstrucción SfM	$10m$	$59{,}312s$	29,22 %
Total	$37m$	$36{,}488s$	100,00 %

Tabla 5.2: Tiempo de ejecución para TORRE_PICASSO_AZCA_MOD_1

Annex

- Orto3D – Keypoints selection
  - Epipolar lines

$$x'^T F x = 0 \qquad l' = Fx \qquad l = F^T x'$$

  - F matrix from P
  - Correlation
    - 30x30 pixels window.
    - Camera 1 & camera 2 ; camera 1 & camera 3

Annex

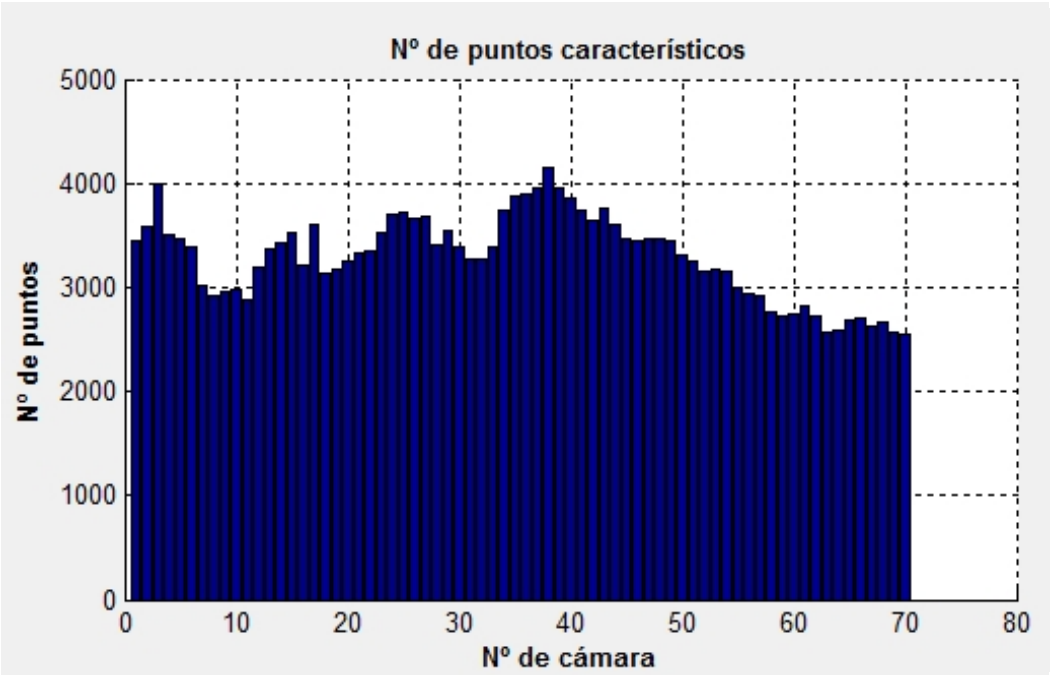
- Orto3D – Triangulation
  - Using 3 cameras
  - Linear method
  - Non-linear method
    - Levenberg-Marquardt

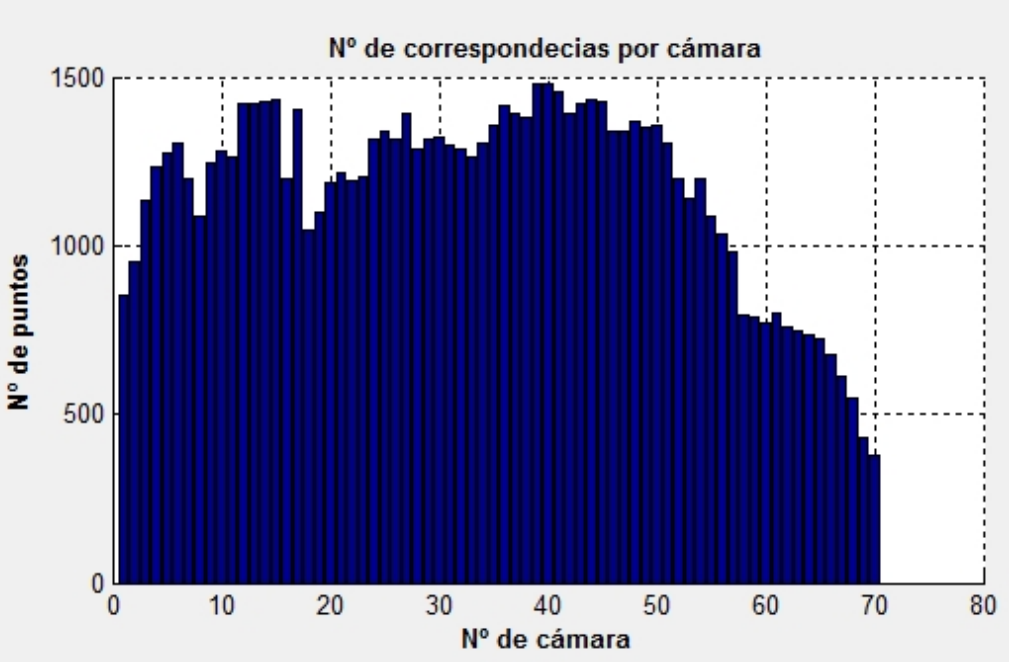
Annex

- Orto3D – Georeference
  - UTM reference points
    - Selected with SIGPAC
    - Minimun 2
  - Using relation meters/pixel
    - Computed from UTM reference points
  - Scale transformation

Annex

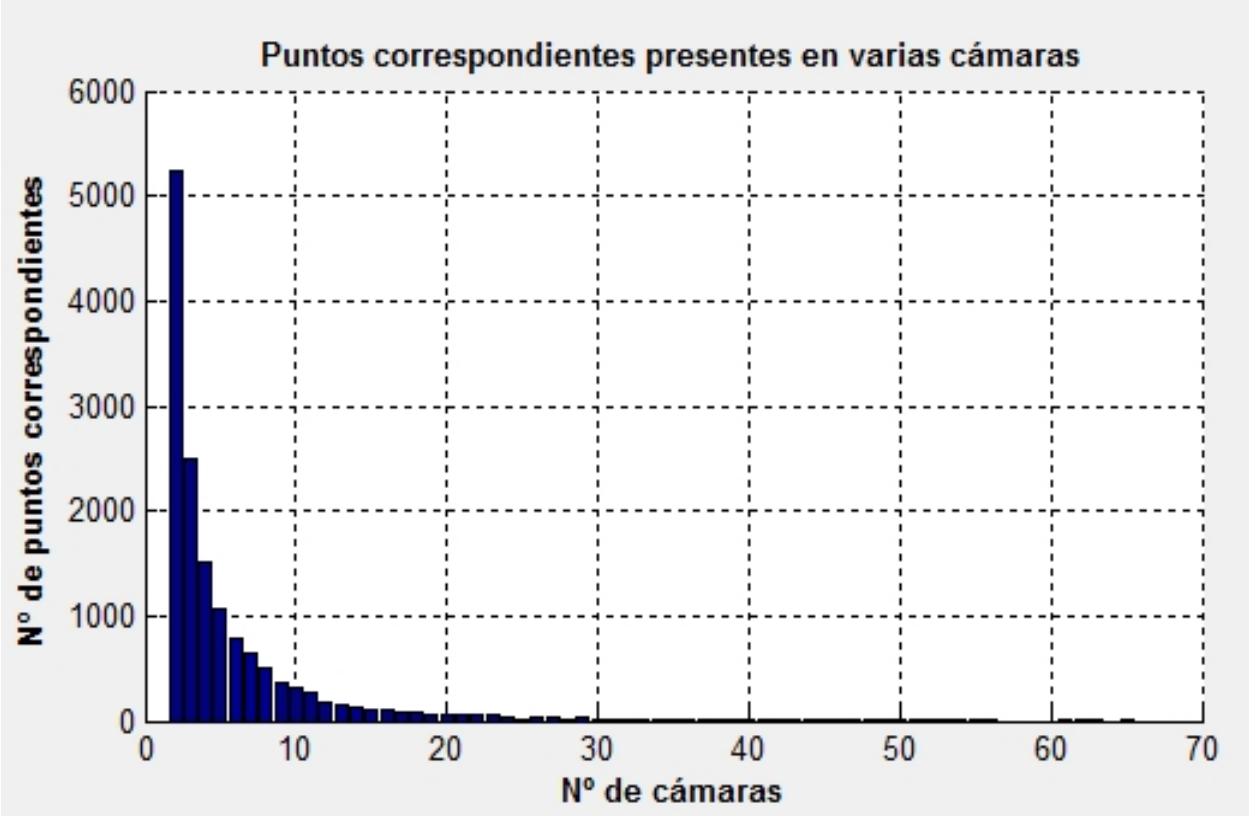
- Orto3D – SIFT keypoints and matches





Annex

- Orto3D – Points per views

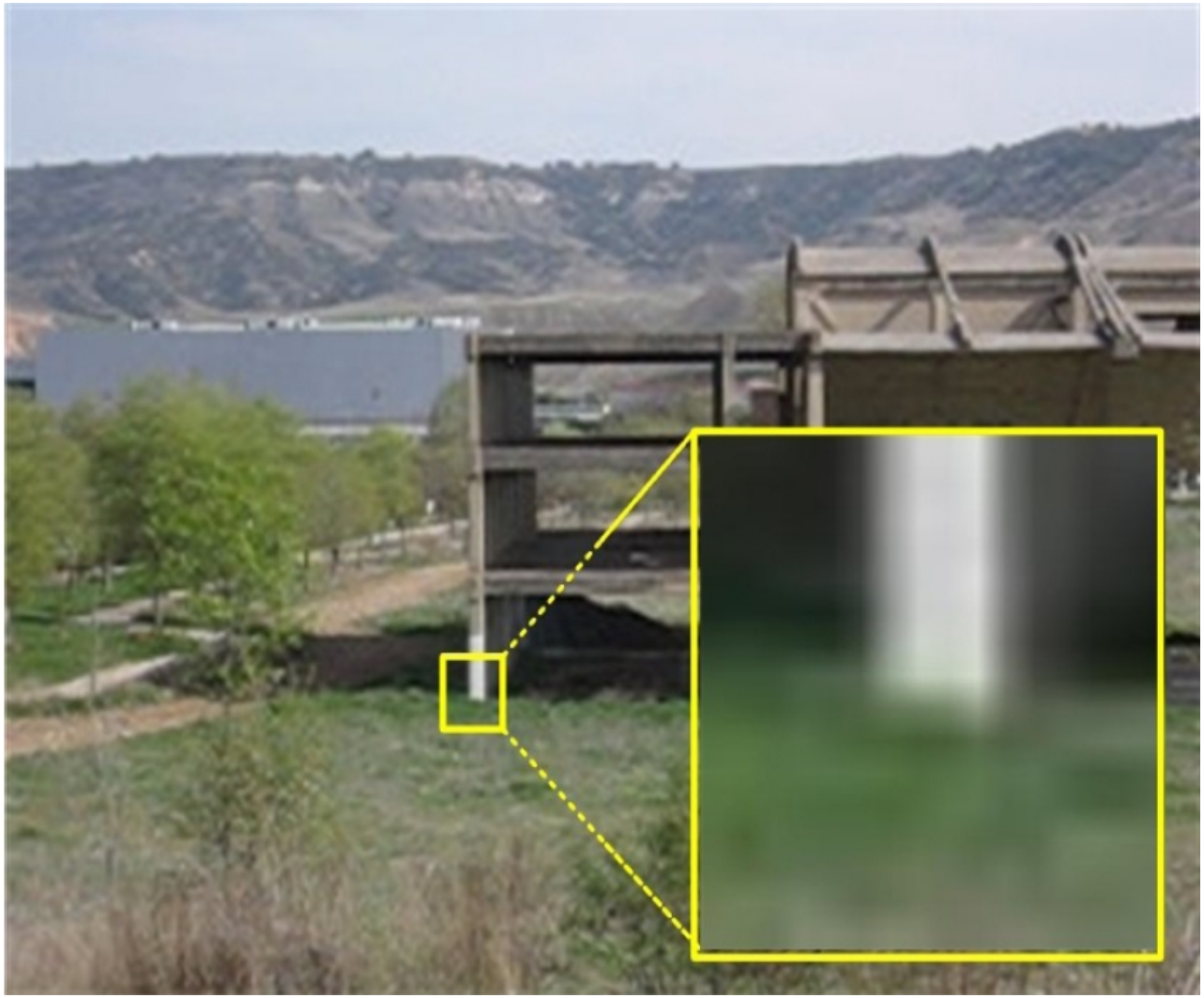


Annex

- Images – SIVA ***(352-288 pixels)***

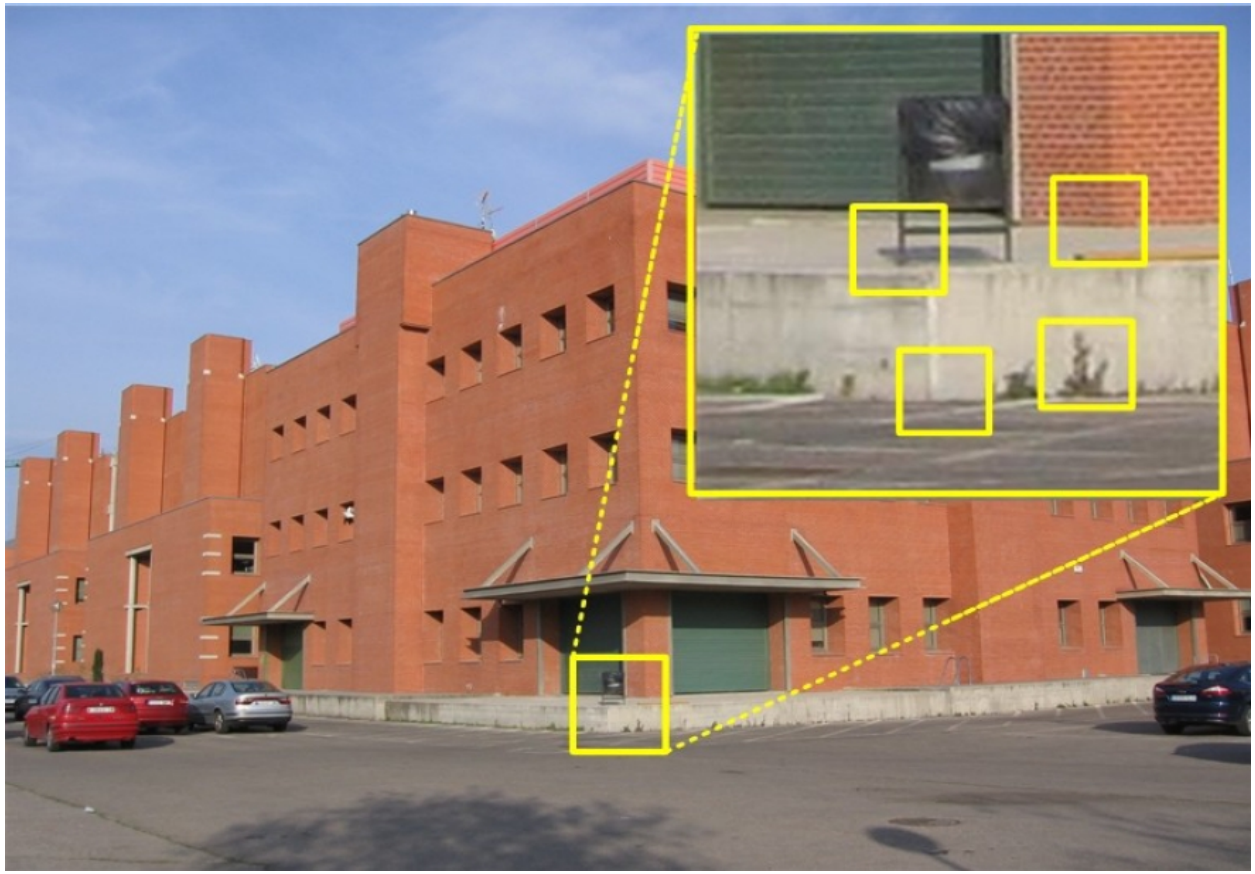
Annex

- Images – HANGAR ***(640-480 píxeles)***



Annex

- Images – POLITECNICA ***(2272-1704 pixels)***



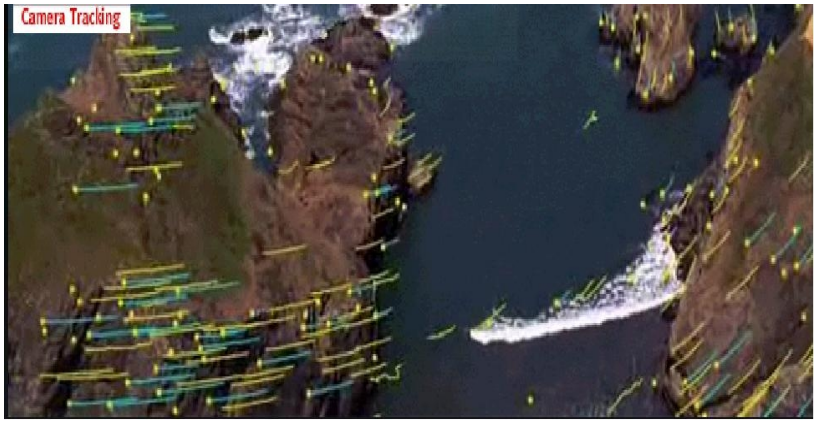
Annex

- UAVs
  - UAV+Computer Vision
  - Relevant UAVs for vision
  - UAVs for SfM

Image sources (from left to right): INTA http://www.inta.es **; UPM (DISAM)** http://www.disam.upm.es/colibri **; Schiebel** http://www.schiebel.net

Annex

- Vision for UAVs
  - SfM for restoration RC-Heli (Milán)
  - 2D3: commercial software
  - SLAM
    - Real time
    - Different approach
  - SfM vs. SLAM
    - SfM only for postprocessing approaches



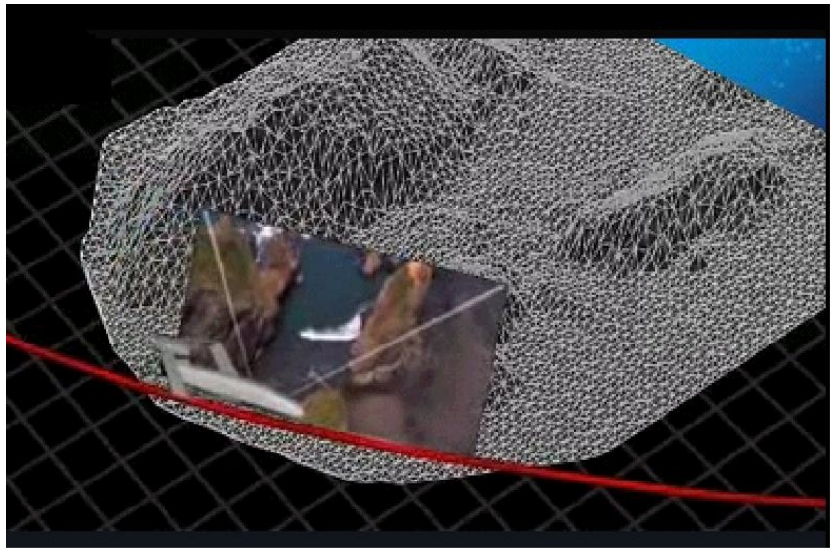
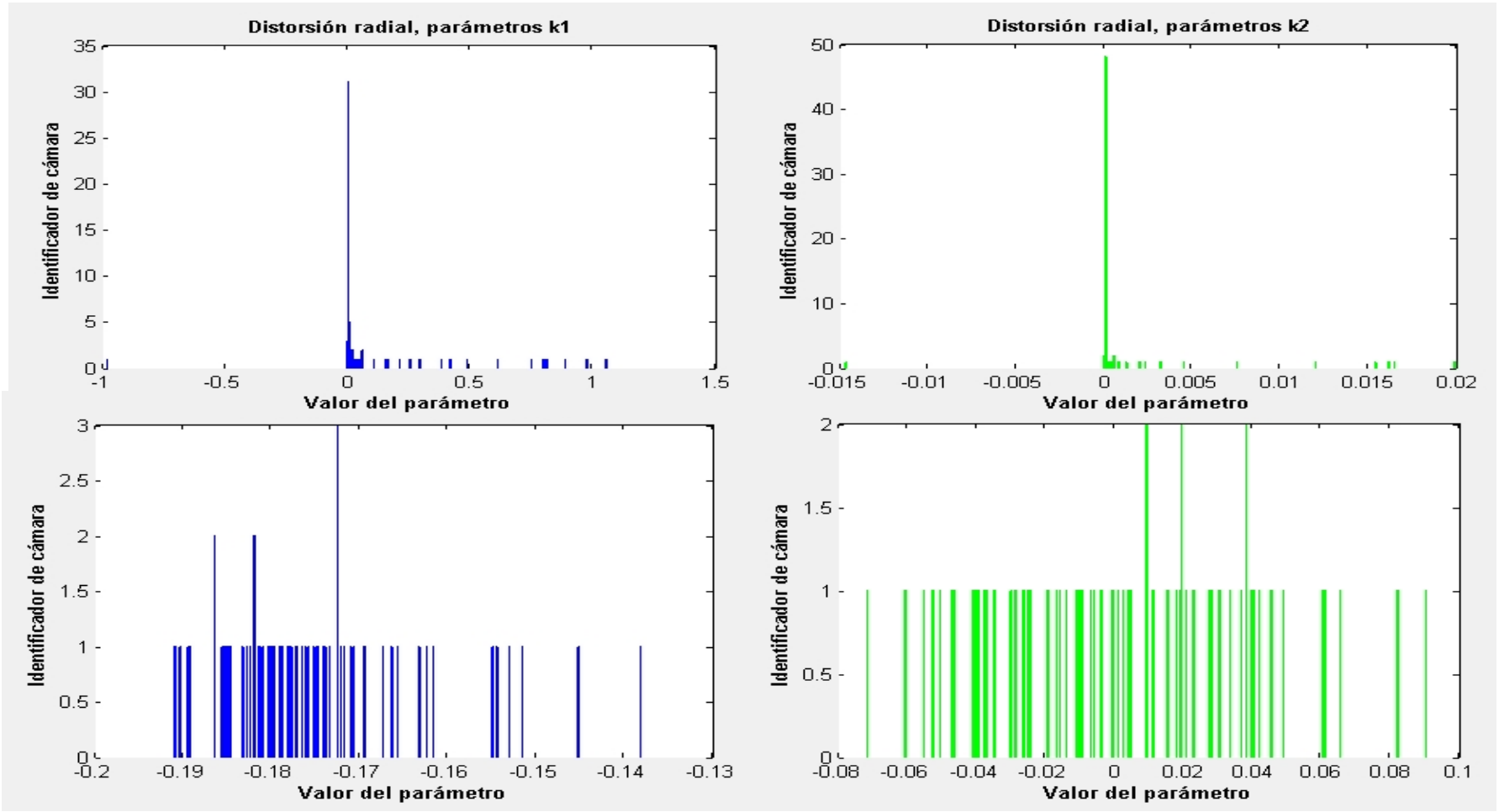


Image sources: http://www.2d3.com

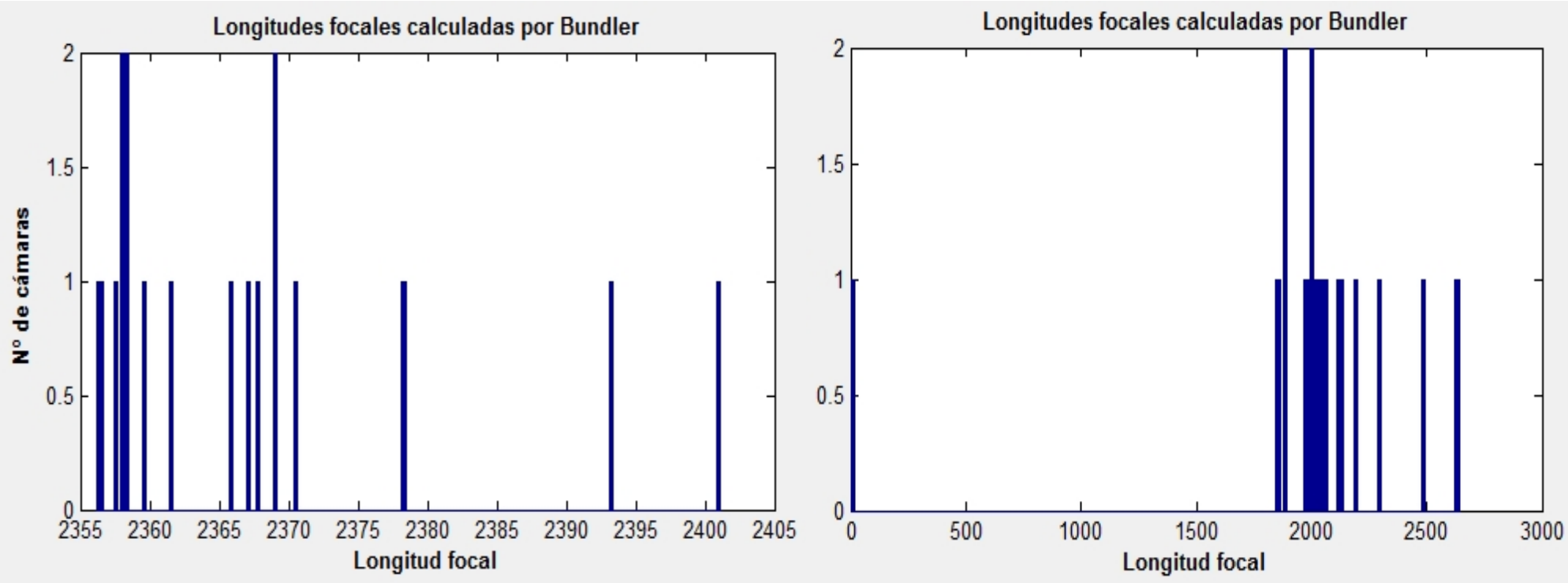
Annex

- Radial distortion estimation ***(upper figure MECO_3 | lower MECO_3_MOD_1)***



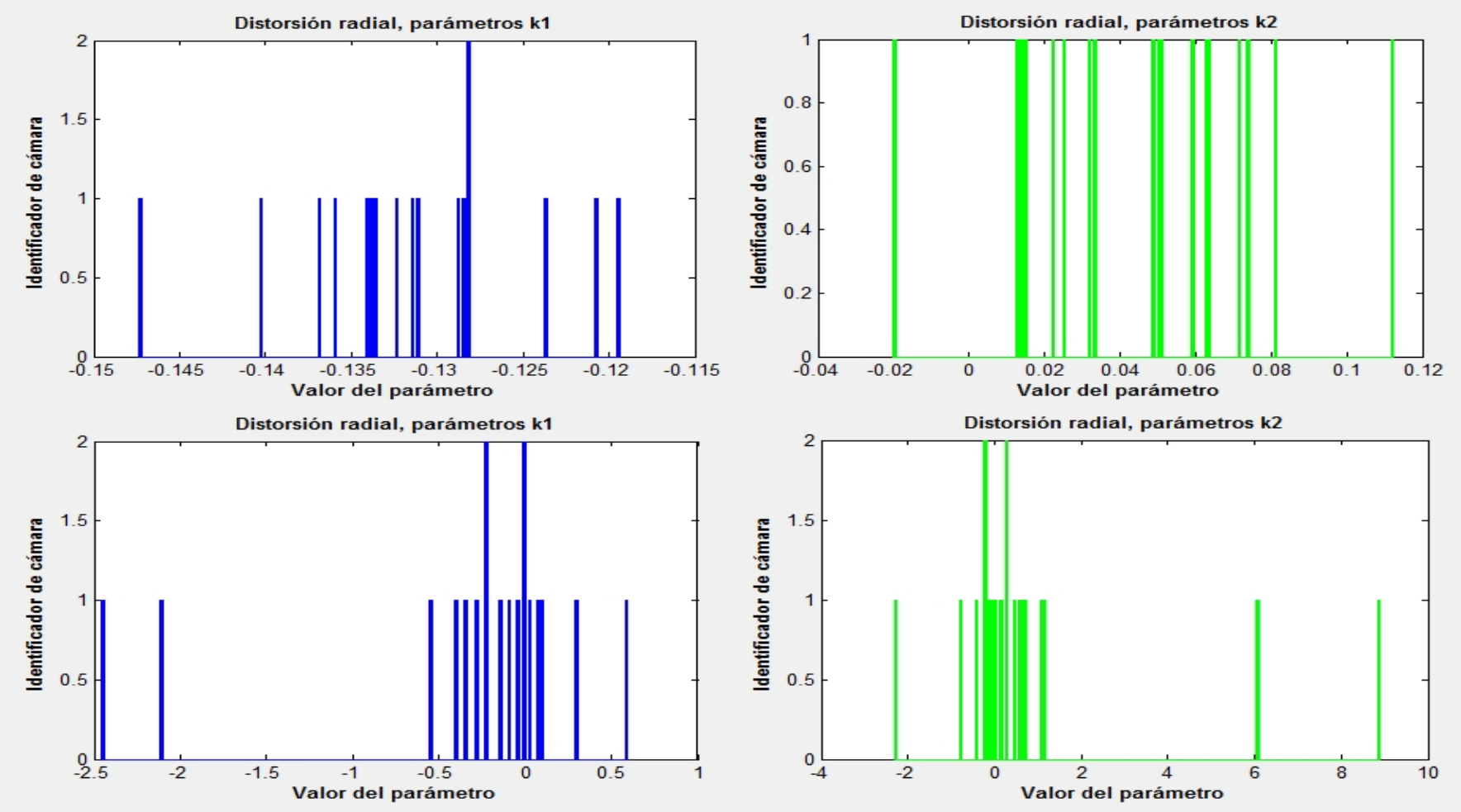
Annex

- Focal length estimation
  - Scenario: POLITECNICA (with EXIF | without EXIF)



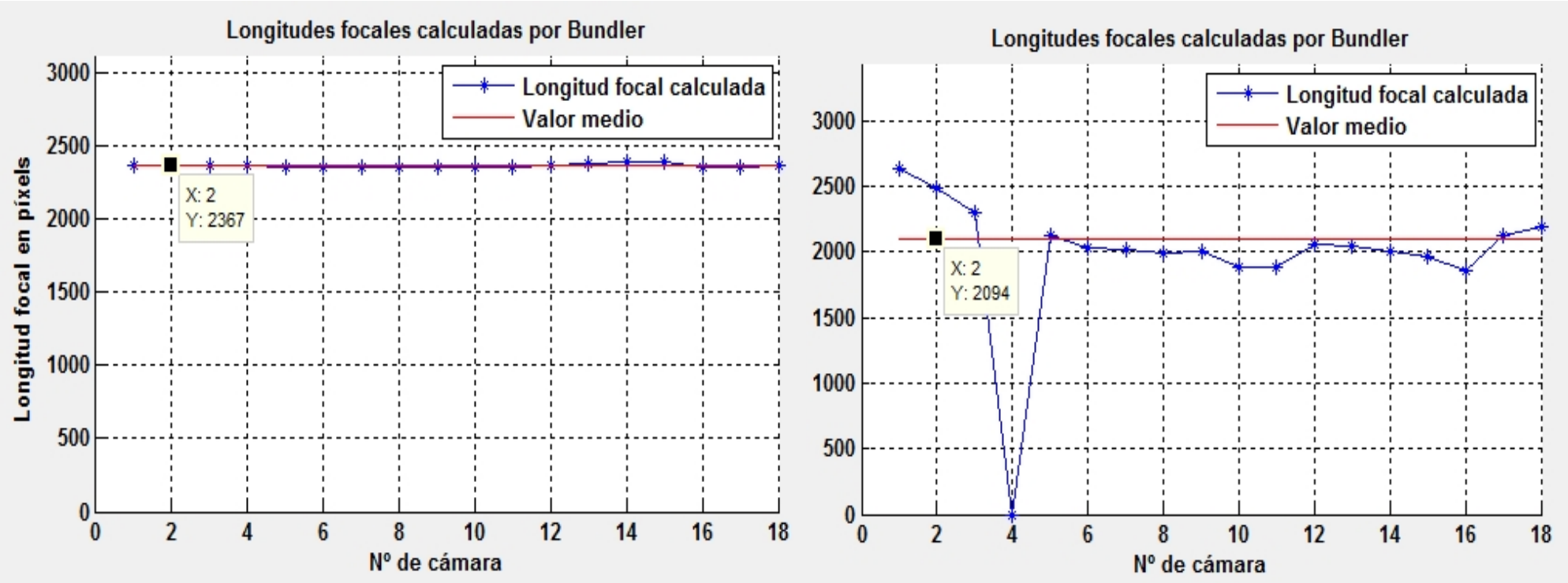
Annex

- Radial distortion estimation *(POLITECNICA – upper figure with EXIF | lower figure without EXIF)*



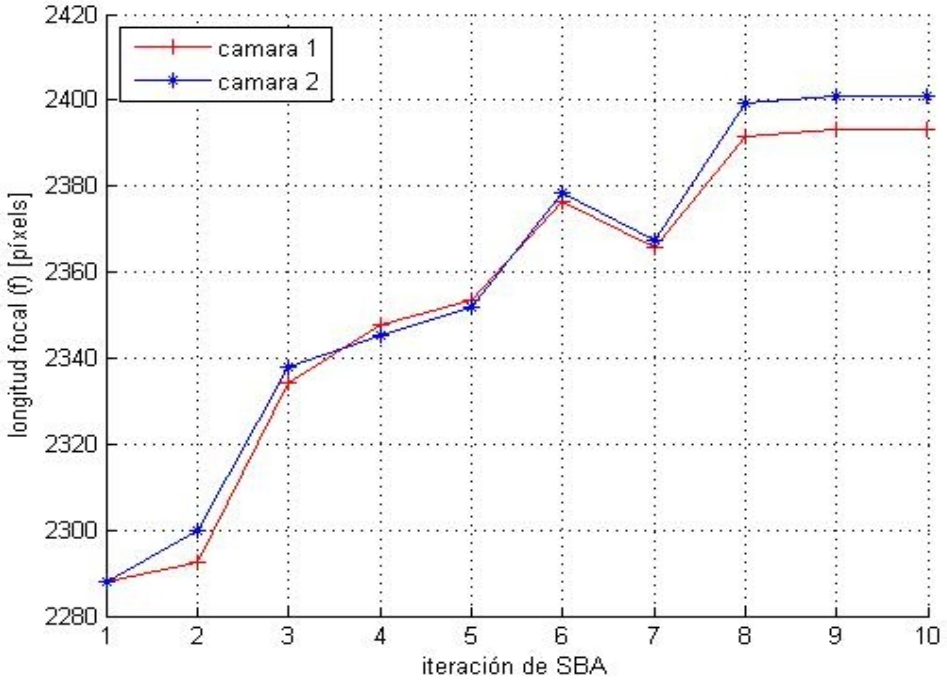
Annex

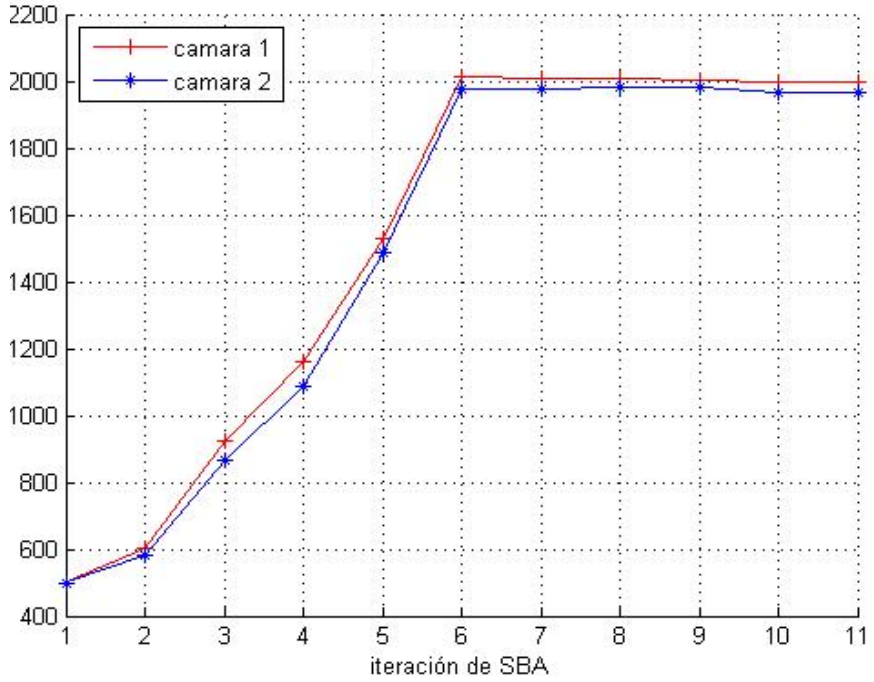
- Focal length estimation
  - Scenario: POLITECNICA (with EXIF | without EXIF)



Annex

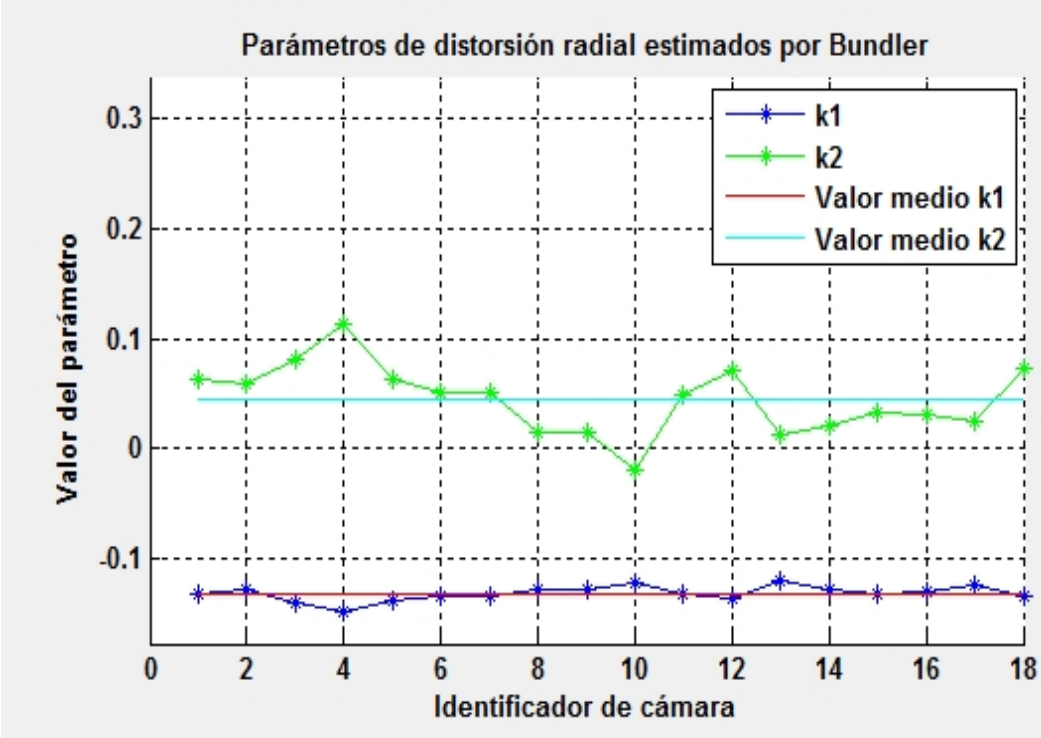
- Focal length estimation
  - Scenario: POLITECNICA (with EXIF | without EXIF)
    (SBA evolution)

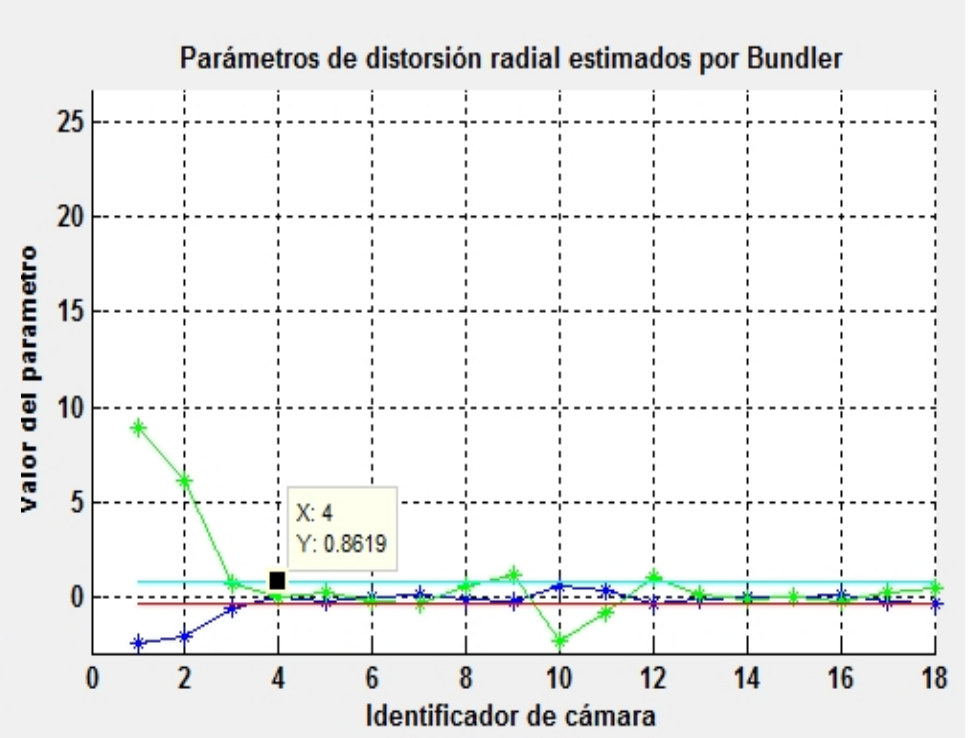




Annex

- Radial distortion estimation
  - Scenario: POLITECNICA (with EXIF | without EXIF)





Anexos

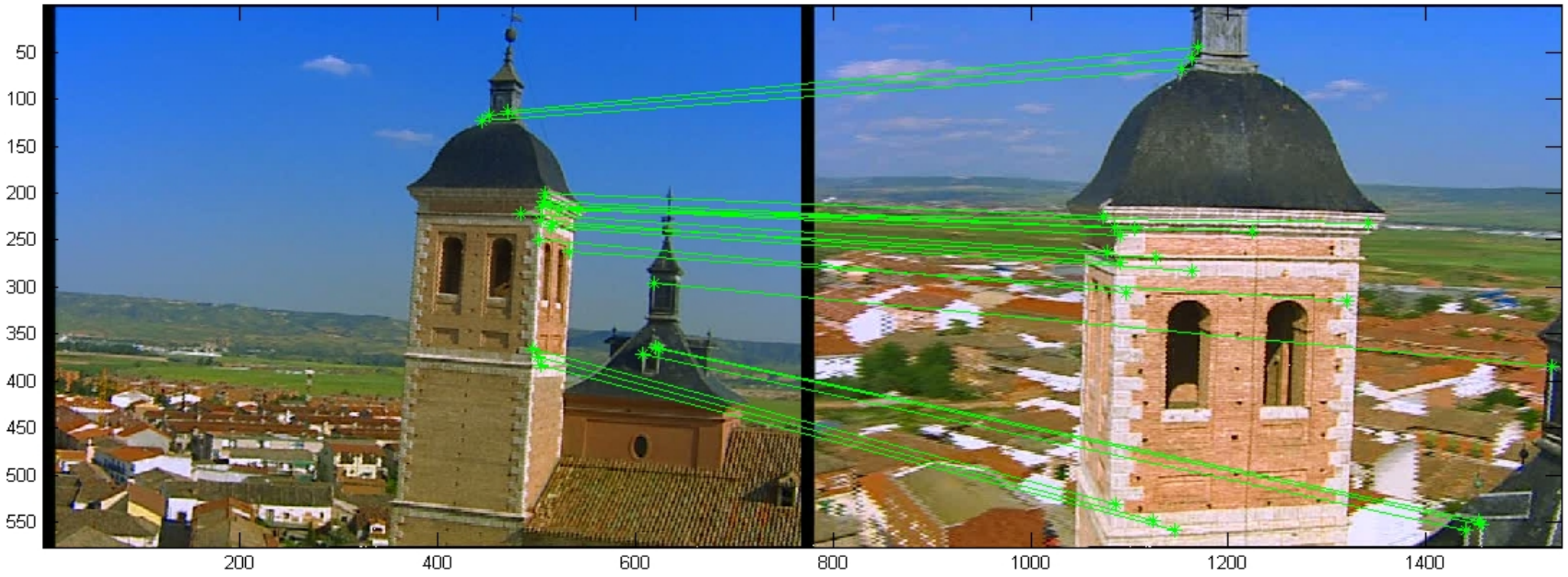
- SfM errors
  - Insufficient overlap
  - Repetitive and ambiguous patterns
  - Bad initialization
    - Necker reversal
    - Insufficient baseline
  - Cascade errors
    - Bad initialization
    - High uncertainty

Anexos

- Bundler: SIFT features

Annex

- Bundler: Keypoint matching



3D Reconstruction Results

- SIVA