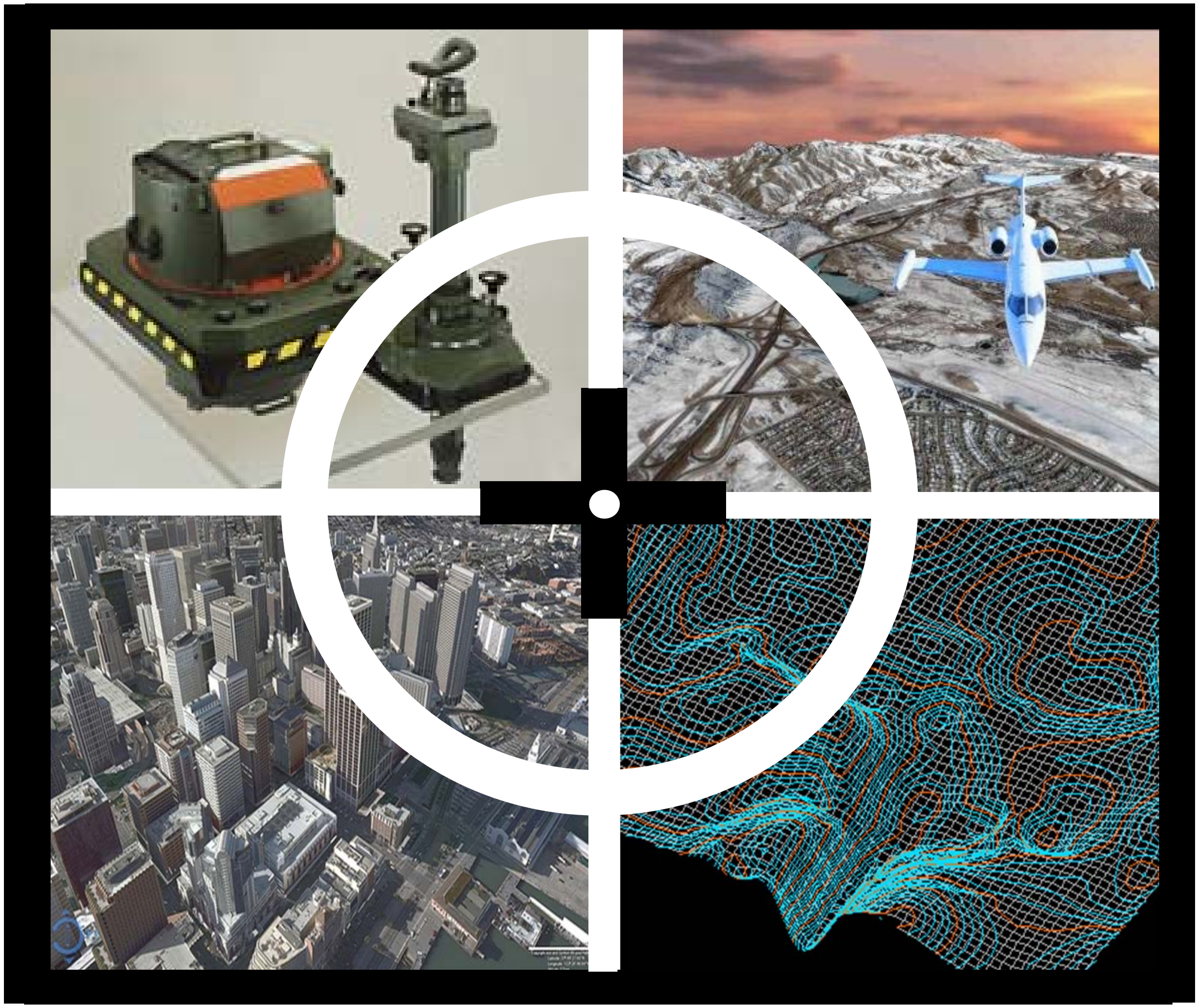
CE59700: Chapter 1

Introduction

Photogrammetry

- Objective: Derive the positions and shapes of objects from imagery



Photogrammetry

- Definition:
  - The art and science of determining the position and shape of objects from photography
  - The process of reconstructing objects without touching them
  - Non contact positioning method
- Contemporary definition:
  - The art and science of tool development for automatic generation of spatial and descriptive information from multi-sensory data and/or systems

Photogrammetry: Progress

- Late 1400s: Renaissance painters (*e.g.*, Leonardo da Vinci) studied the principles of geometric analysis of pictures.
- Mid 1600s ~ Mid 1700s: Desargues, Pascal, and Lambert introduced projective geometry, which forms the mathematical basis of photogrammetry.
- 1839: Invention of photography by Niepce and Dagueree: 1st Generation
- 1858: Nadar (France) captured photographs from a balloon.
- 1859: Laussedat "*Father of photogrammetry*" created the first suitable camera and procedure for photogrammetric measurements called "*iconometry*".
- 1867: The word "photogrammetry" was introduced by Meydenbauer.
- 1886: Deville (Canada) introduced topographic mapping using photogrammetry.

Photogrammetry: Progress

- 1901: Invention of stereo-photogrammetry by Fulfrich: 2nd Generation *"Analog photogrammetry"*
- 1902: Invention of the airplane by Wilbur and Orville Wright brothers provided the great impetus for the emergence of modern aerial photogrammetry.
- 1909: Wilbur Wright took the first photographs from an aircraft in Italy.
- Early 1900s: Development of early analog plotters and the first highly corrected wide-angle lens for use in aerial cameras.
- 1911: von Orel and Zeiss produced the stereo-autograph for plotting from terrestrial photographs.
- 1913: Aerial photographs were first used for mapping purpose.
- WW I: Aerial photographs were used extensively for reconnaissance.
- 1934: American Society of Photogrammetry was founded.

Photogrammetry: Progress

- Mid 1900s: Analog plotters were produced by Zeiss, Wild, Bausch & Lomb, and Kern. Mathematical basis for photogrammetric triangulation was developed.
- WW II: Mapping programs accelerated new developments in instruments and techniques. Progress in mass production of topographic maps. Air photo interpretation was employed more widely than ever before for reconnaissance and intelligence.
- 1946: Invention of computer
- 1950s: Principles of multi-station analytical photogrammetry were developed by Schmid and Brown: 3rd Generation *"Analytical photogarmmetry"*.
- 1957: Computer-controlled stereo-plotter patented by Helava
- 1961: The first analytical plotter was developed by Helava.
- 1980s ~ current: Advances in optics, electronics, imaging systems and computer technologies have introduced new generation in photogrammetry: 4th Generation *"digital photogrammetry"*.

Photogrammetry: Progress

- Recent activities: Automation of photogrammetric processes, real-time image analysis, high-resolution imagery of various types from aircraft, satellites, and **UAV(unmanned aerial vehicles)**

Photogrammetry: Progress

Generation of photogrammetry	Major progress
First generation	**Invention of photography (1839):** Pioneering phase with terrestrial and balloon photogrammetry
Analog photogrammetry	**Invention of stereo-photogrammetry (1901) and airplane (1902):** Between WW I & II, foundations of aerial surveying techniques were built and they still stand.
Analytical photogrammetry	**Invention of computer (1946):** Development of computer technology had a major impact on photogrammetry.
Digital photogar-mmetry	**Digital images from various sensors and devices:** Advanced computer technologies are available to tackle photogrammetric processes.

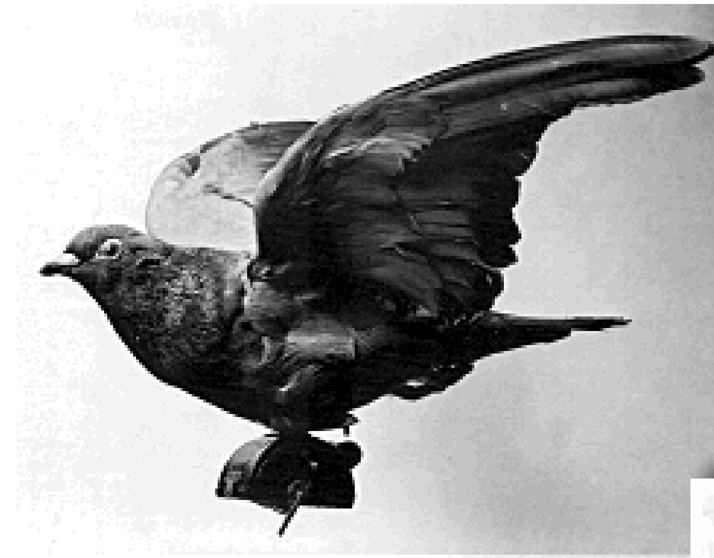
1850 Invention of Photography

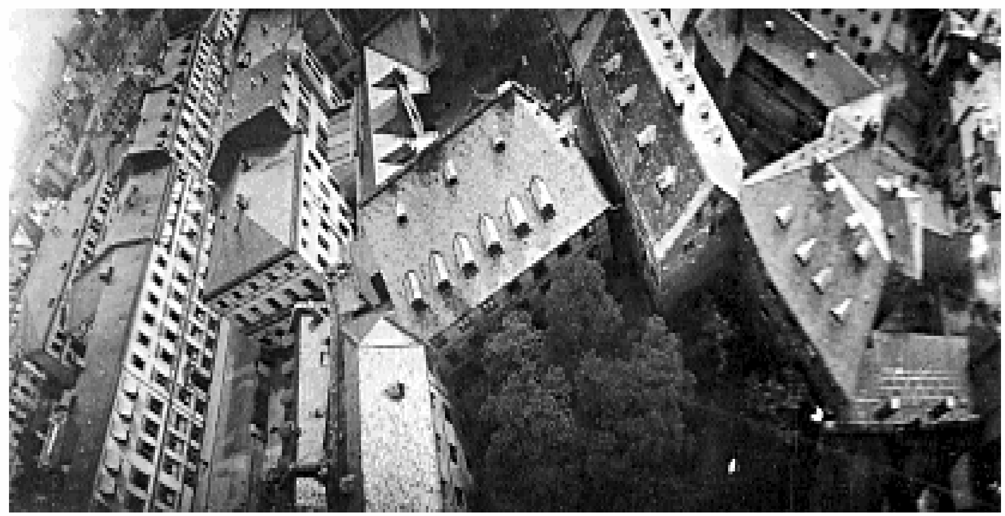
1900 Invention of Airplane

1950 Invention of Computer

2000

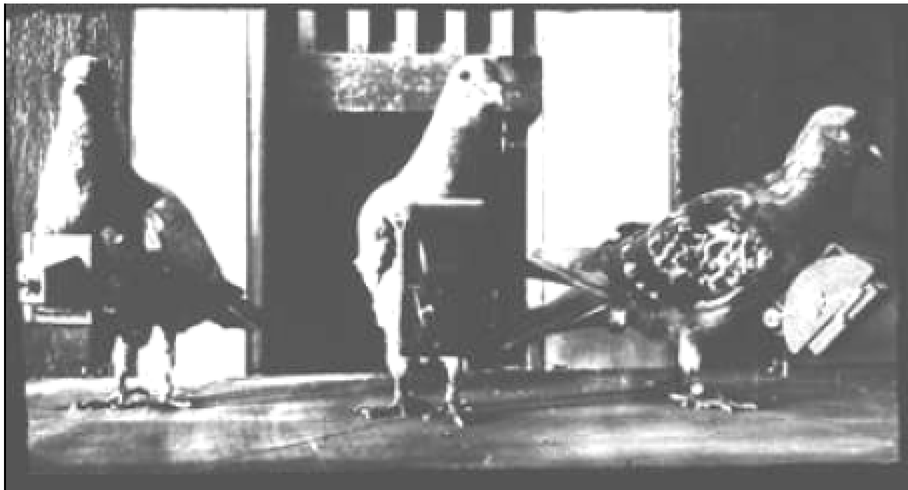
Aerial Imagery





http://en.wikipedia.org/wiki/Pigeon_photography

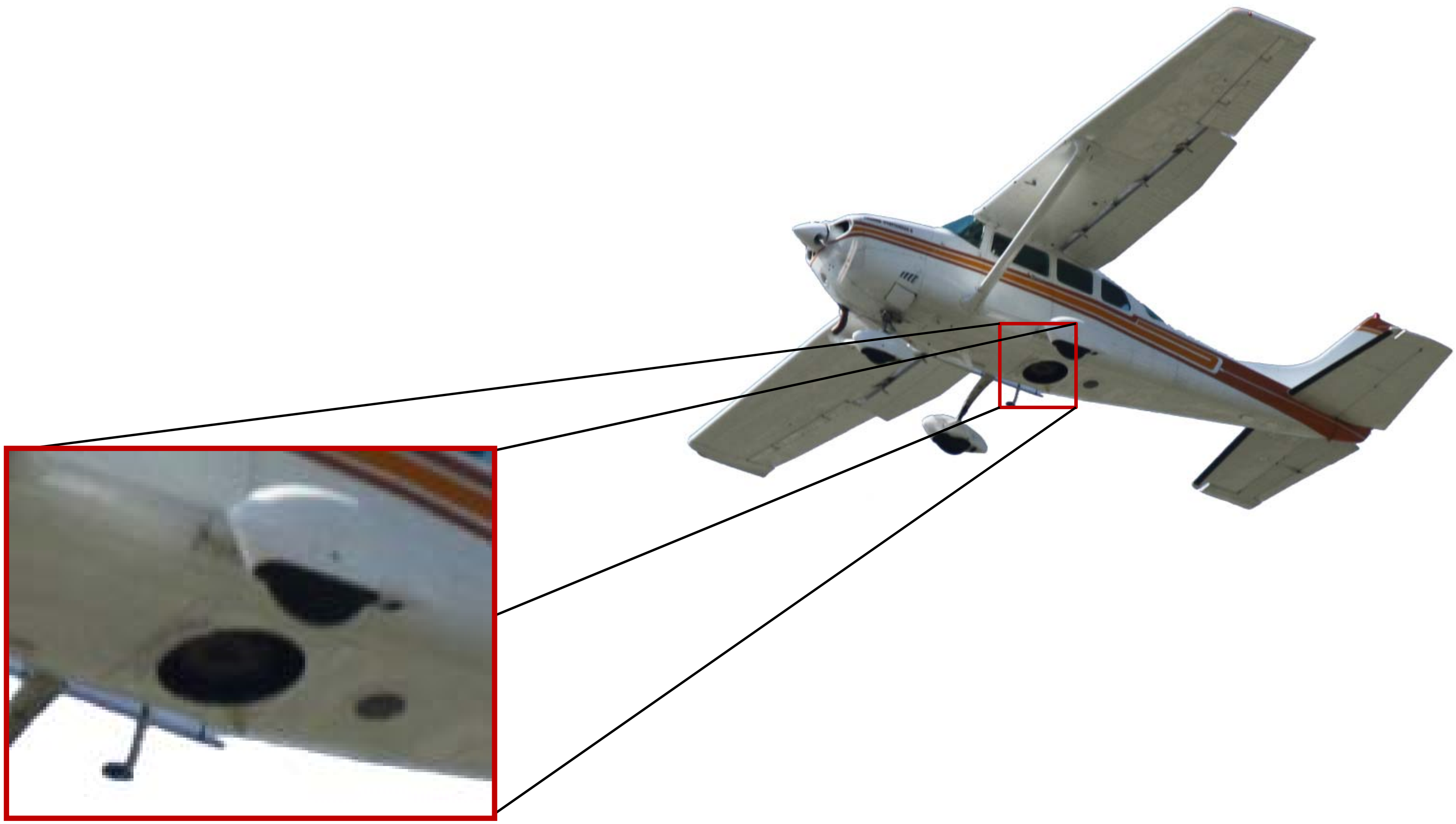
Aerial Imagery



Bavarian Pigeon Corps, 1903

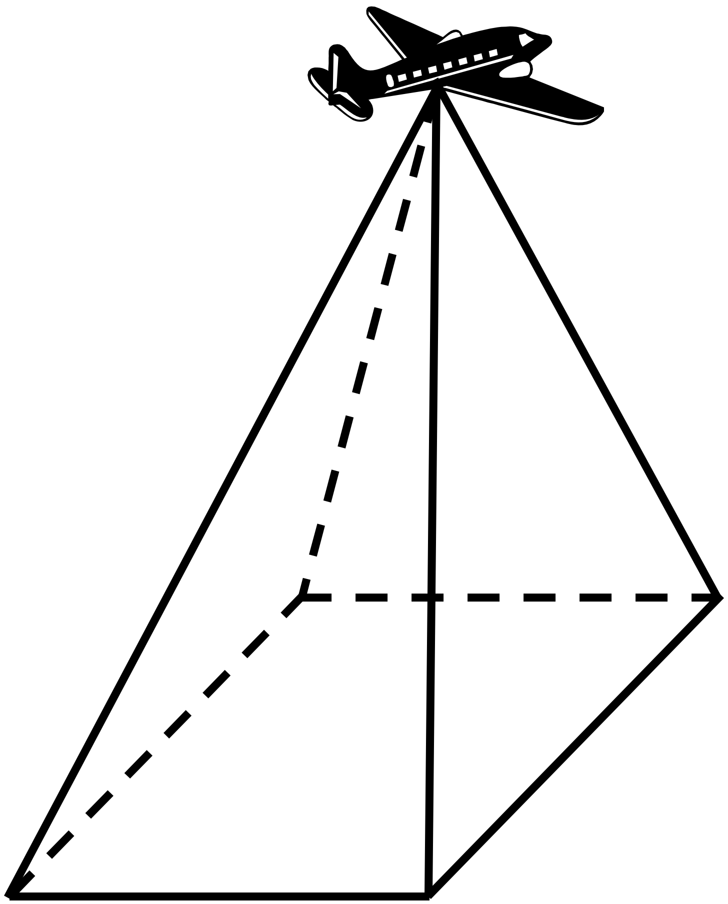
http://en.wikipedia.org/wiki/Pigeon_photography

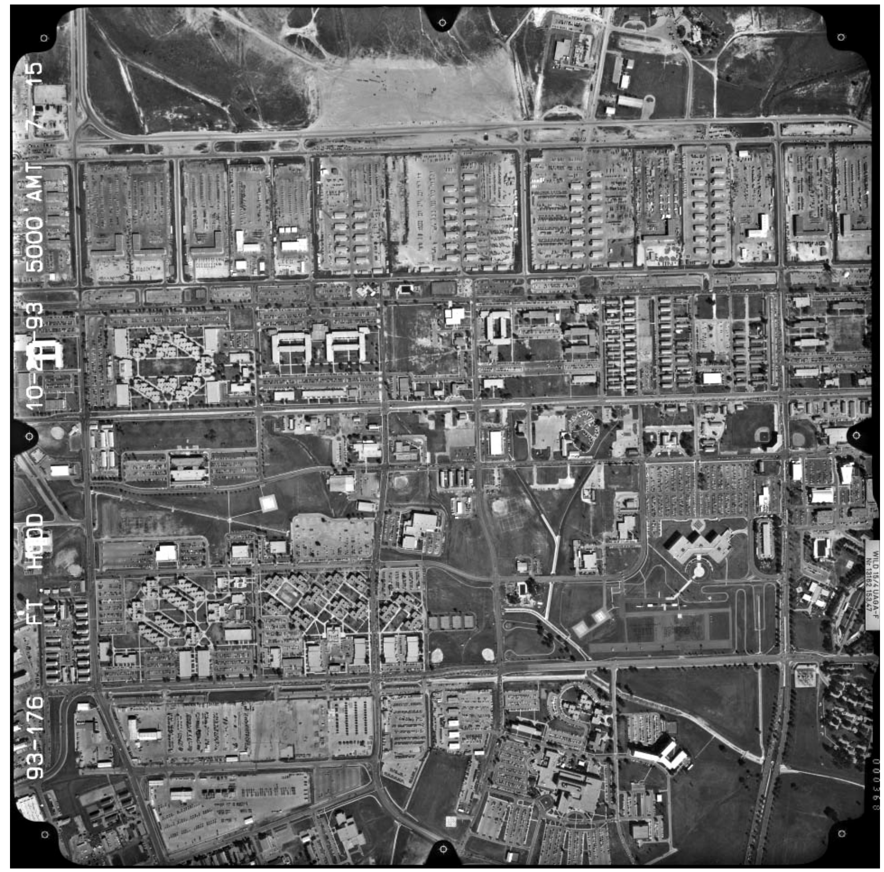
Aerial Imagery



http://www.in.gov/indot/images/plane_4-15-11.jpg

Aerial Imagery





http://cmapspublic.ihmc.us/rid=1235786206554_857097895_24622/Photogramm%C3%A9trie

Data Acquisition Systems

Traditional Mapping Cameras

Large Format Imaging Systems

Low-Cost Digital Cameras

Medium and Small Format Digital Imaging Systems

Data Acquisition Systems

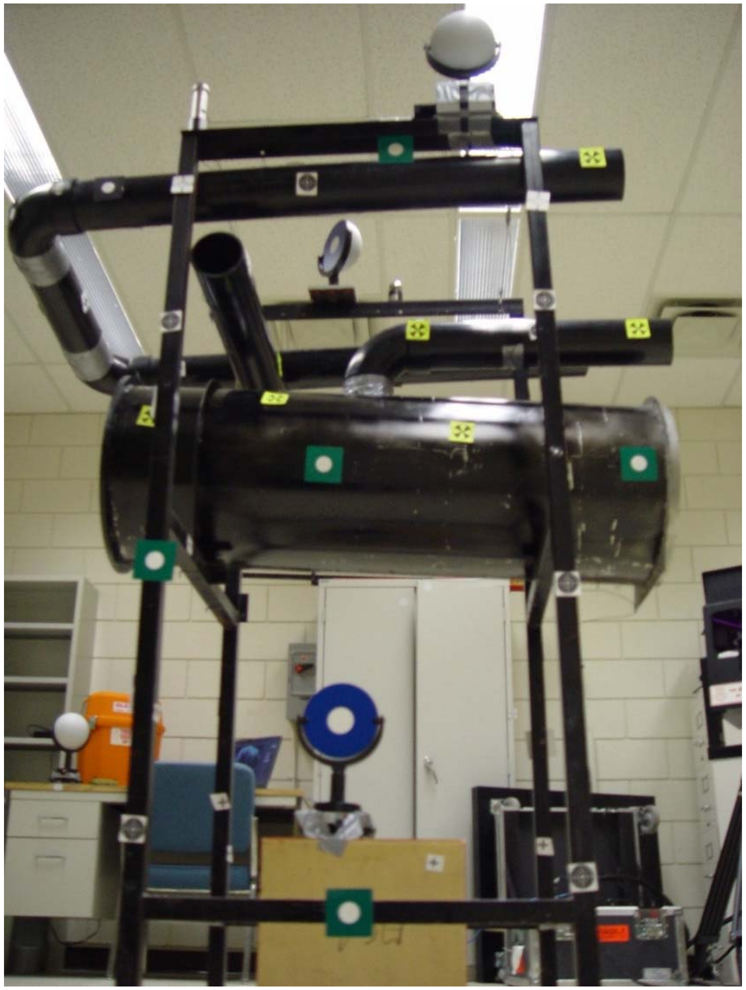
WILD RC10

Data Acquisition Systems

SONY DSC F717

Terrestrial (Close Range) Imagery

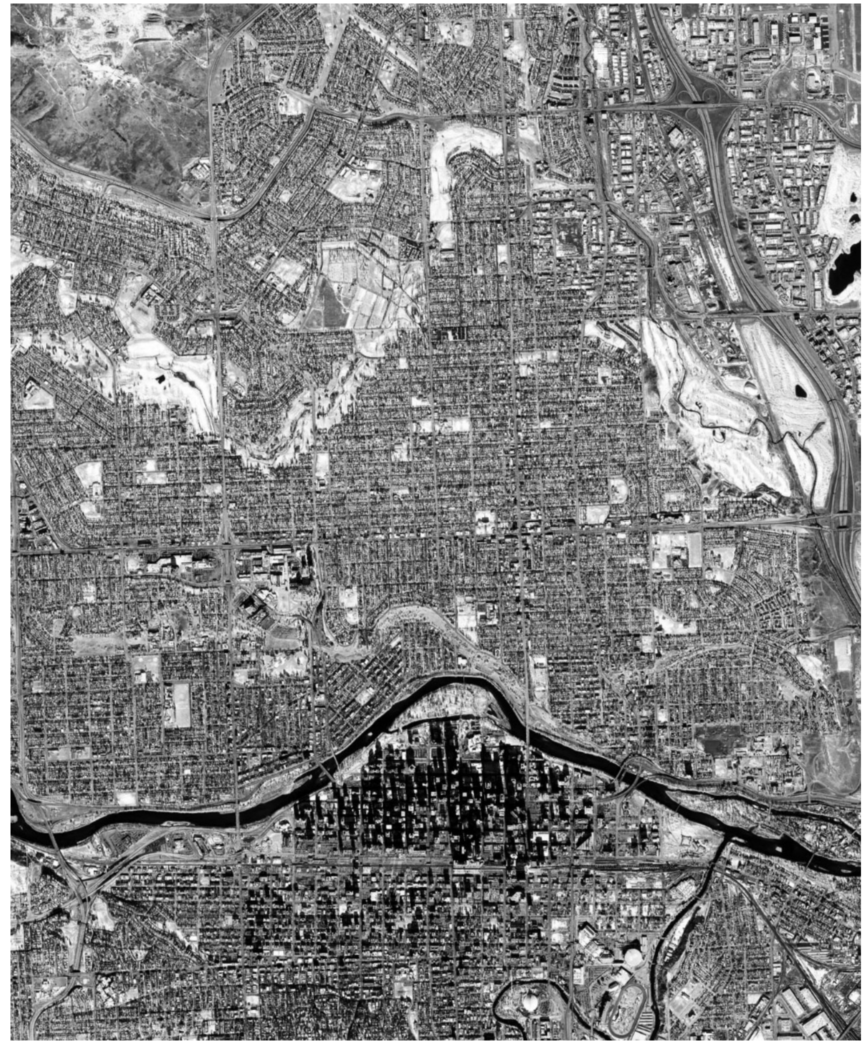
http://www.dpreview.com/reviews/sonydscf717



Terrestrial (Close Range) Imagery

Satellite Imagery

IKONOS Satellite (currently owned by DigitalGlobe)
http://www.freeoboi.ru/eng/wallpaper/4342.html



Satellite Imagery

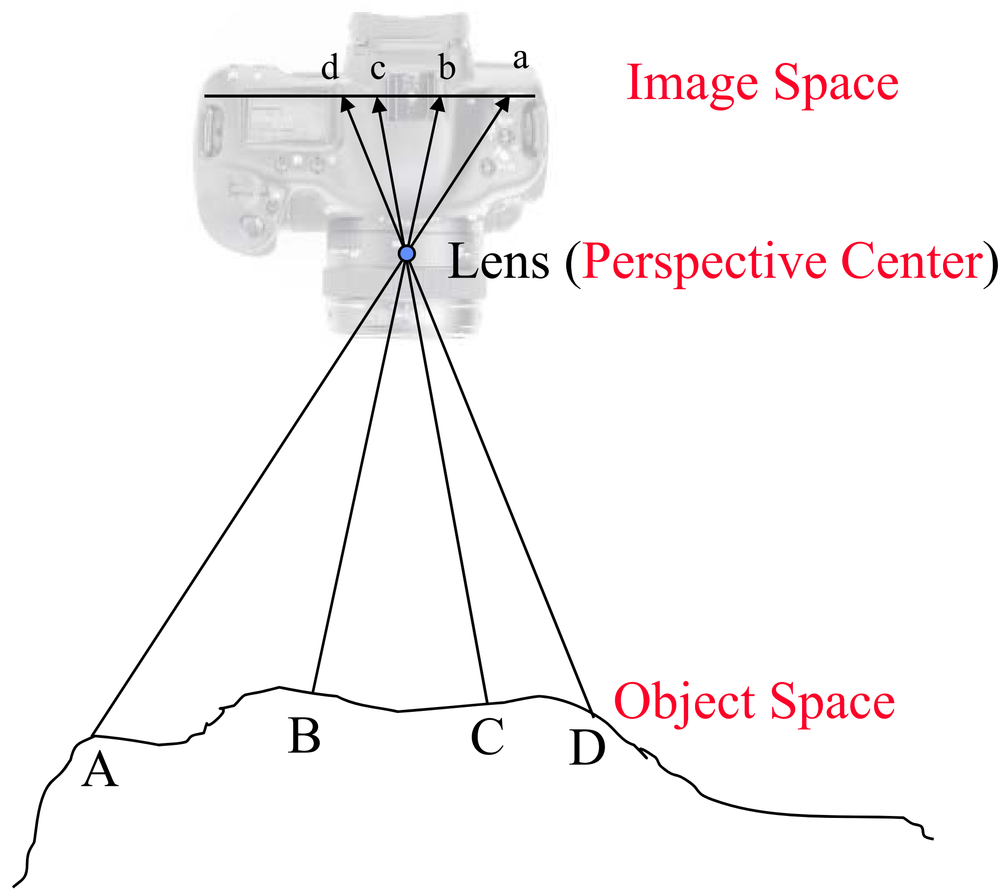
IKONOS

http://www.spatialmapping.com/images/RSD/IKONOS_manhattan_after_Sept11.jpg

QUICKBIRD

http://ngeocomp.ru/photo_img/27/32.jpg

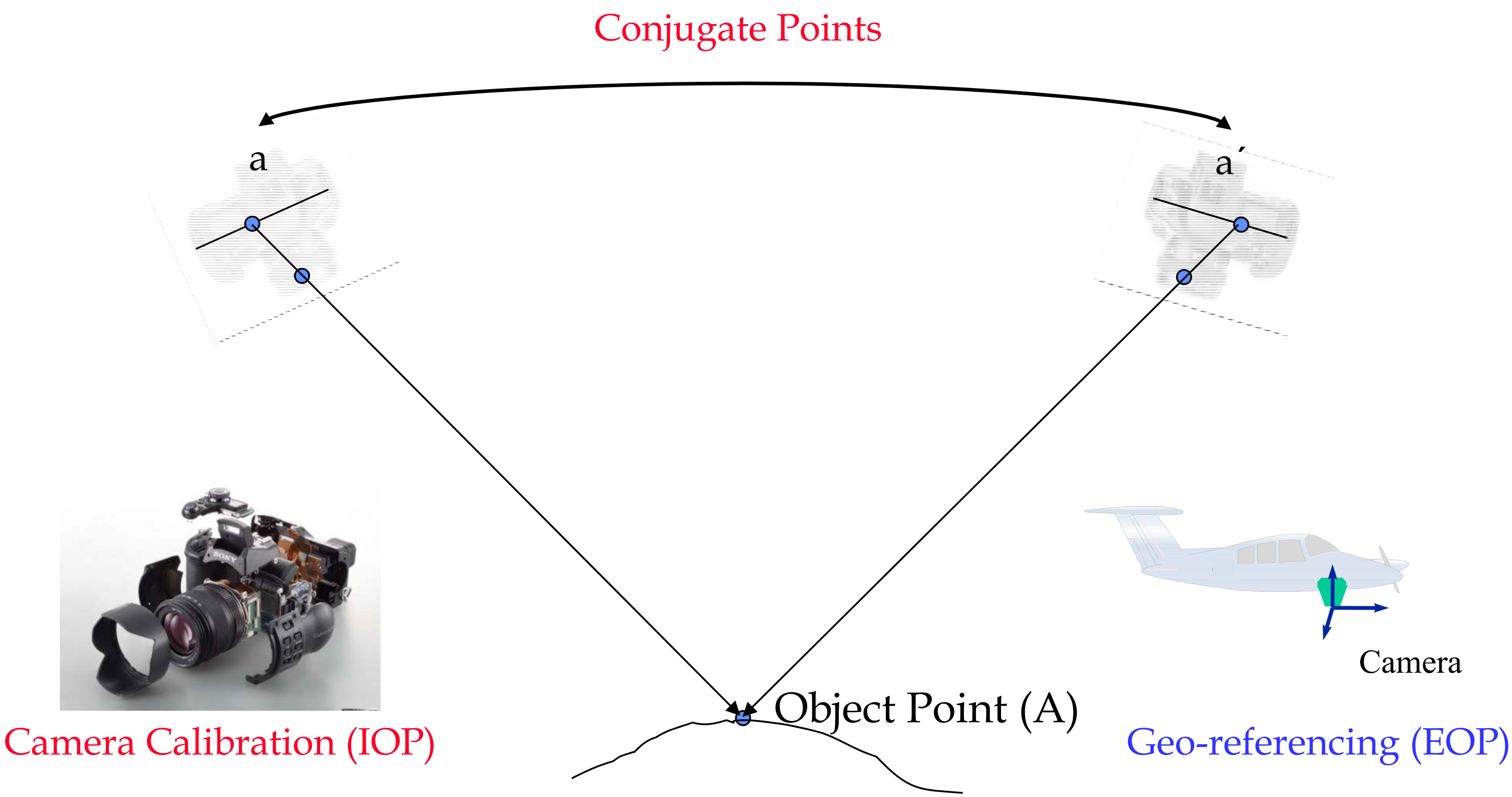
Photography



Photogrammetry

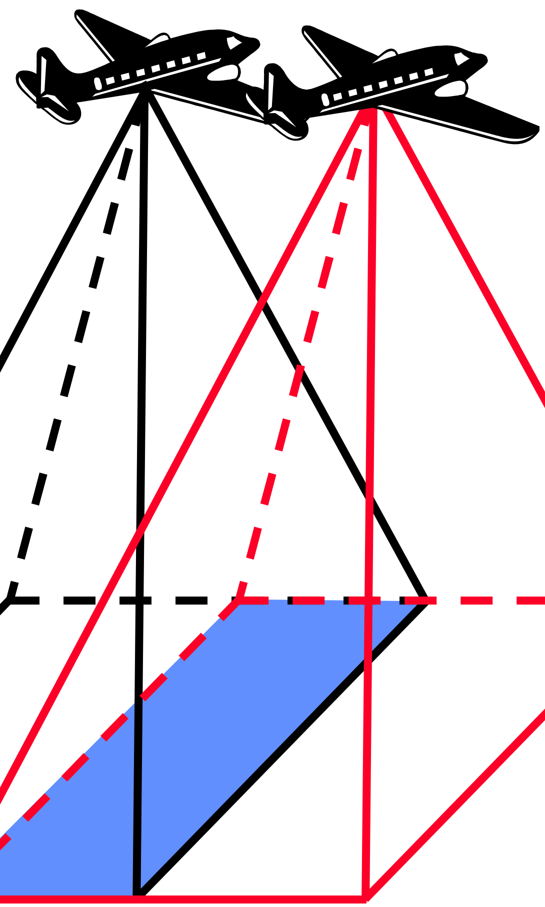
- Objective:
  - Invert the process of photography
  - Reconstruct the object space from imagery
  - Derive 3-D information from 2-D imagery

Photogrammetry



- The interior orientation parameters of the involved cameras have to be known.
- The position and the orientation of the camera stations have to be known.

Stereo-Photography

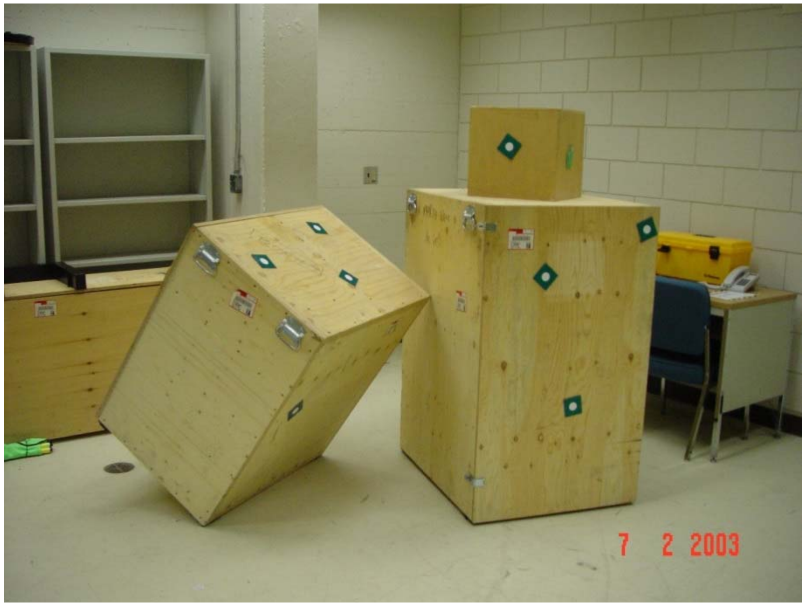


Overlap

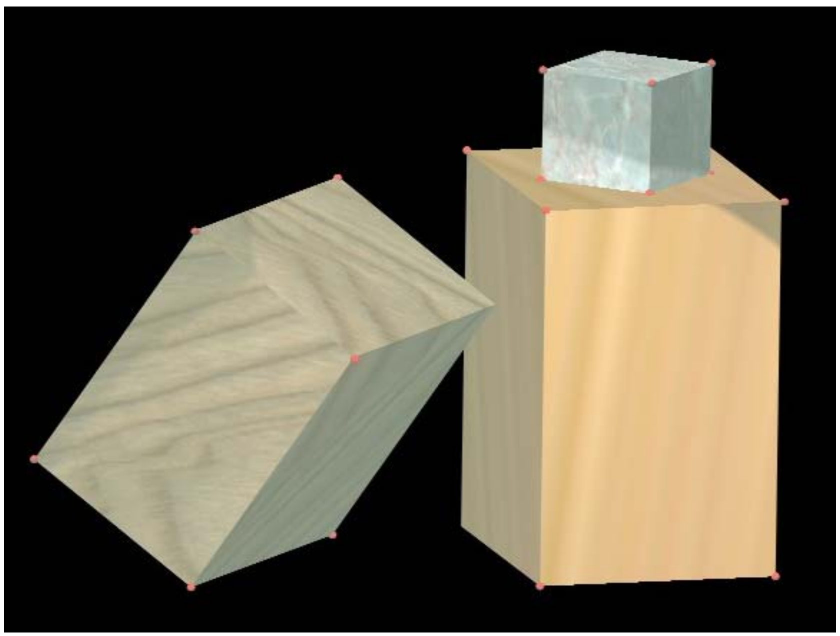
Stereo-Photography

Stereo-Photography

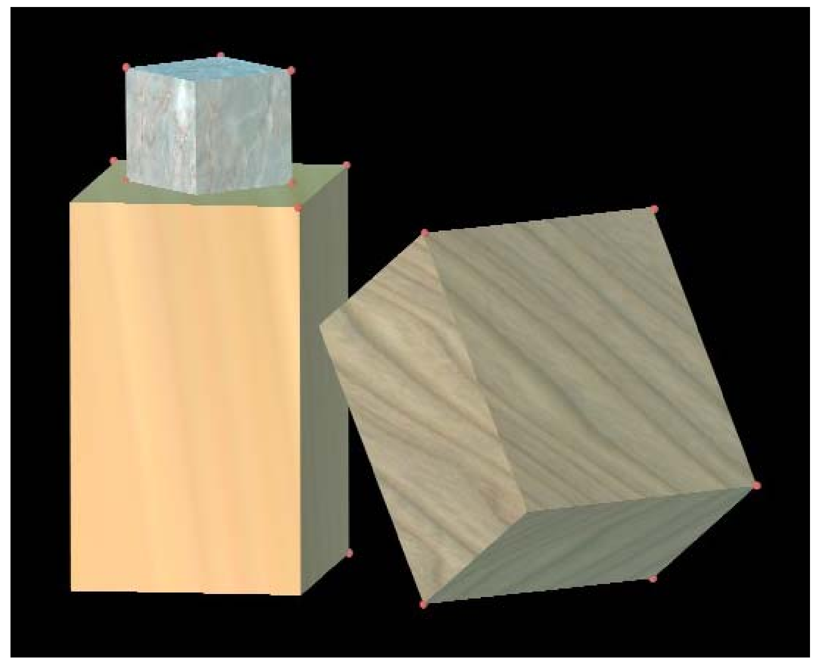
Photogrammetric Input



Photogrammetric Output



Front View

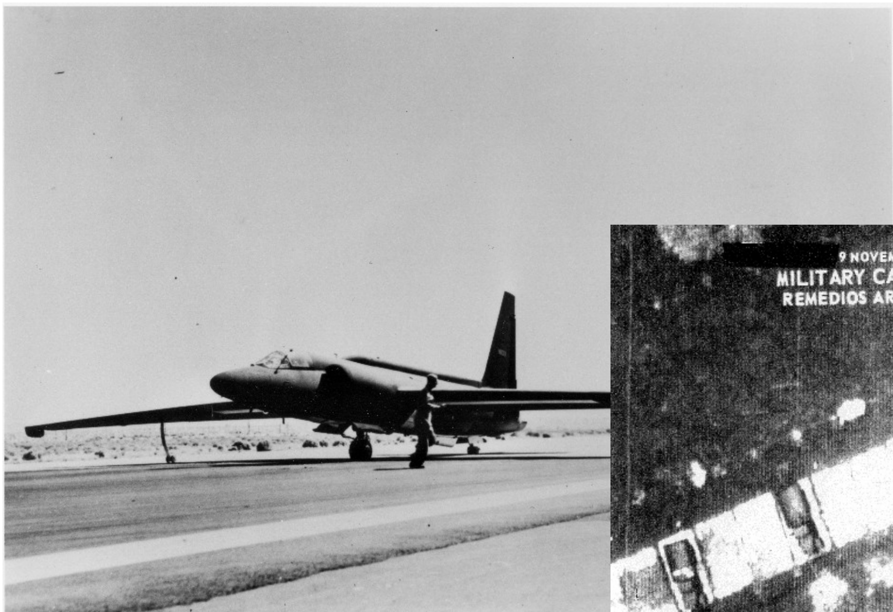


Back View

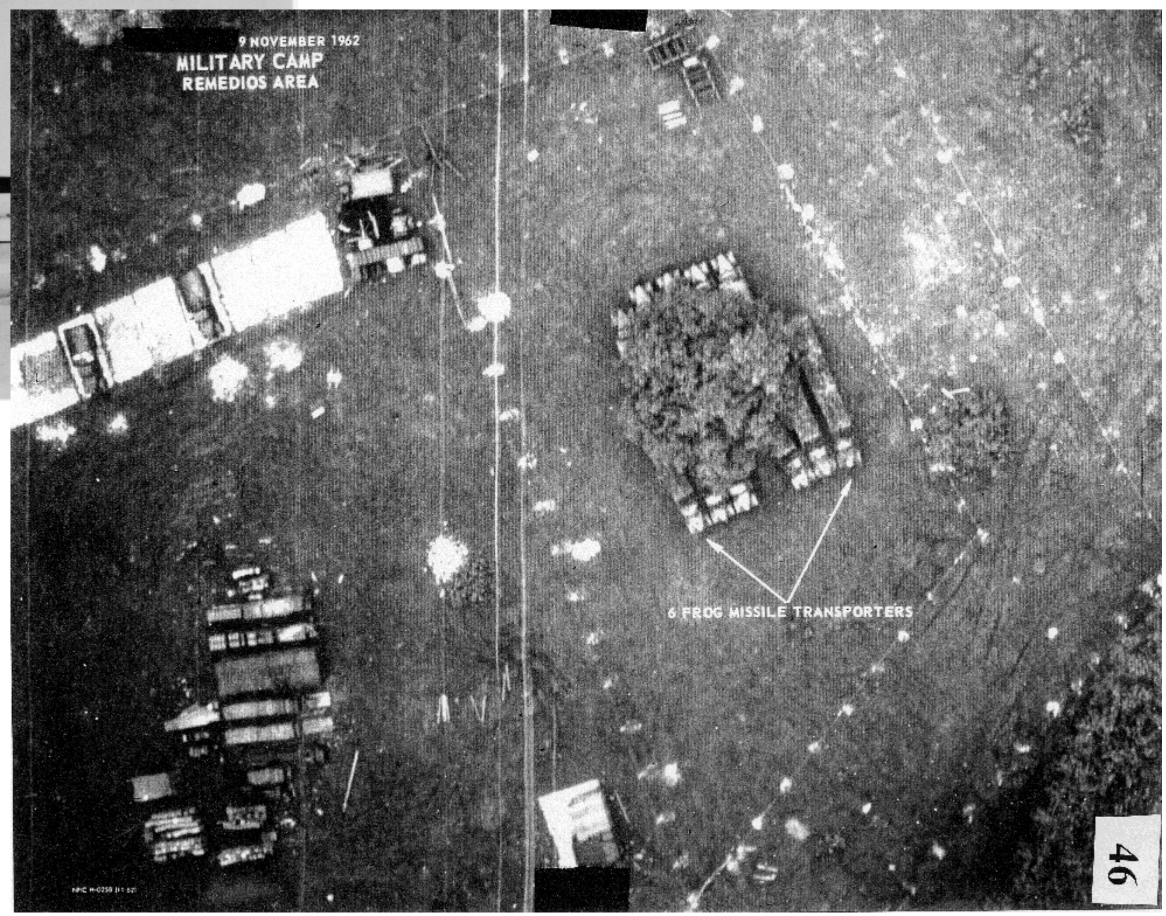
Photogrammetry

- Applications:
  - Reconnaissance
  - Production of Topographic Maps
  - DEM Generation
  - Close Range Photogrammetry:
    - Precision survey of buildings and engineering objects
    - Documentation of historical buildings
    - Medical applications
    - Mapping of roads and nearby objects (terrestrial mobile mapping systems)
  - Digital agriculture

Reconnaissance

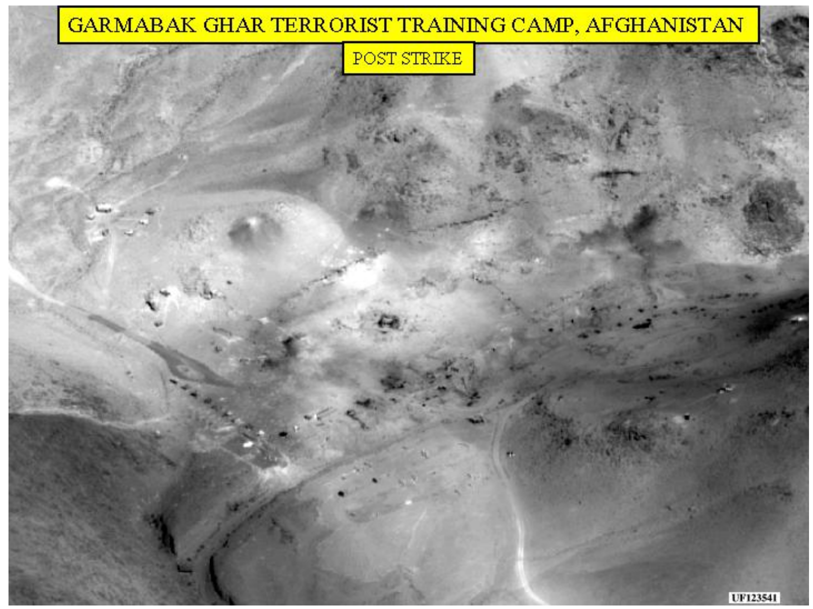


http://news.usni.org/tag/cuban-missile-crisis



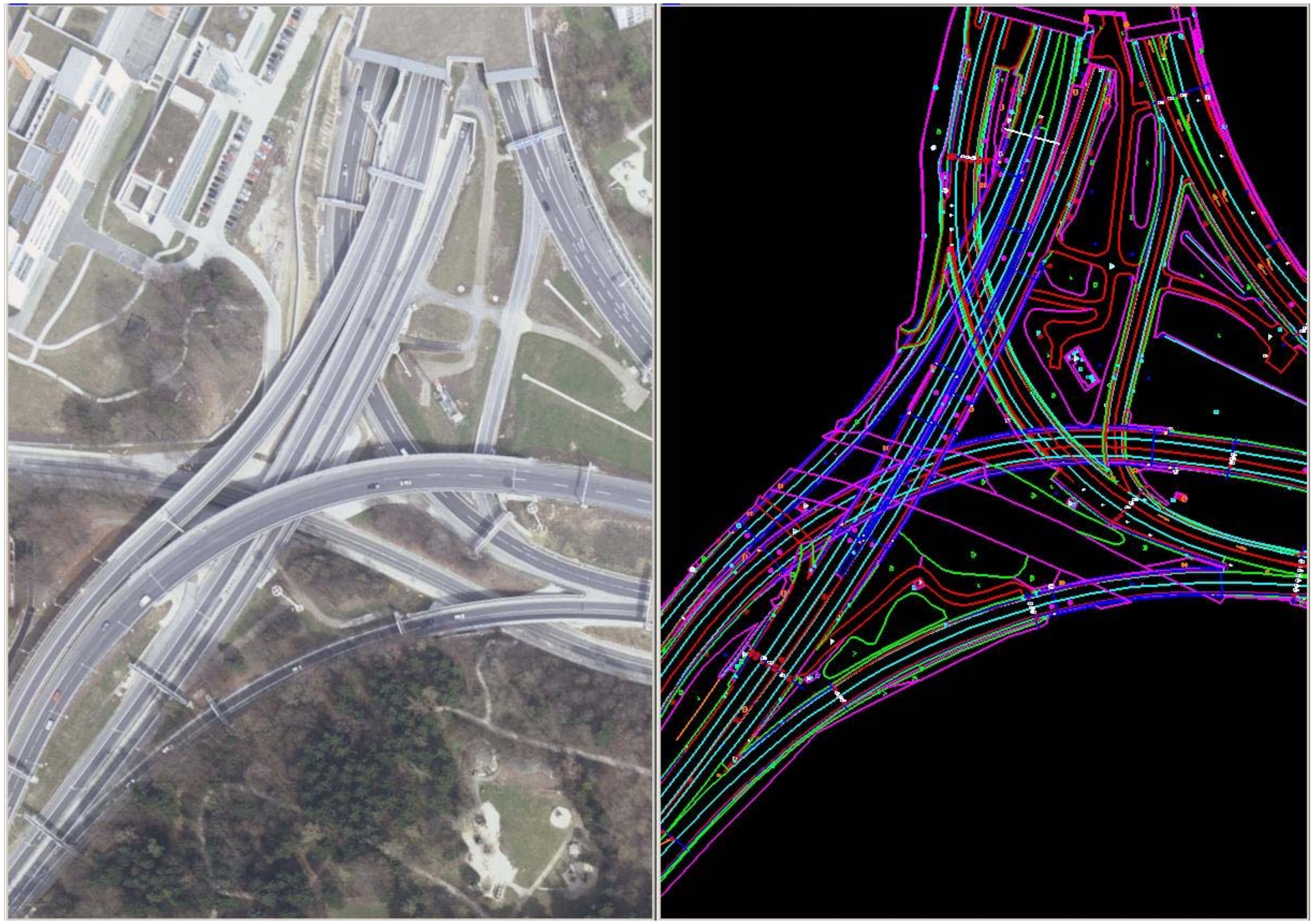
Cuban Missile Crisis (1962)

Reconnaissance



http://www.defense.gov/news/briefingslide.aspx?briefingslideid=184

Mapping

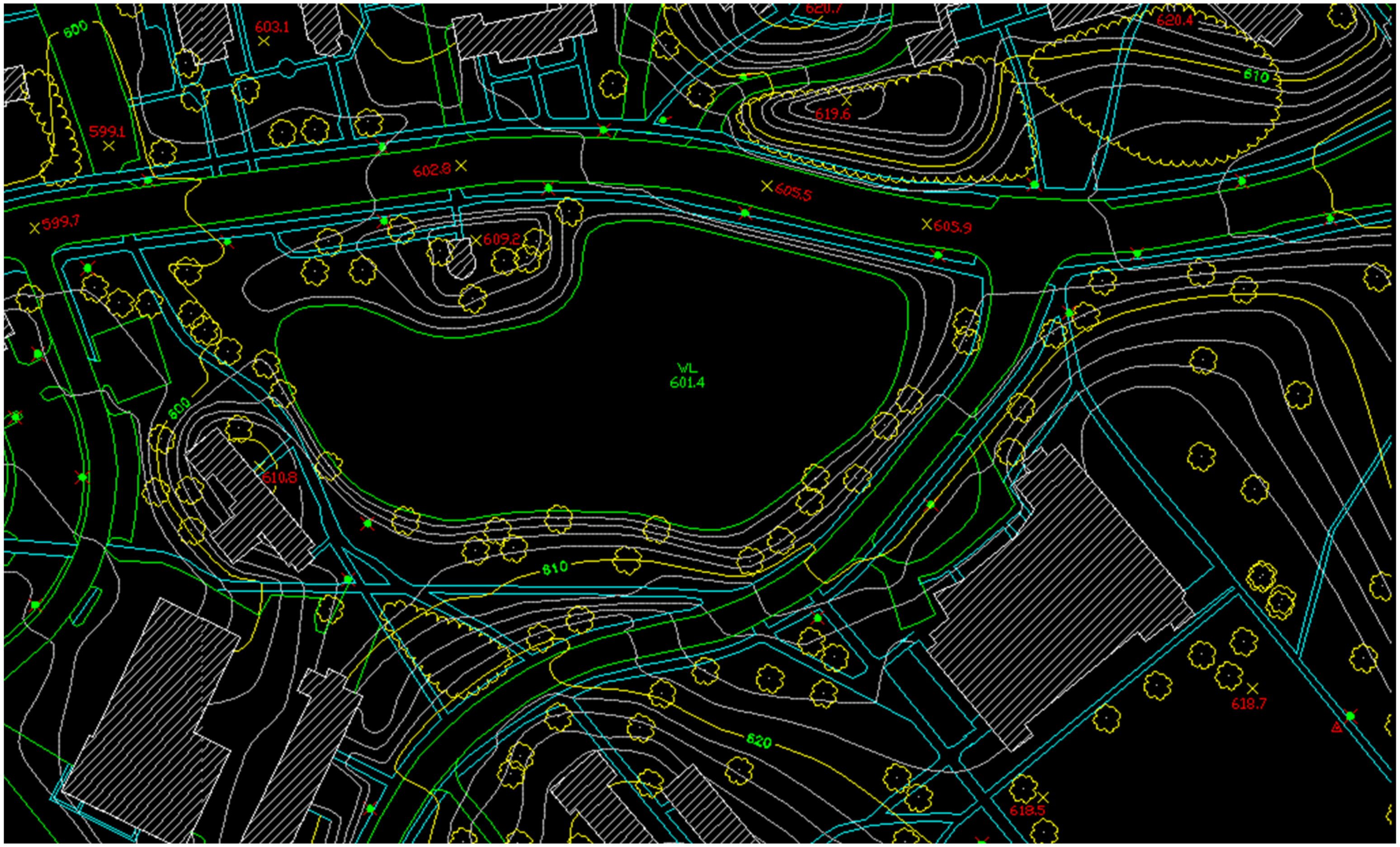


http://sluzby.geodis.cz/services/photogrammetry?lang=2

Resource Management

http://spreadthemustard.com/images/mummert_gis.jpg

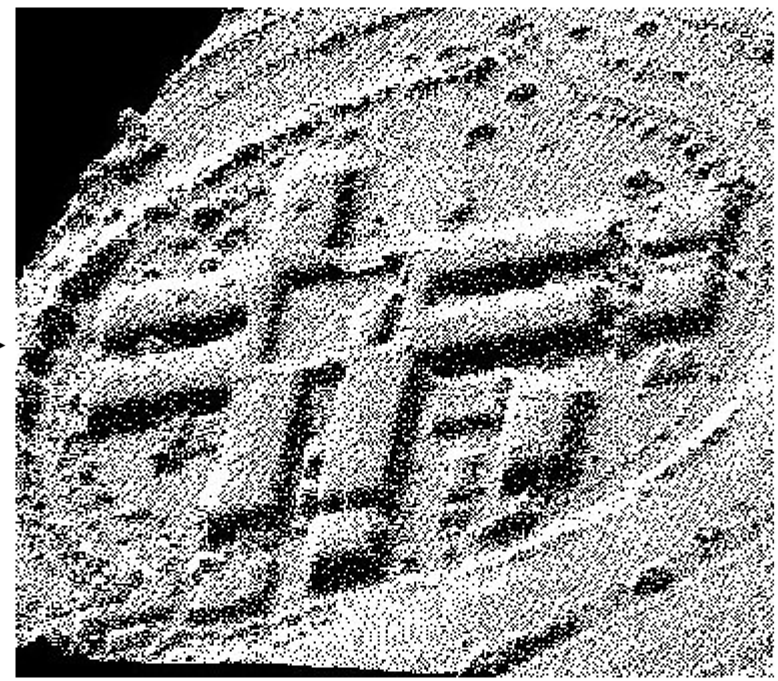
Topographic Mapping



http://www.sp.uconn.edu/~epsywqp/GeeWisWeb/thumbs.html

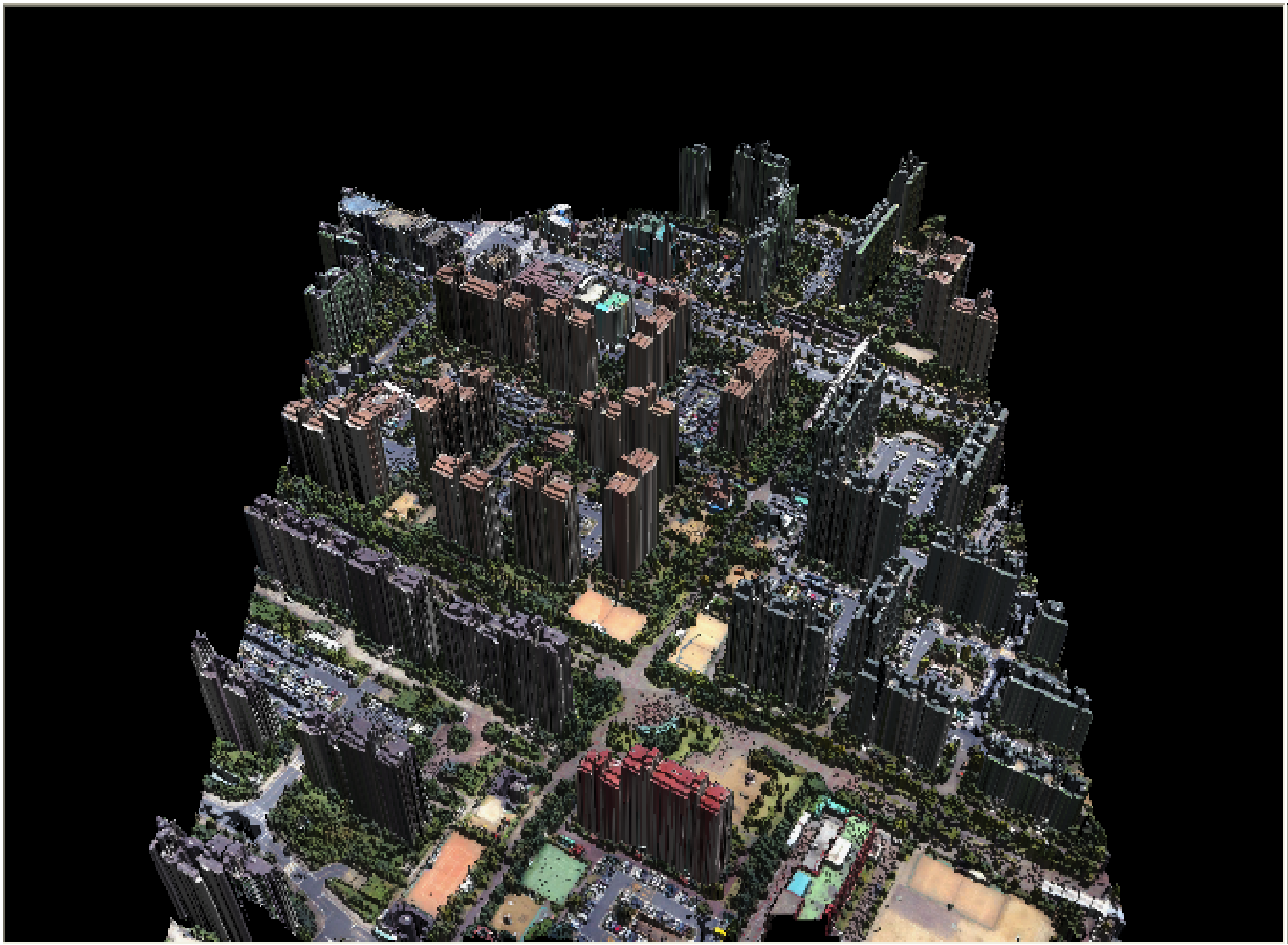
Digital Elevation Models (DEM)

Input

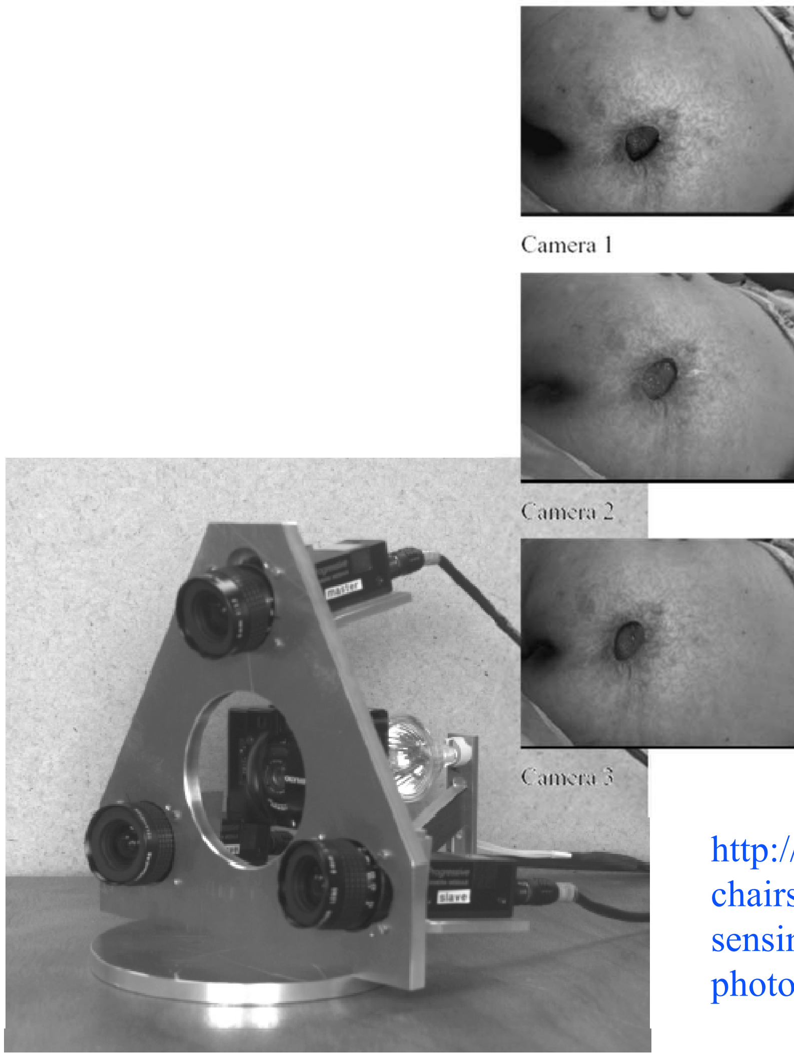


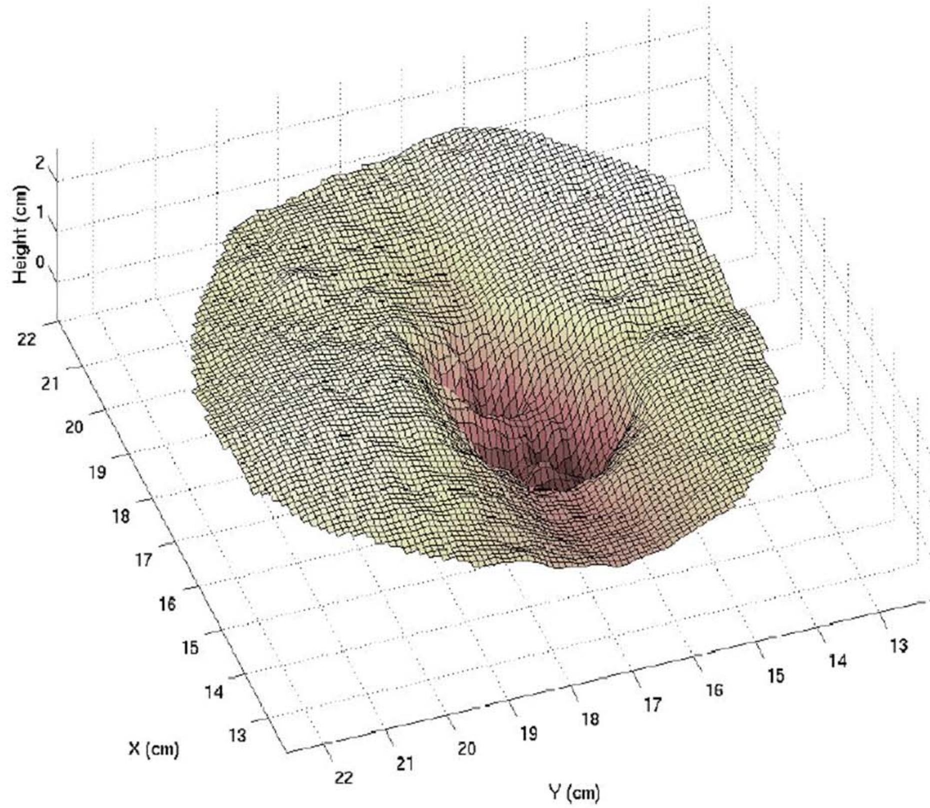
Output

3-D Perspective Views



Medical Applications

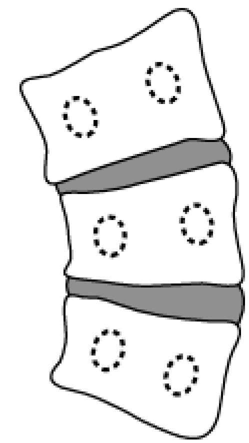




http://www.lr.tudelft.nl/en/organisation/departments-and-chairs/remote-sensing/optical-and-laser-remote-sensing/research/research-fields/heritage-and-medical/medical-photogrammetry/wound-measurement/

Medical Applications

- **<u>Scoliosis:</u>**
- 3D deformity of the human spine
- Affects 2-3% of the population
- Impacts the quality of life
- Early detection is vital

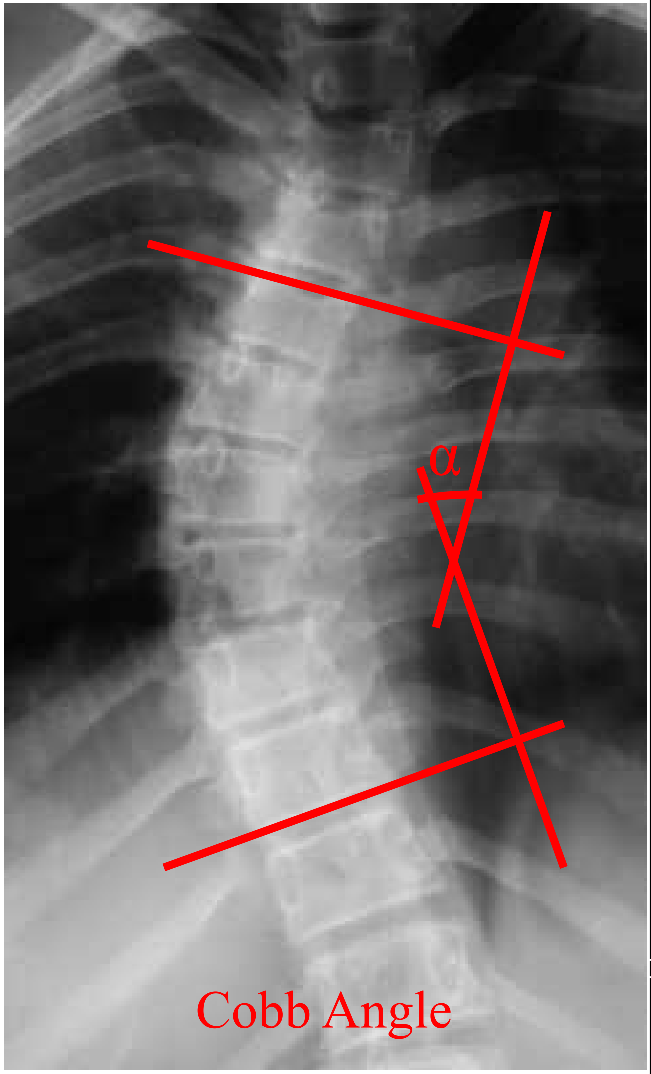


www.rad.washington.edu/mskbook/scoliosis.html

www.nlm.nih.gov/MEDLINEPLUS/ency/images/ency/fullsize/19466.jpg

Medical Applications

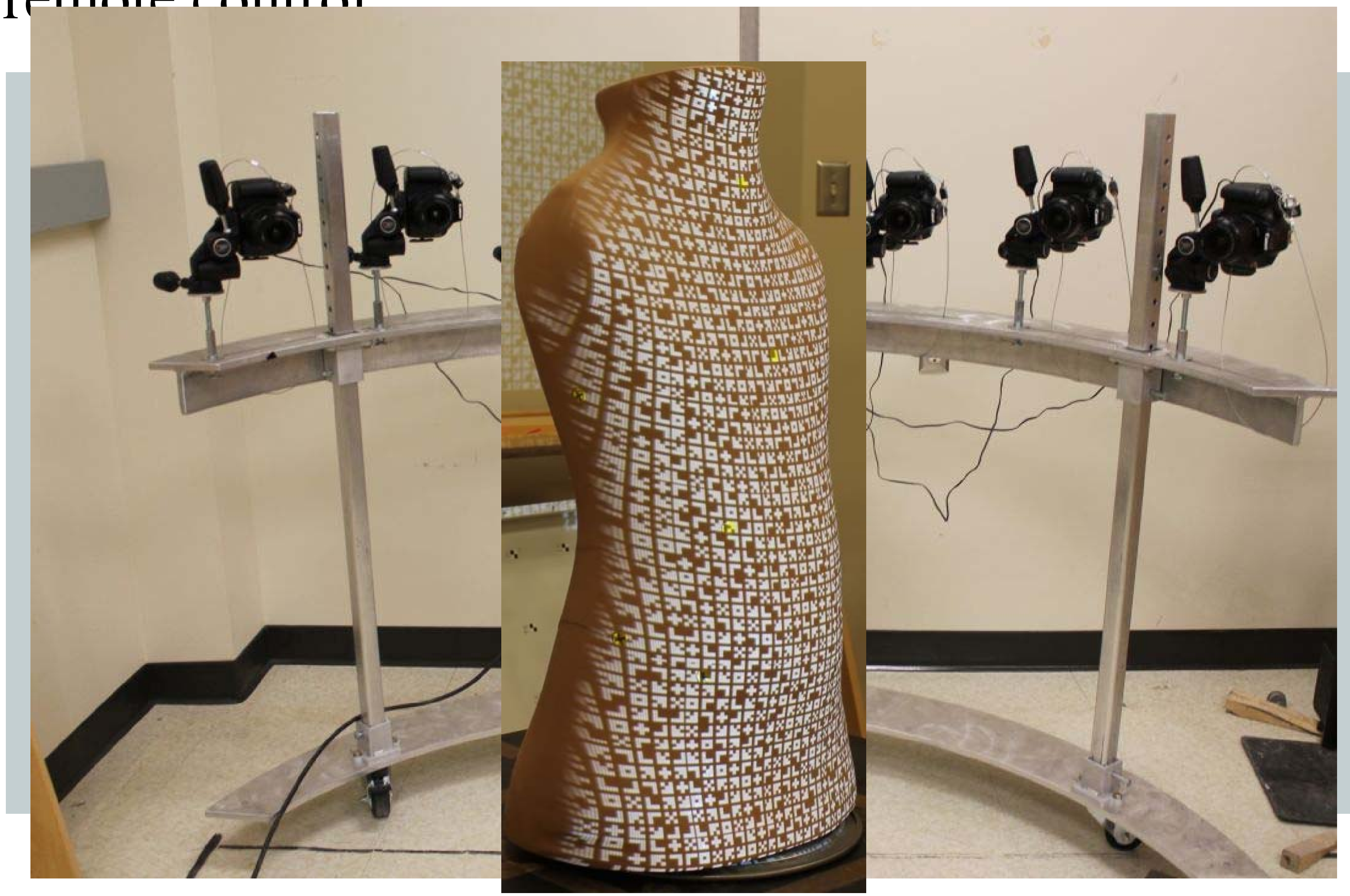
- **<u>Scoliosis Detection & Monitoring</u>**
  - Traditional method: Full-length spinal x-ray in a standing position
- Consequences:
  - Frequent exposure to radiation
  - (4-5 times a year, for 3-5 years)
  - Increased risk of cancer



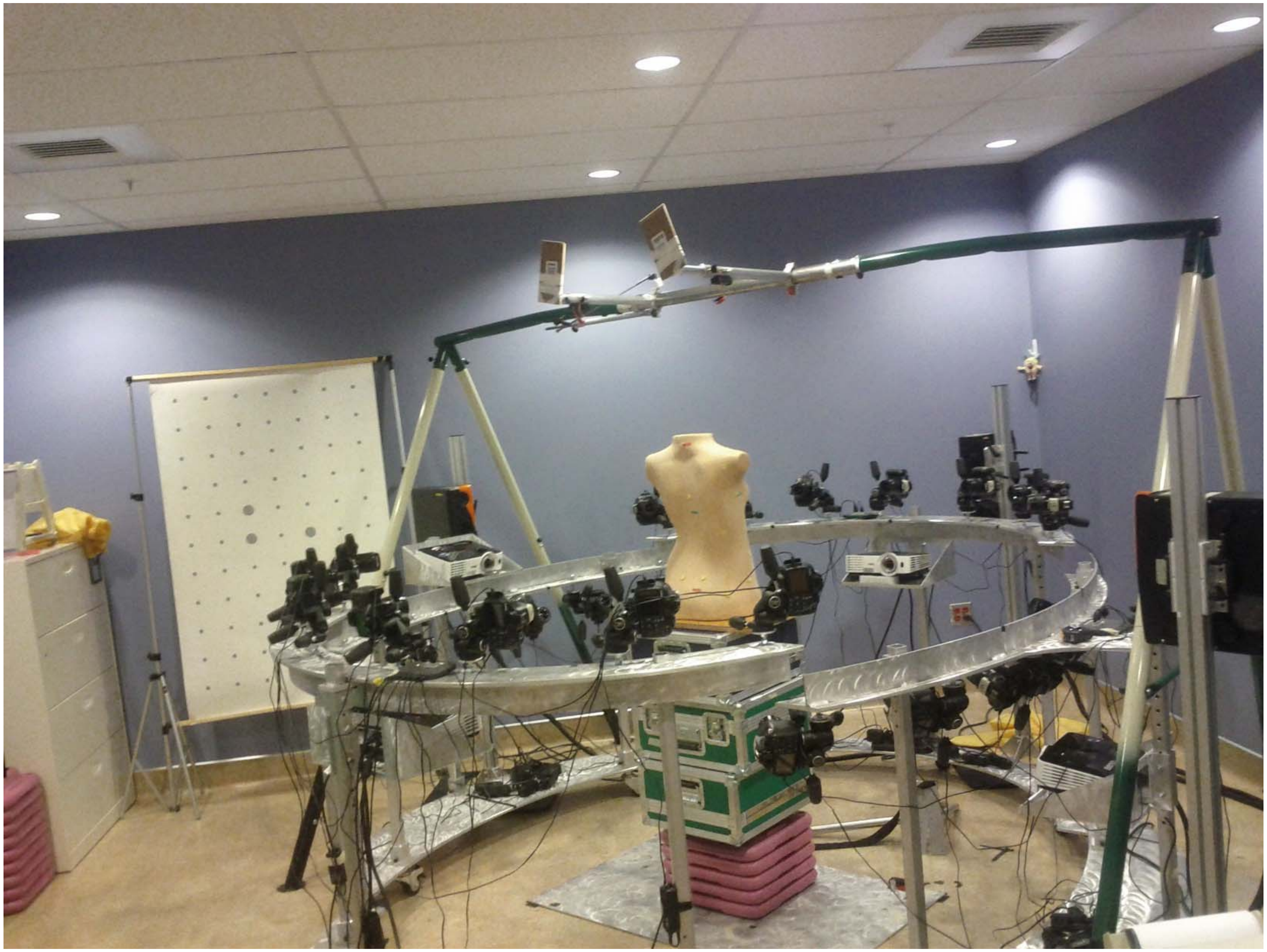
http://www.e-radiography.net/radpath/c/cobb-angle.jpg

Medical Applications

- Cameras, projectors, frame, target board, computer(s), remote control

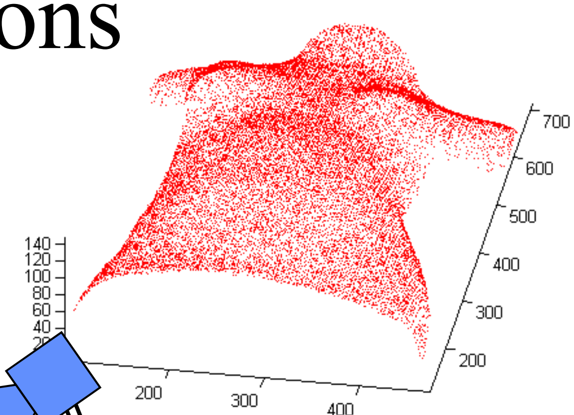


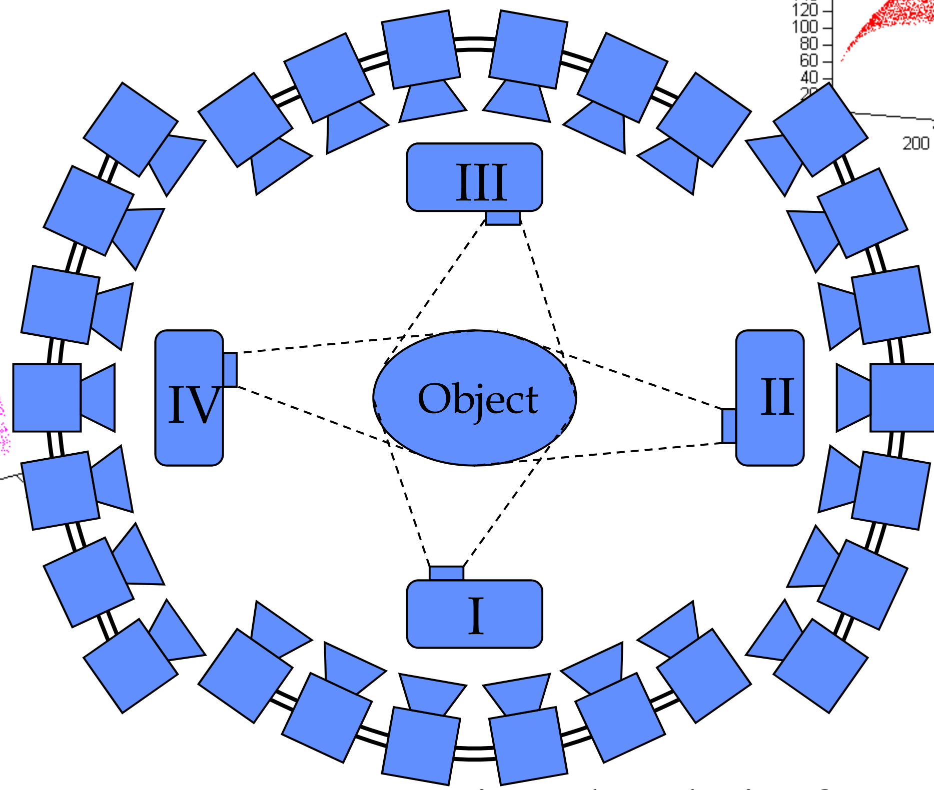
Medical Applications

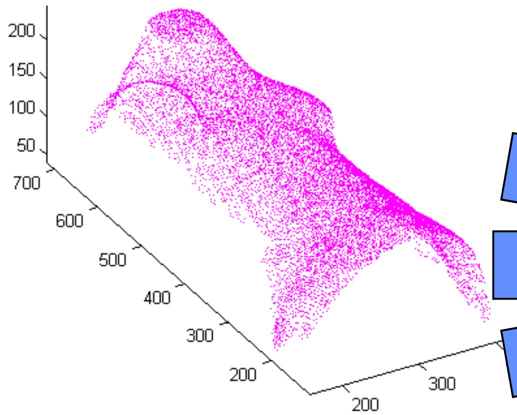


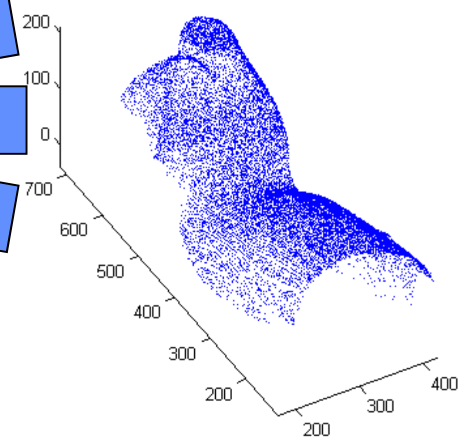
Medical Applications

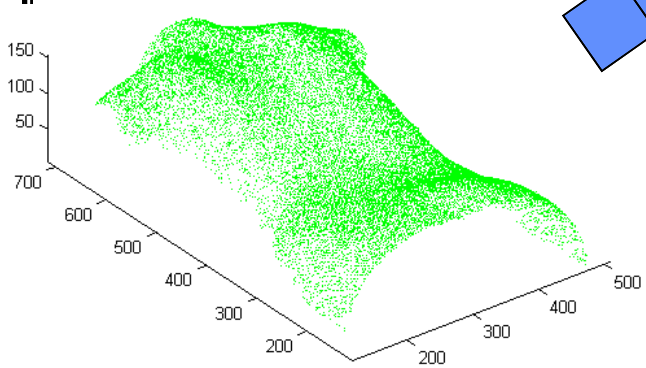
Medical Applications







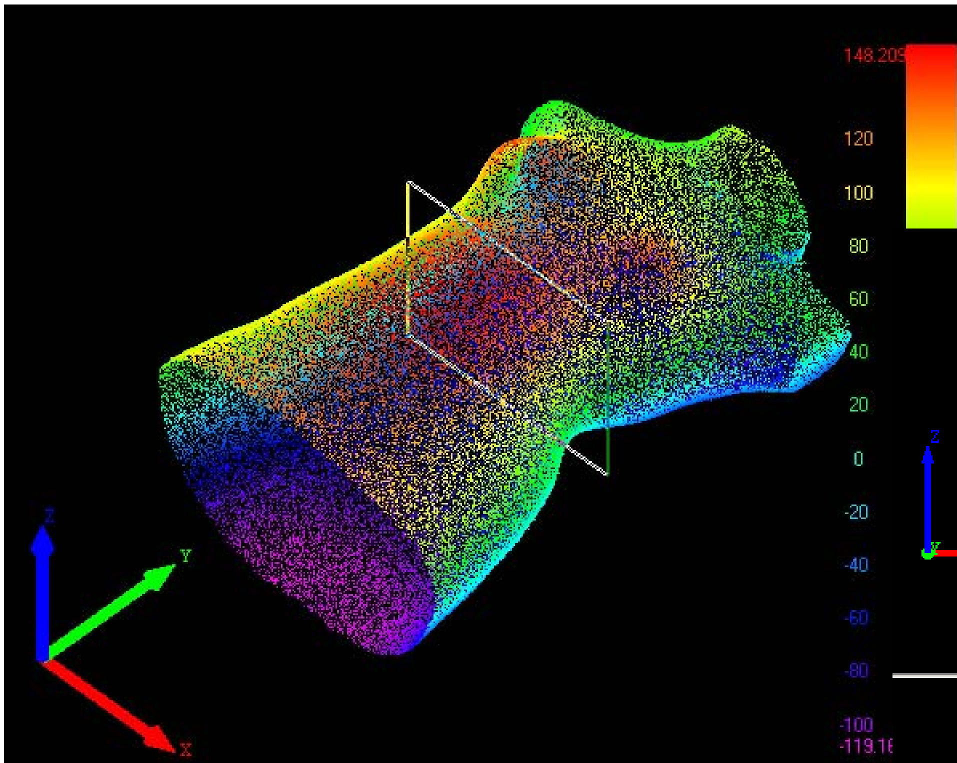




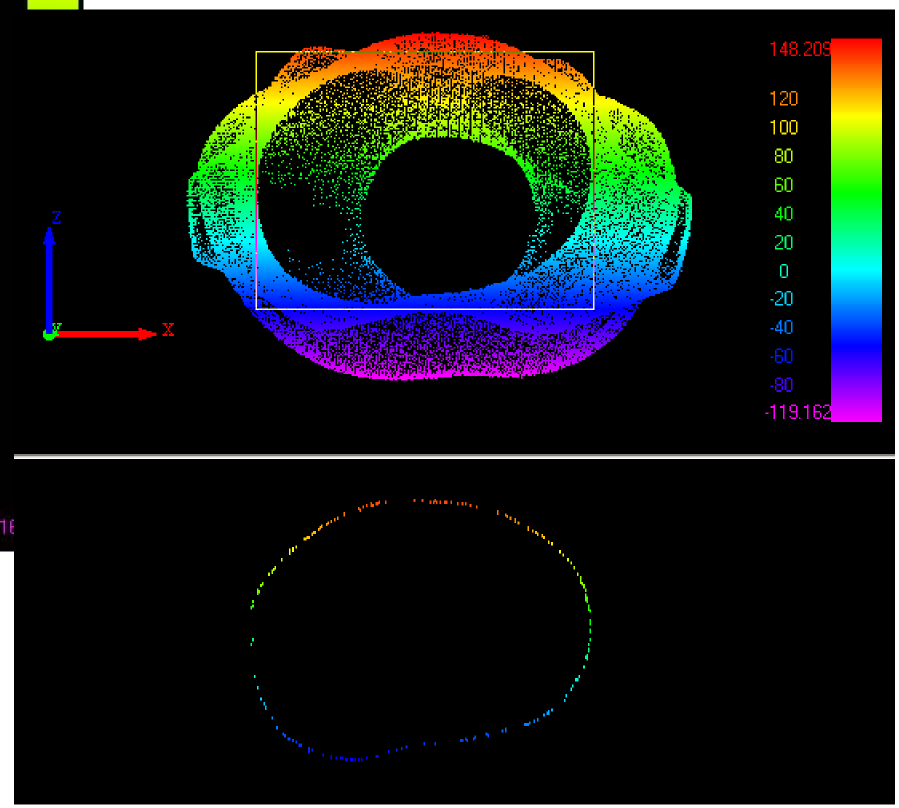
Four point clouds in four different reference frames → necessity for a registration to a common reference frame

Medical Applications

- Multiple surface registration: complete 3D torso model

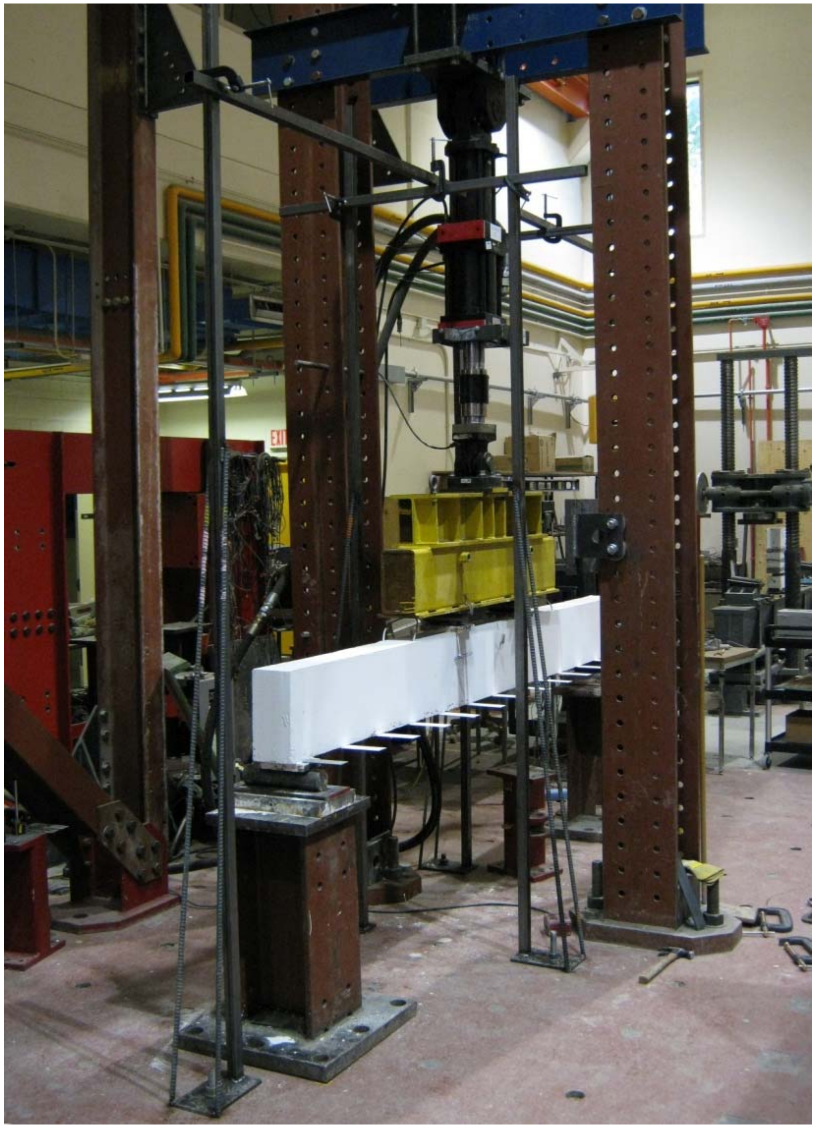


Qualitative assessment



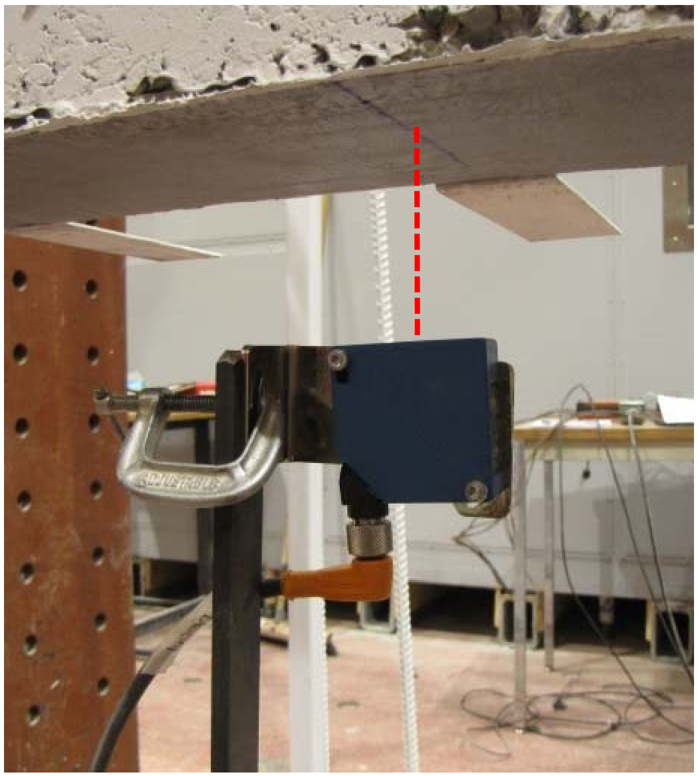
Infrastructure Monitoring

- Objective:
  - Develop a system that can evaluate the deflection along the beam under static and dynamic loading conditions
- Design target function:
  - Low cost
  - Non-contact
  - Accurate
  - Reusable
  - Continuous evaluation of the deflection along the beam



Infrastructure Monitoring

- Current technology for deflection measurement



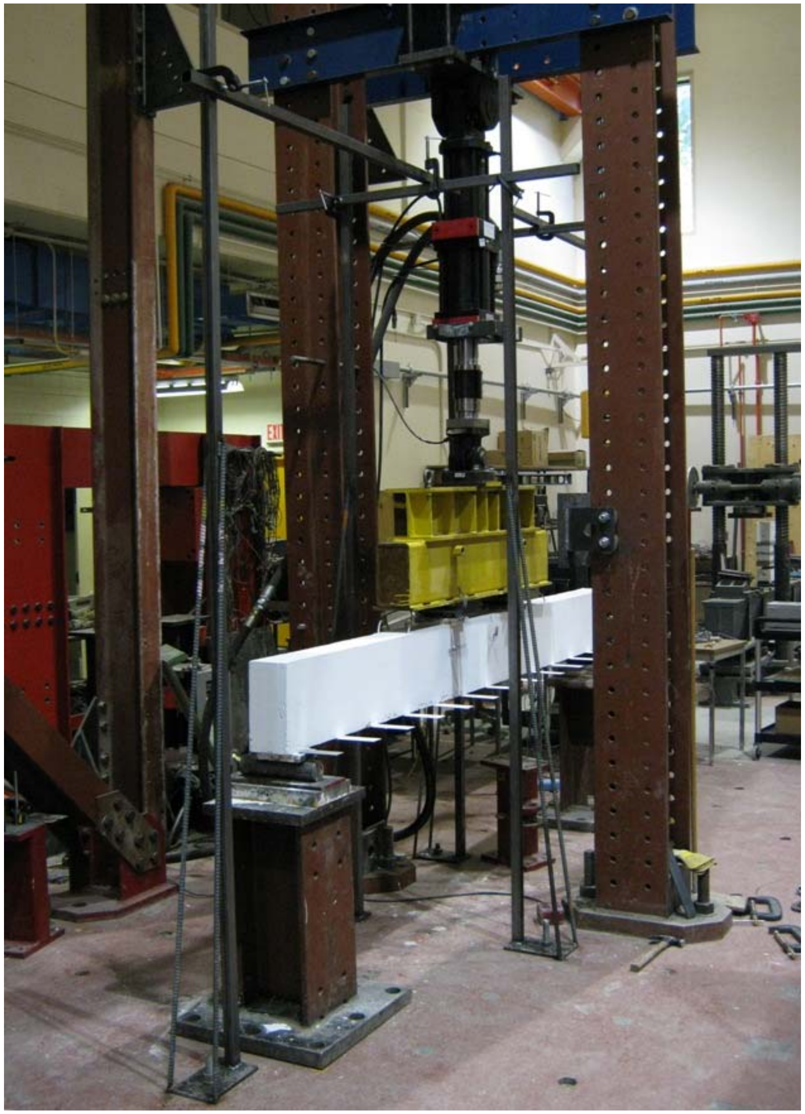
Laser Transducer

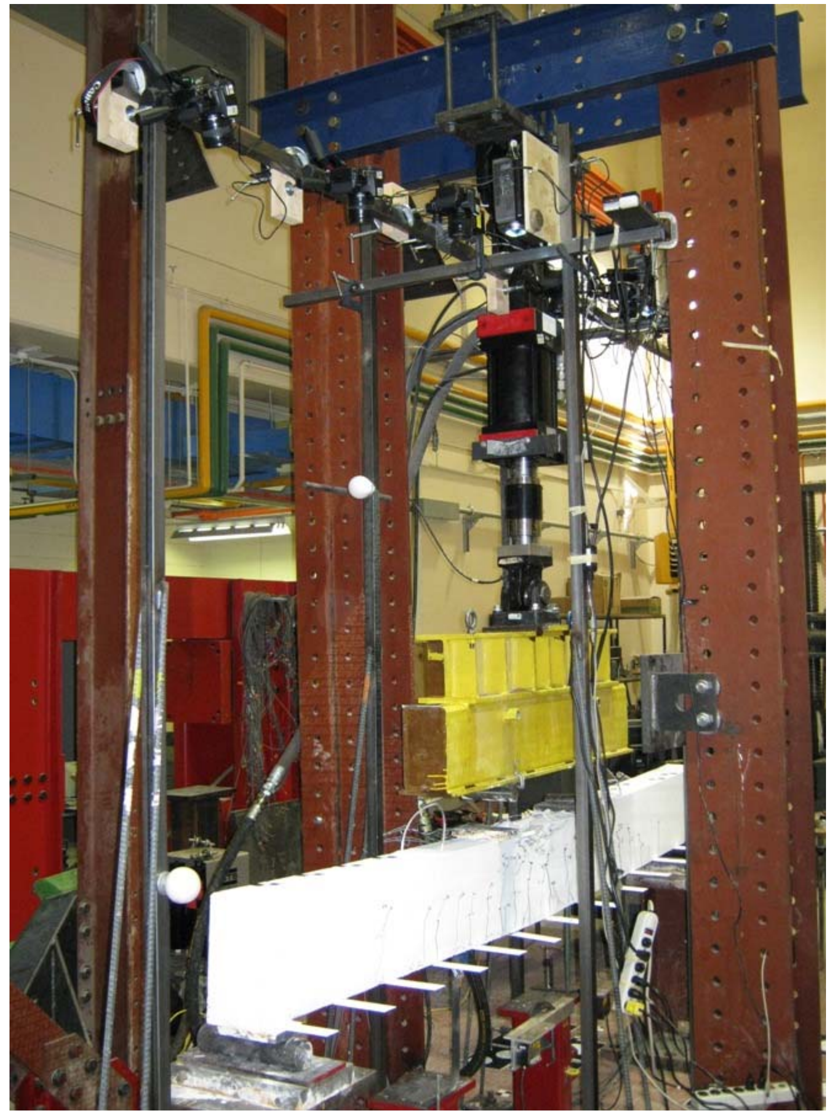
Mechanical Transducer

http://www.instron.com/fileuniverse/live/images/Accessories/2601-093_P.jpg

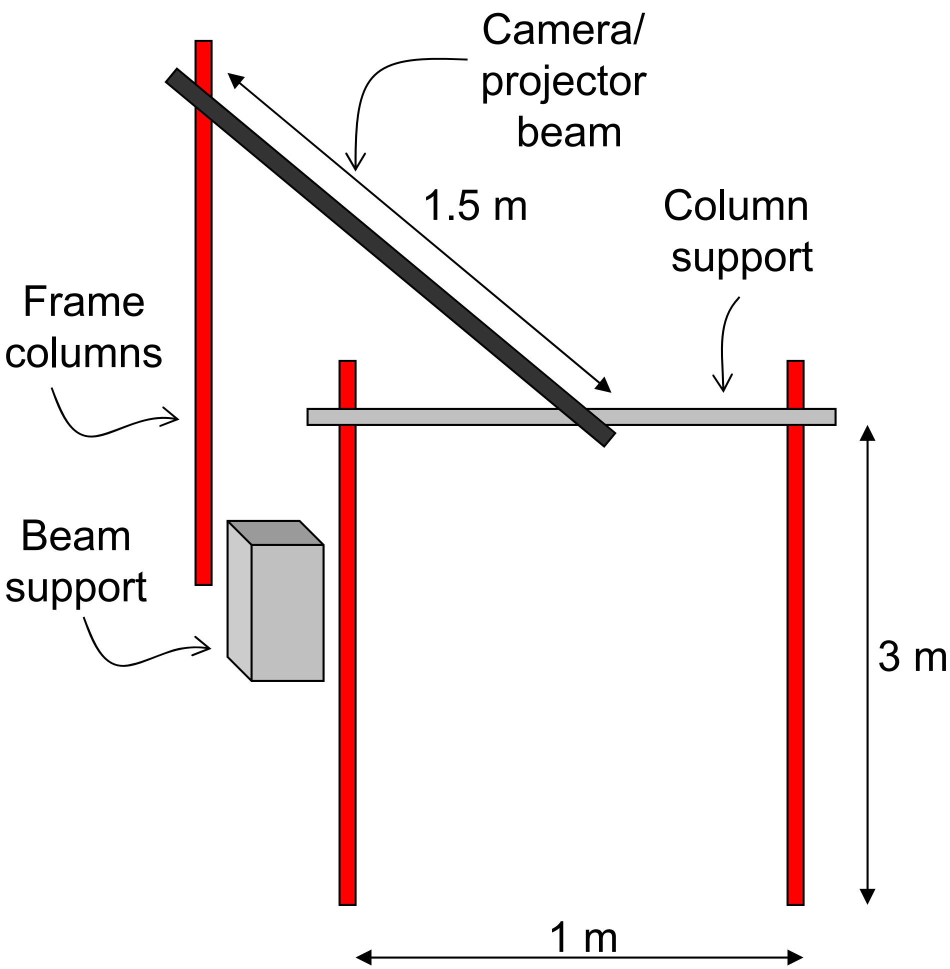
These are point sensors.

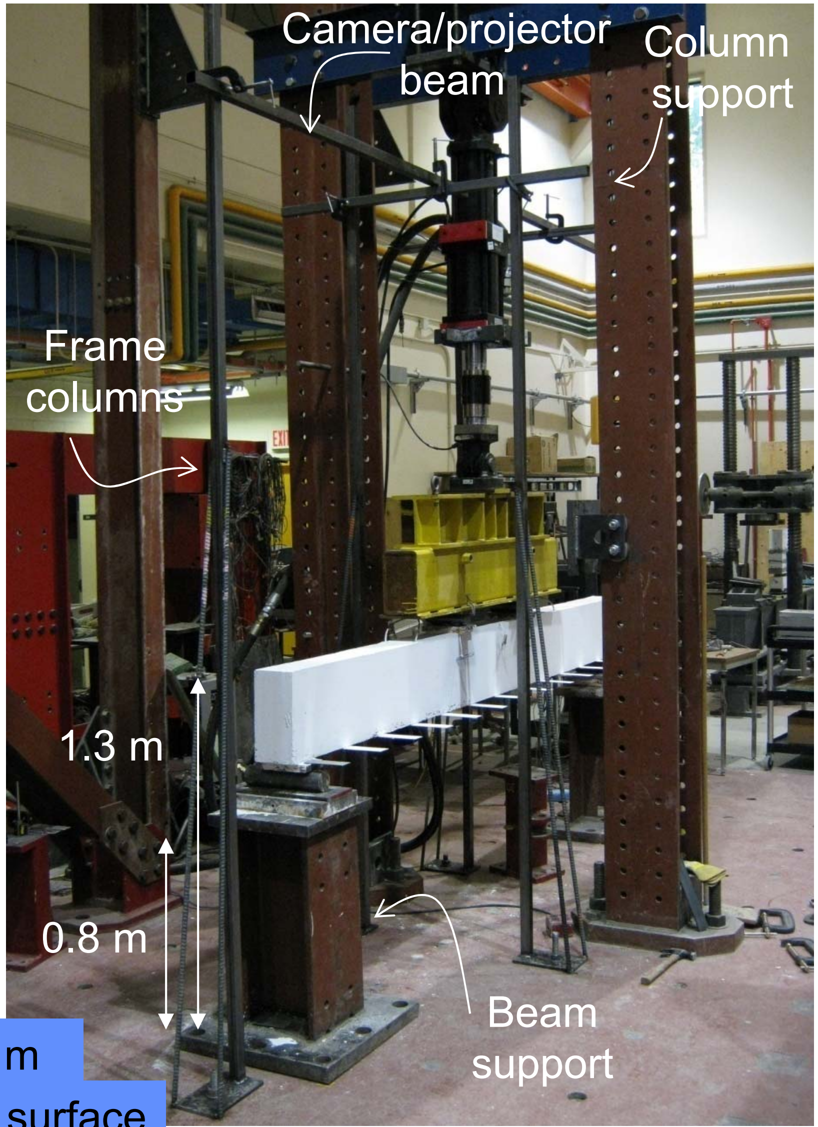
Infrastructure Monitoring





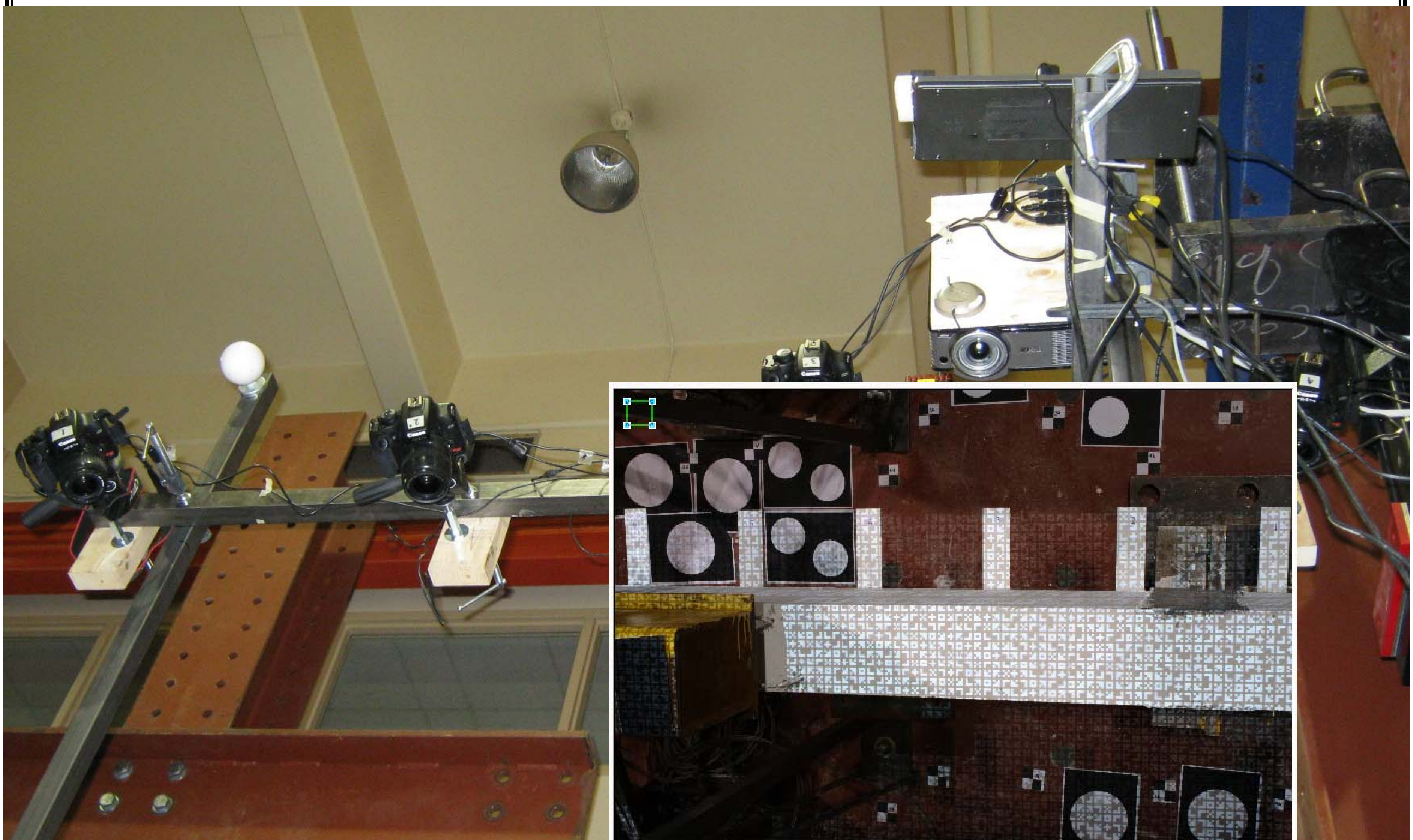
Infrastructure Monitoring



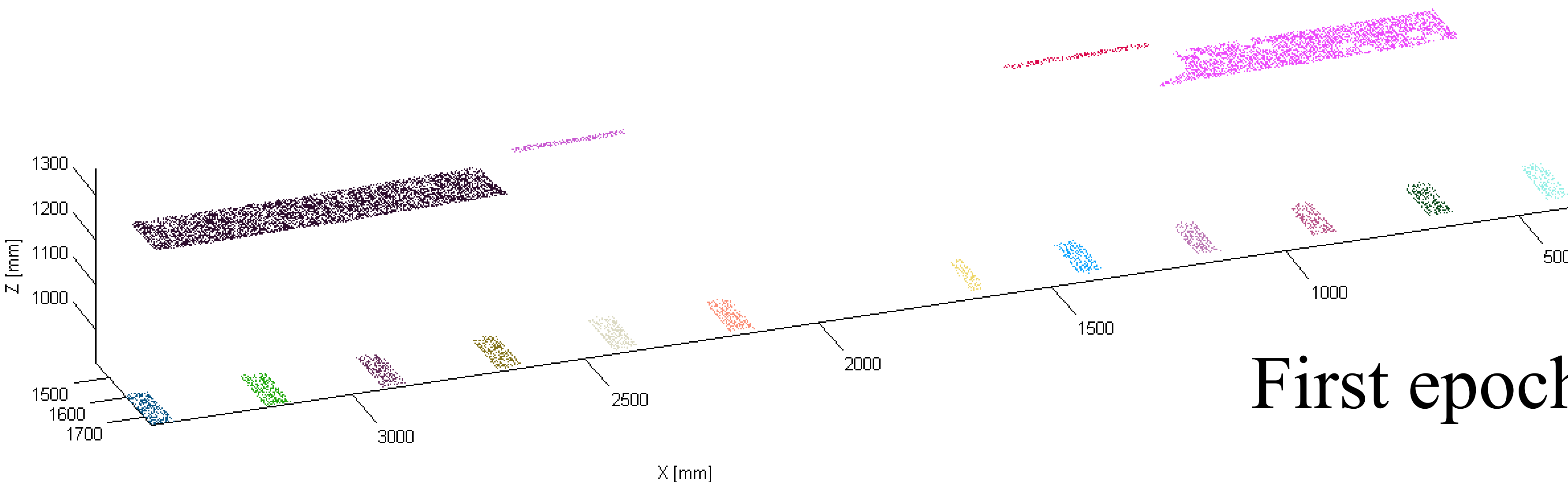


Camera beam @ 3.0 m
Beam support @ 0.8 m and beam surface @ 1.3 m
Cameras @ 2.8 m and @ 1.5 m above the beam surface

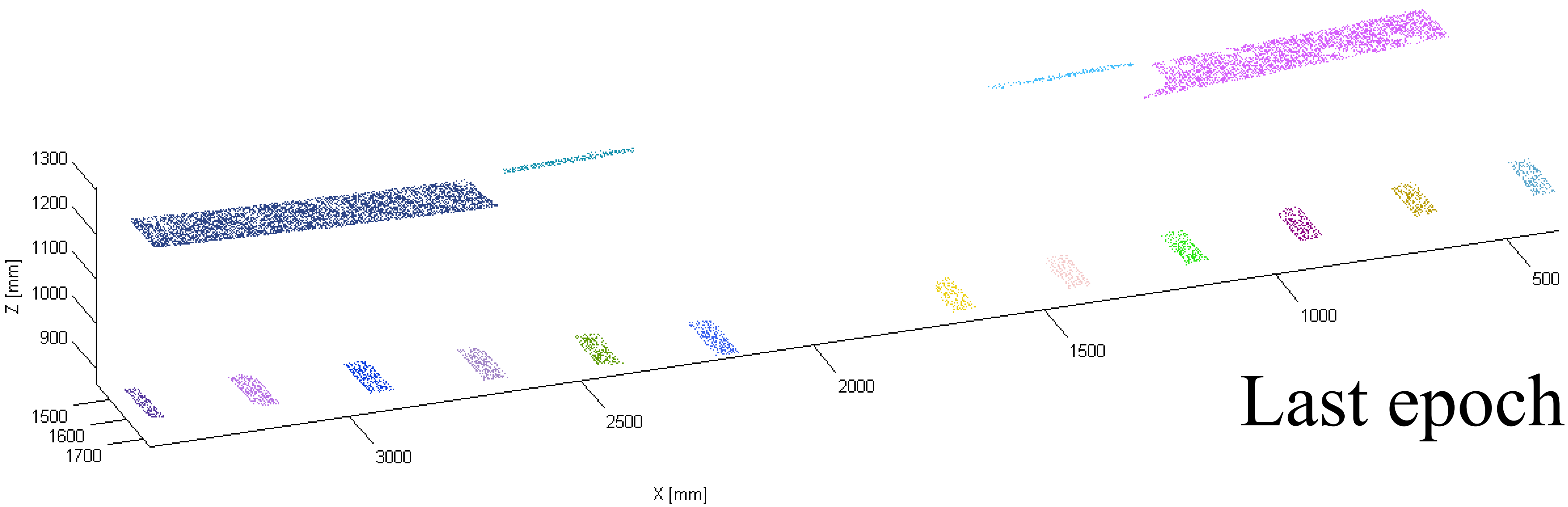
Infrastructure Monitoring



Infrastructure Monitoring

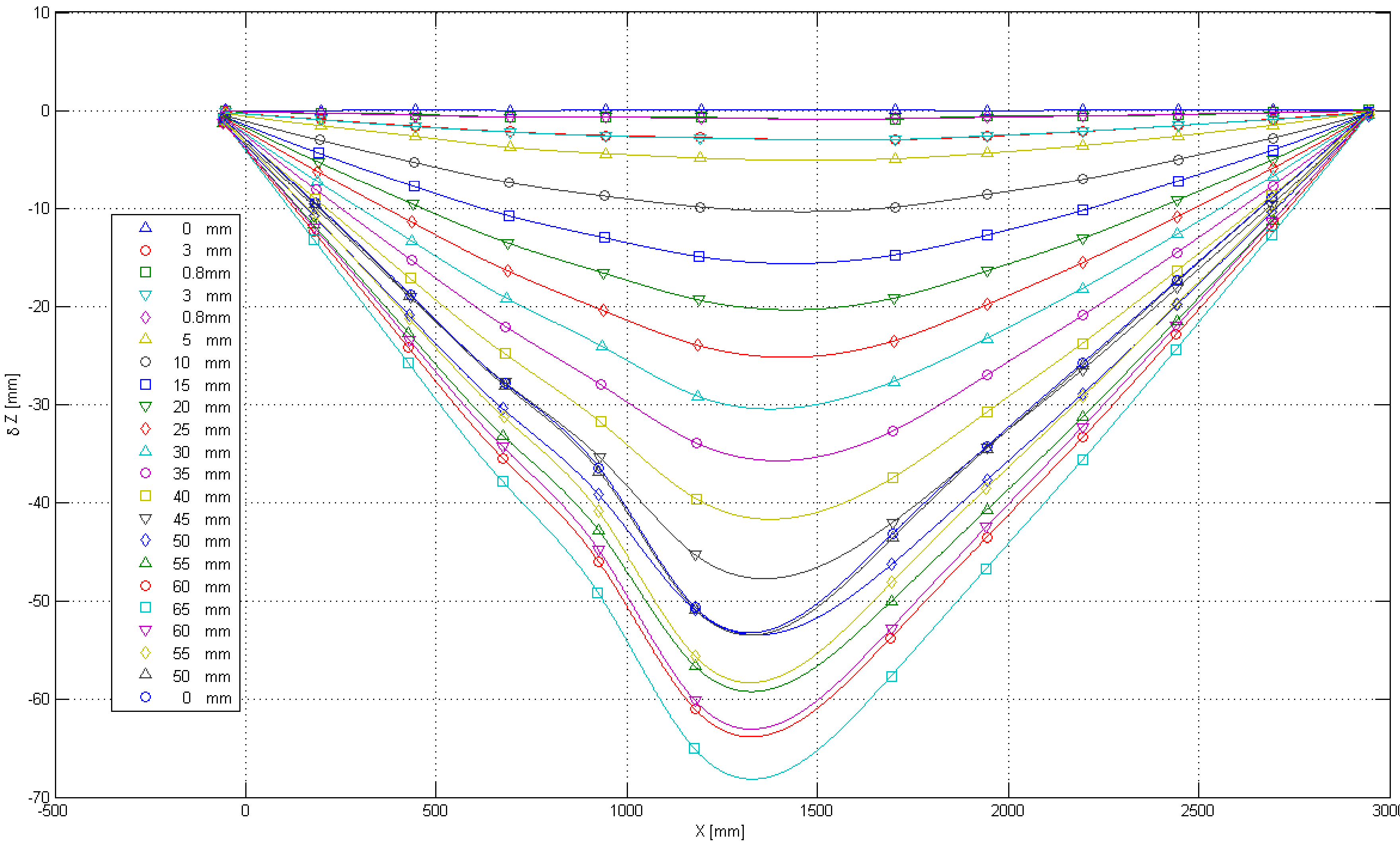


First epoch



Last epoch

Infrastructure Monitoring



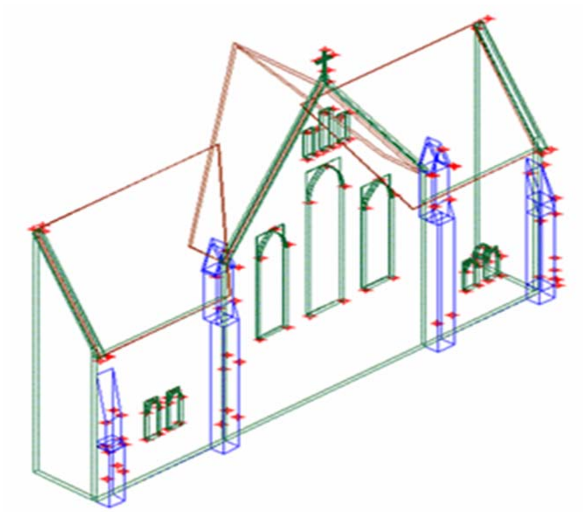
Documentation of Historical Buildings

Historical church in downtown Calgary, Canada

Documentation of Historical Buildings

Generate 3-D CAD model for archiving.

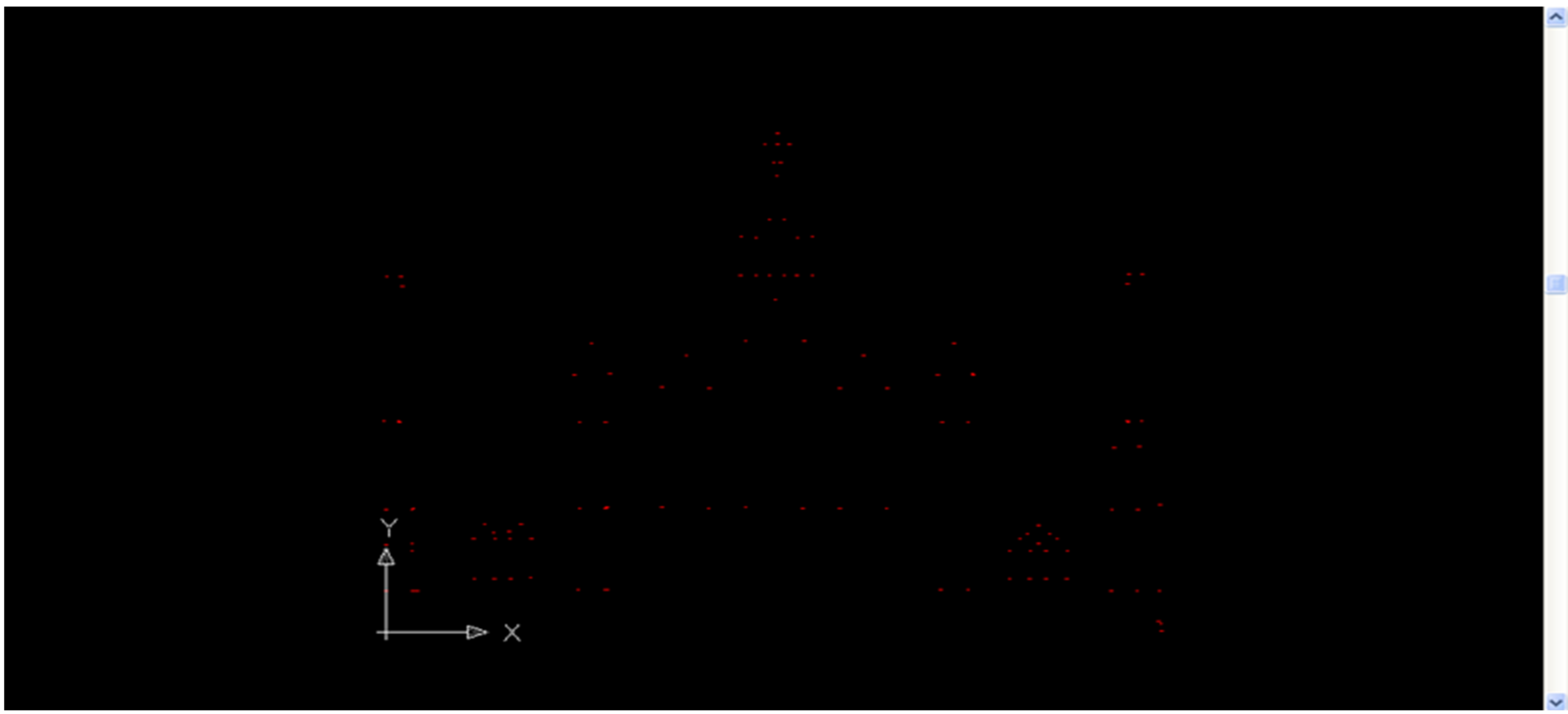
Documentation of Historical Buildings



AutoCAD wire frame representation of the church

3D model of the church with surface rendering

Documentation of Historical Buildings

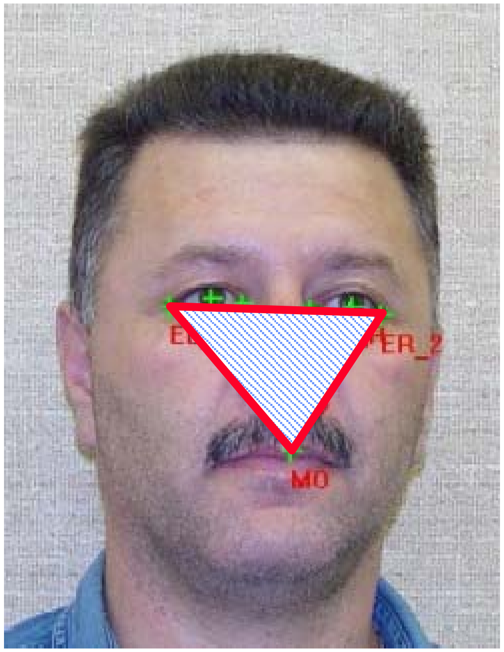


Facial Measurements

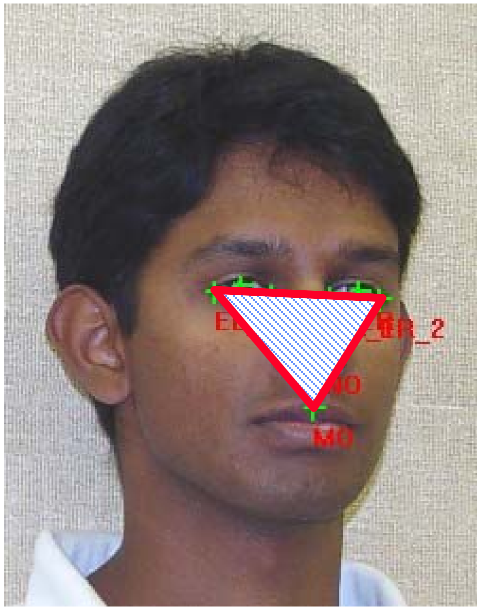
Left Image

Right Image

Personal Identification

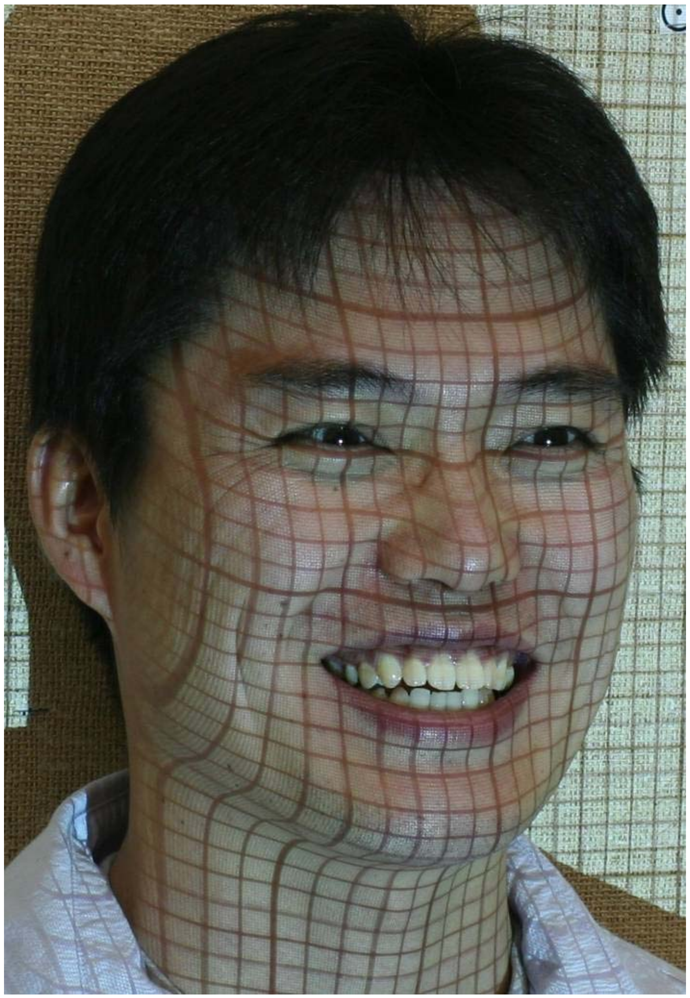


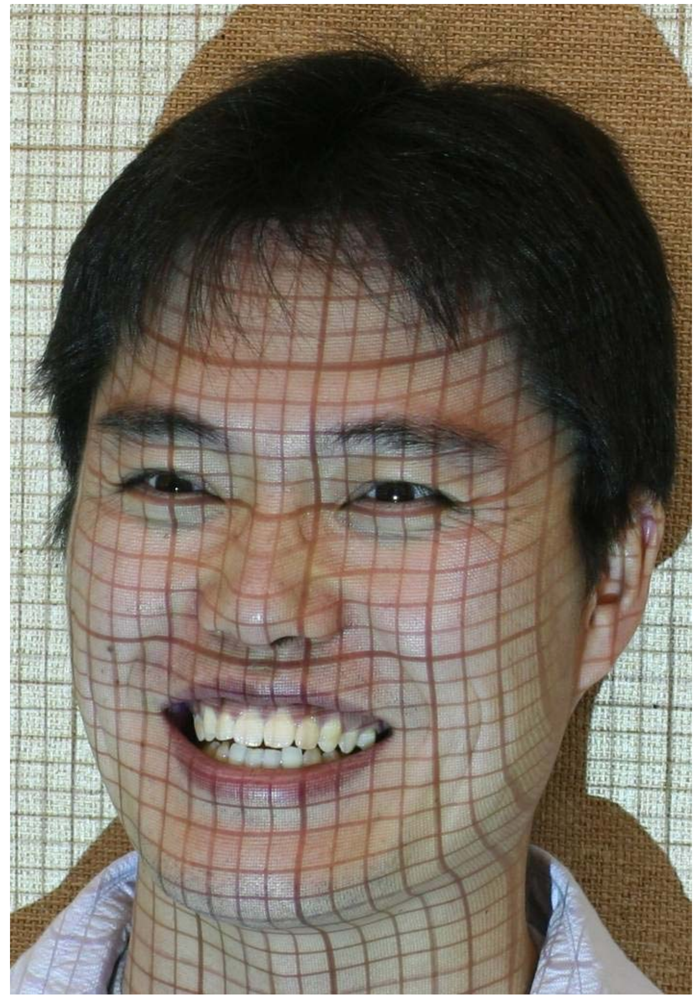
Area = 36.0704 cm^2



Area = 28.4765 cm^2

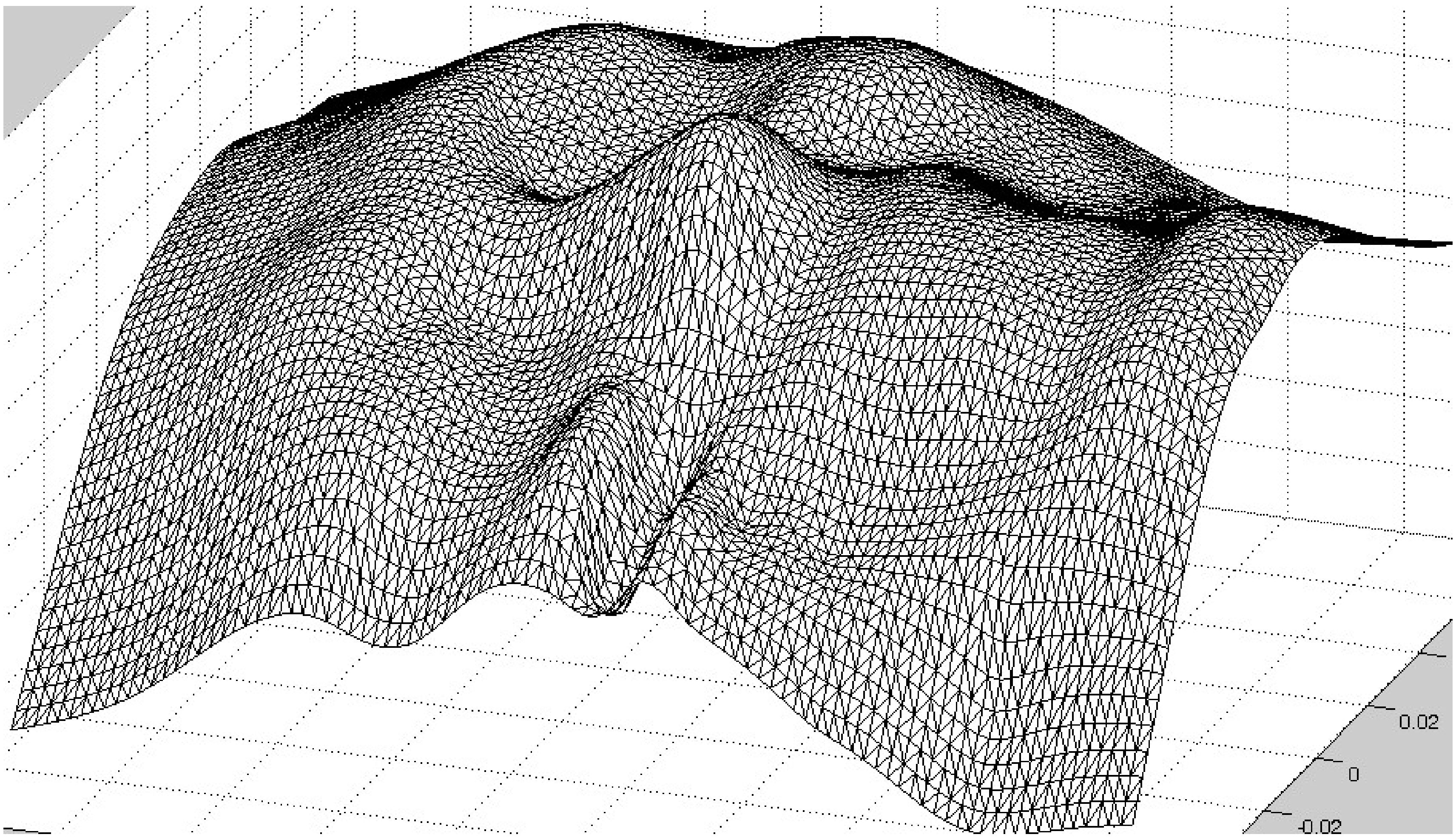
Facial Reconstruction





Input Stereo Imagery

Facial Reconstruction



Output Three-Dimensional Model

Facial Reconstruction

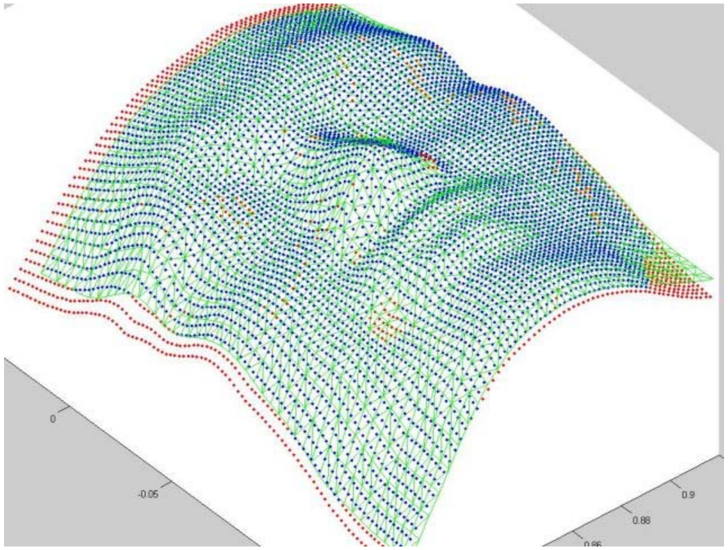
- Experiments:

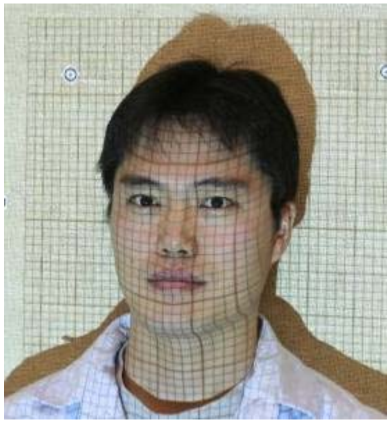
Test	Descriptions
1	Subject 1: Time 1 & Time 2
2	Subject 1: No Smile & Smile
3	Subject 2 & Subject 3

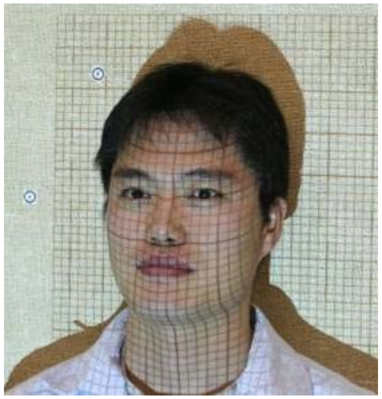
- Results:

Test 1

Green: Reference
Blue: Matches
Red: Non-matches







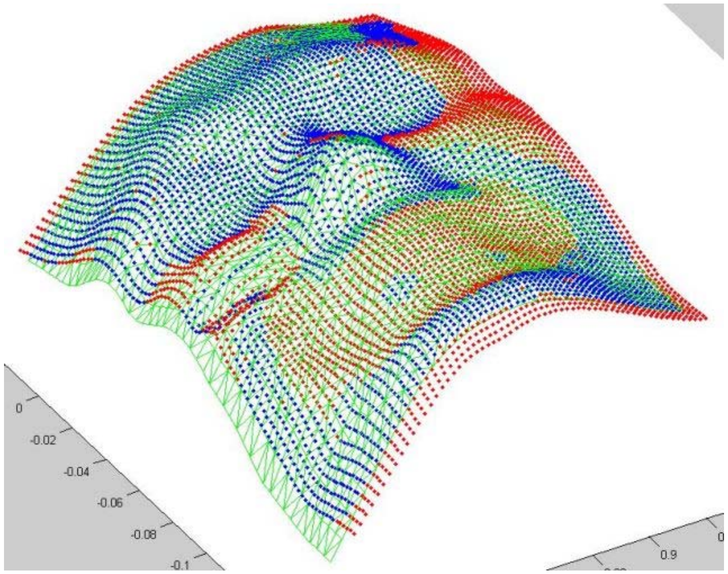
Facial Reconstruction

- Experiments:

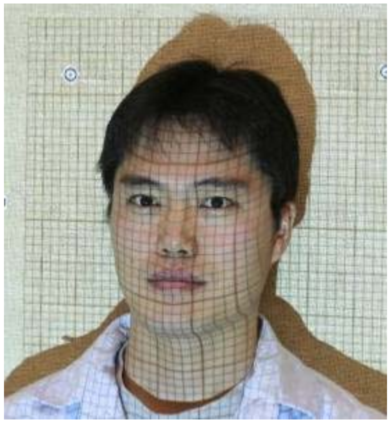
Test	Descriptions
1	Subject 1: Time 1 & Time 2
2	Subject 1: No Smile & Smile
3	Subject 2 & Subject 3

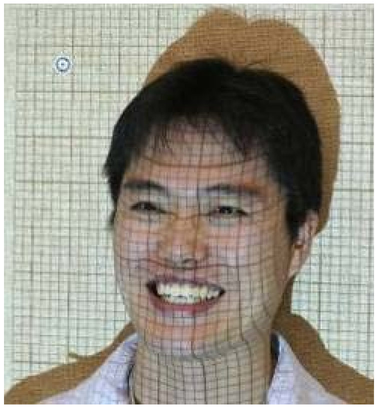
- Results:

Test 2



Green: Reference
Blue: Matches
Red: Non-matches





Facial Reconstruction

- Experiments:

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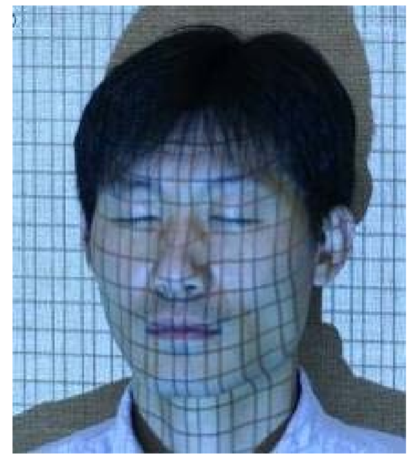
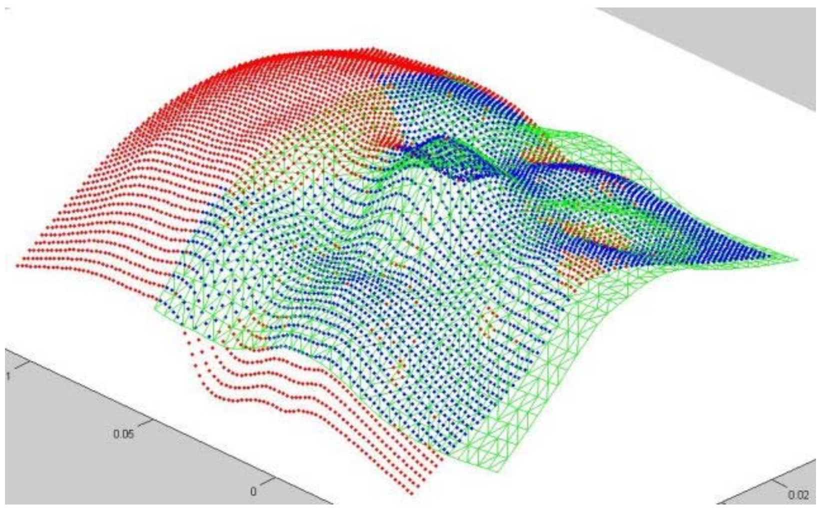



- Results:

Test 3



Green: Reference
Blue: Matches
Red: Non-matches

Facial Reconstruction

Terrestrial Mobile Mapping Systems

Terrestrial Mobile Mapping Systems

University of Calgary

Terrestrial Mobile Mapping Systems

Purdue Wheel-based Mobile Mapping System (PWMMS-HA*)

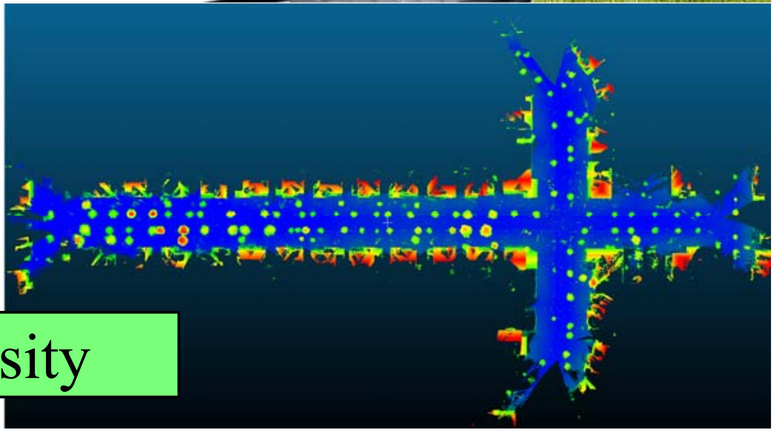
***High Accuracy**

Purdue University

Terrestrial Mobile Mapping Systems

Purdue Wheel-based Mobile Mapping System (PWMMS-UHA*)

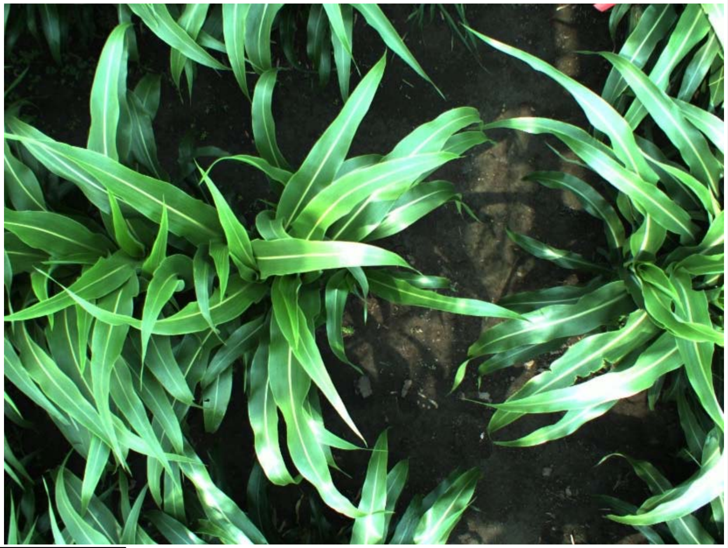
***Ultra High Accuracy**



Purdue University

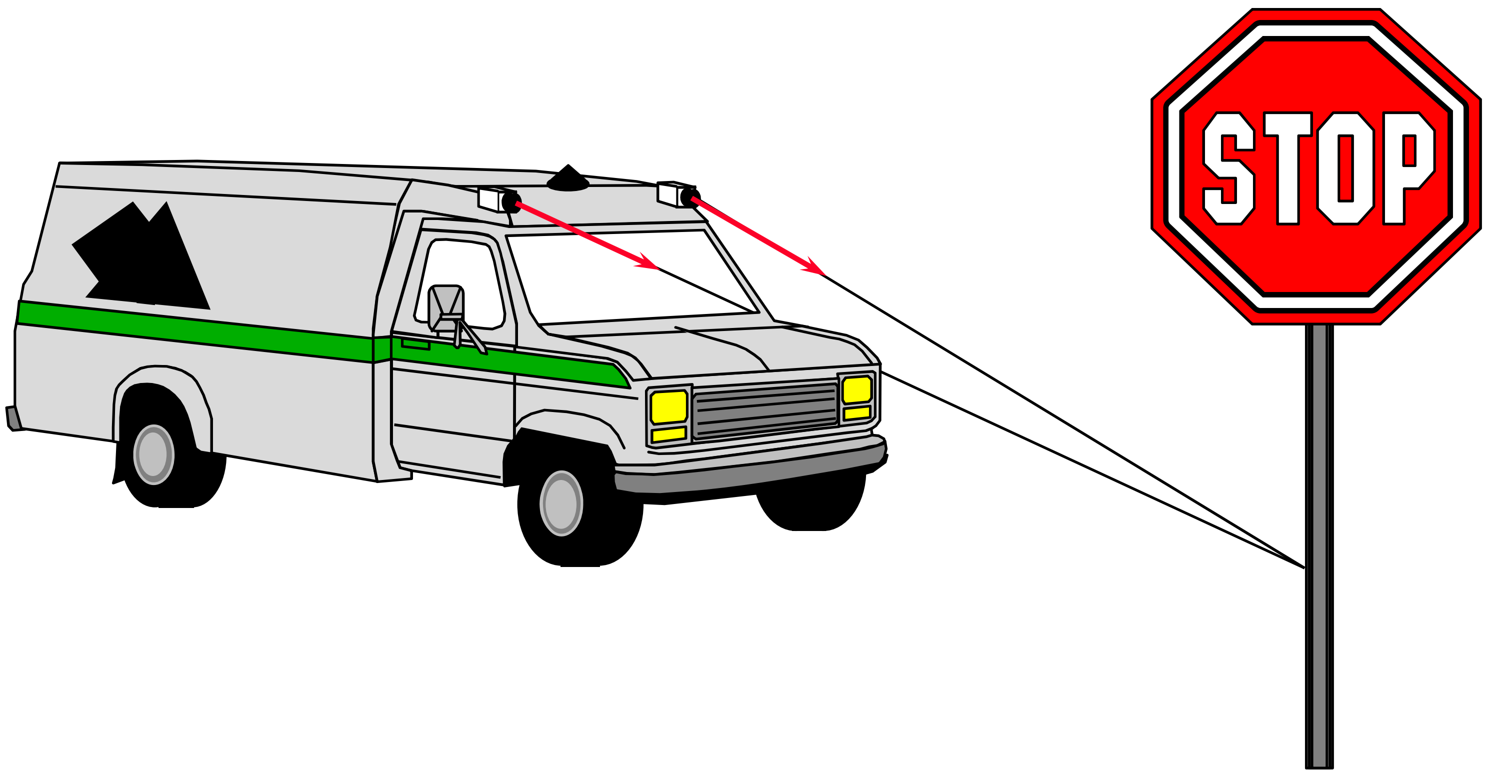
Terrestrial Mobile Mapping Systems

PhenRover: RGB, Hyperspectral, and LiDAR



Purdue University

Stereo-Positioning



Traffic Signs

sign type

height above pavement

offset from road edge

coordinate locations

size of sign

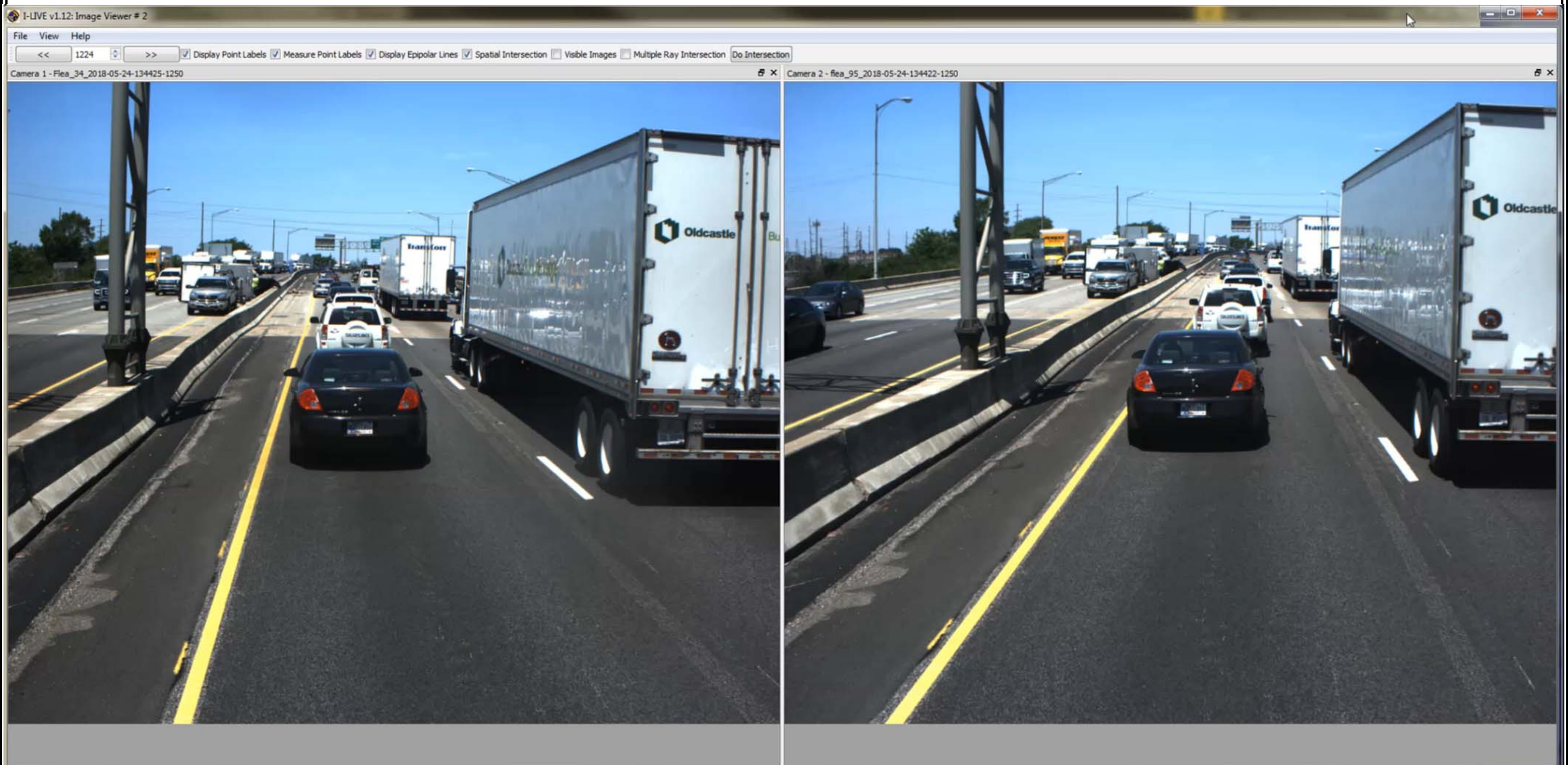
Asset Management

Collecting inventories

Database integration

On-going maintenance

Transportation Corridor Monitoring



Precision Agriculture

VRT Herbicide and
Pesticide Applications

VRT Fertilizer Applications

Sampling

Field S

Tile Line Identi

Planting

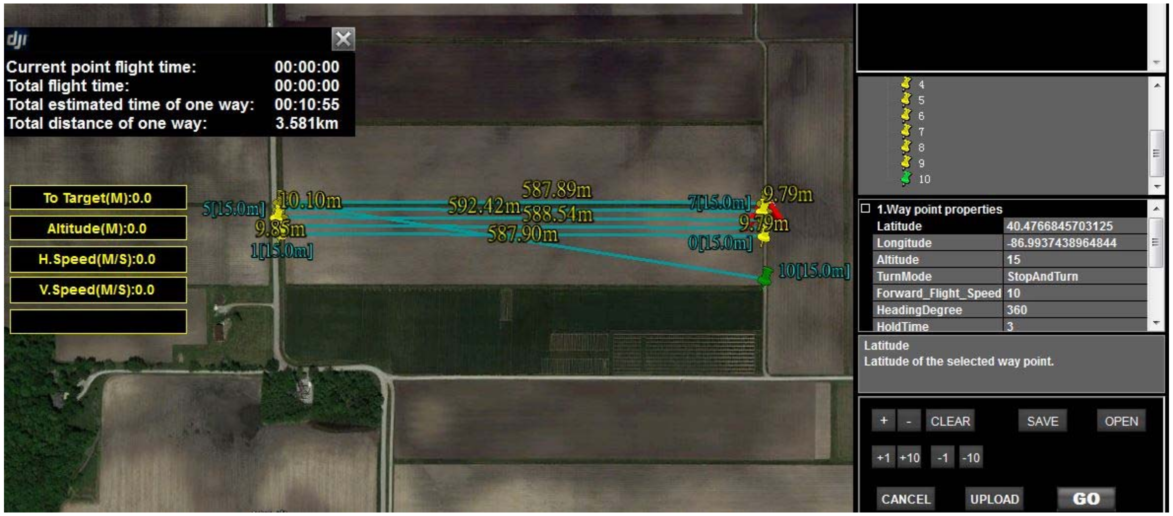
UAVs for Precision Agriculture

UAVs for Precision Ag.: Mission Planning

- South Part (Field 42)
  - 6 flight lines
  - Flying height: 15 meters
  - Flying speed: 8 m/s

UAVs for Precision Ag.: Mission Planning

- North Part (Field 42)
  - 5 flight lines
  - Flying height: 15 meters
  - Flying speed: 8 m/s



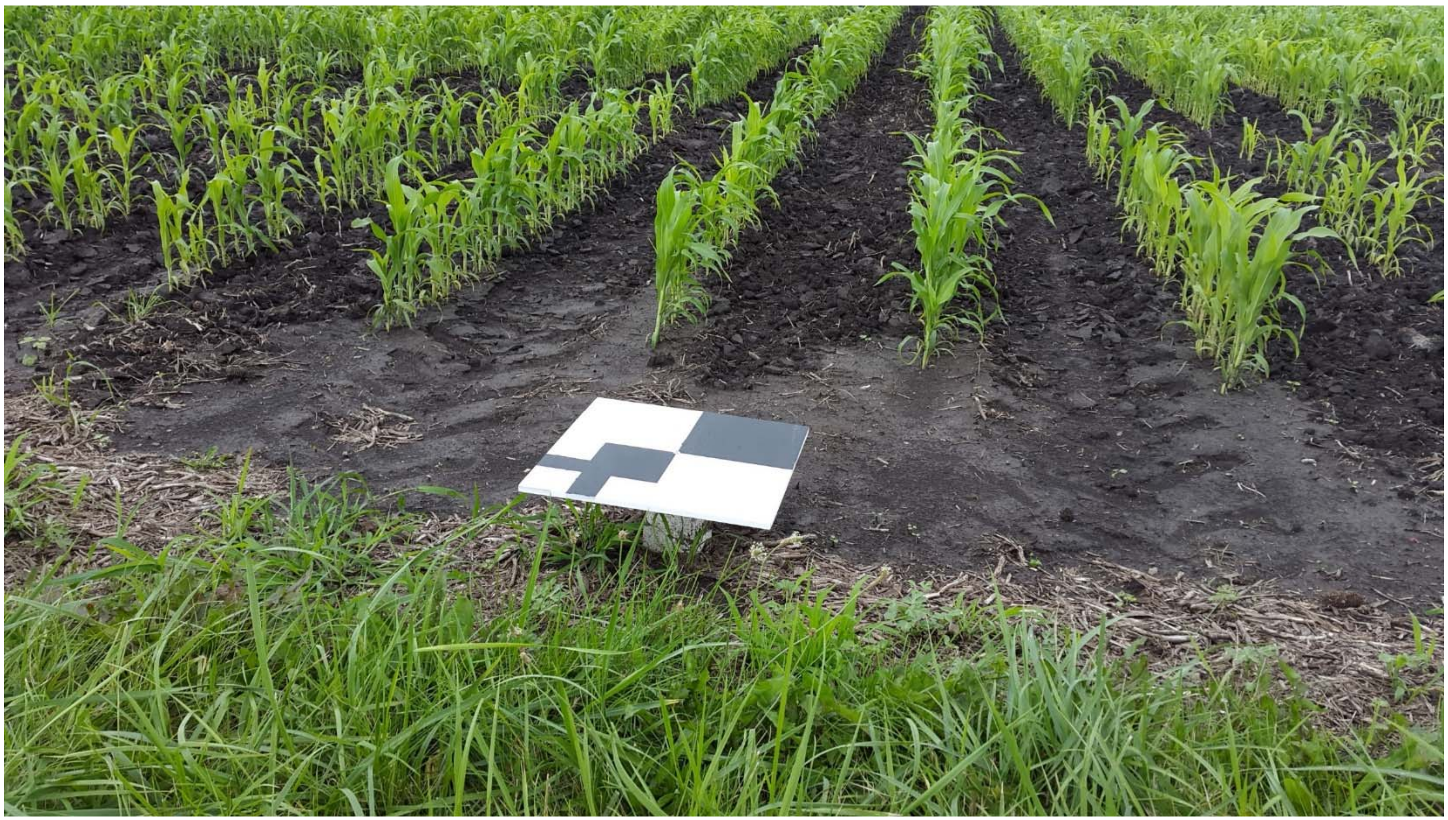
UAVs for Precision Ag.: Sample Images

Before Calibration

After Calibration

UAVs for Precision Ag.: Control Targets

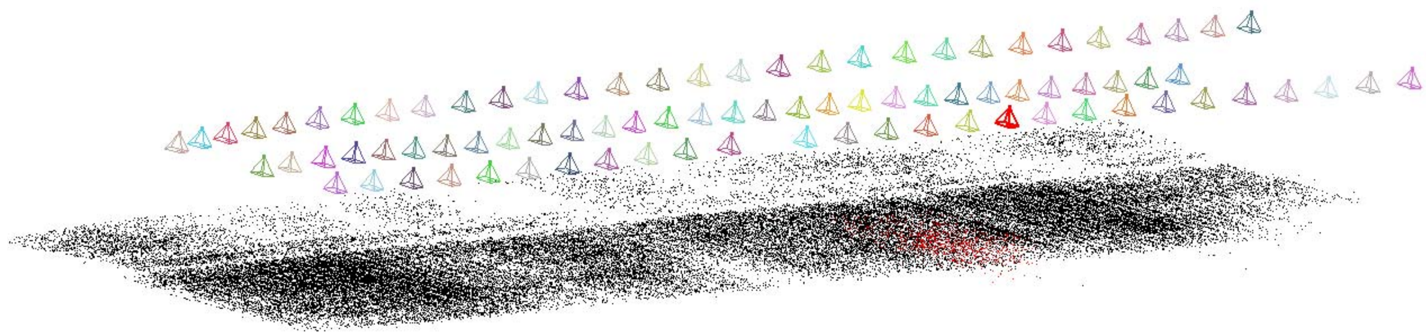
UAVs for Precision Ag.: Control Targets



UAVs for Precision Ag.: Control Targets

UAVs for Precision Ag.: Control Targets

UAVs for Precision Ag.: Reconstructed Block



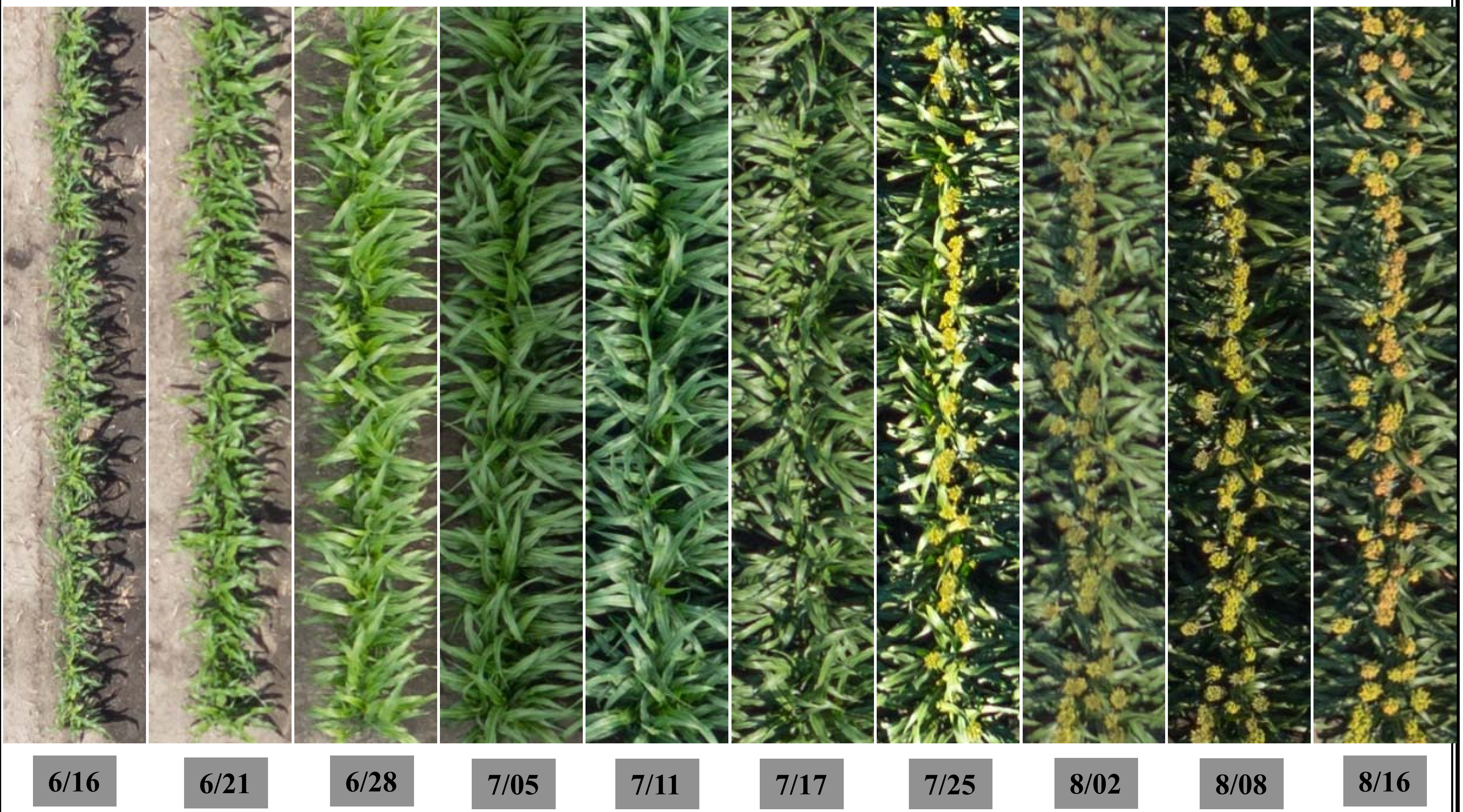
UAVs for Precision Ag.: RMSE Analysis

- 470 images captured on June 15th, 2015 are processed.
- 10 GCPs and 18 Check Points are utilized.
- For Check Points:

UAVs for Precision Ag.: Derived Orthophoto

UAVs for Precision Ag.: S1000+

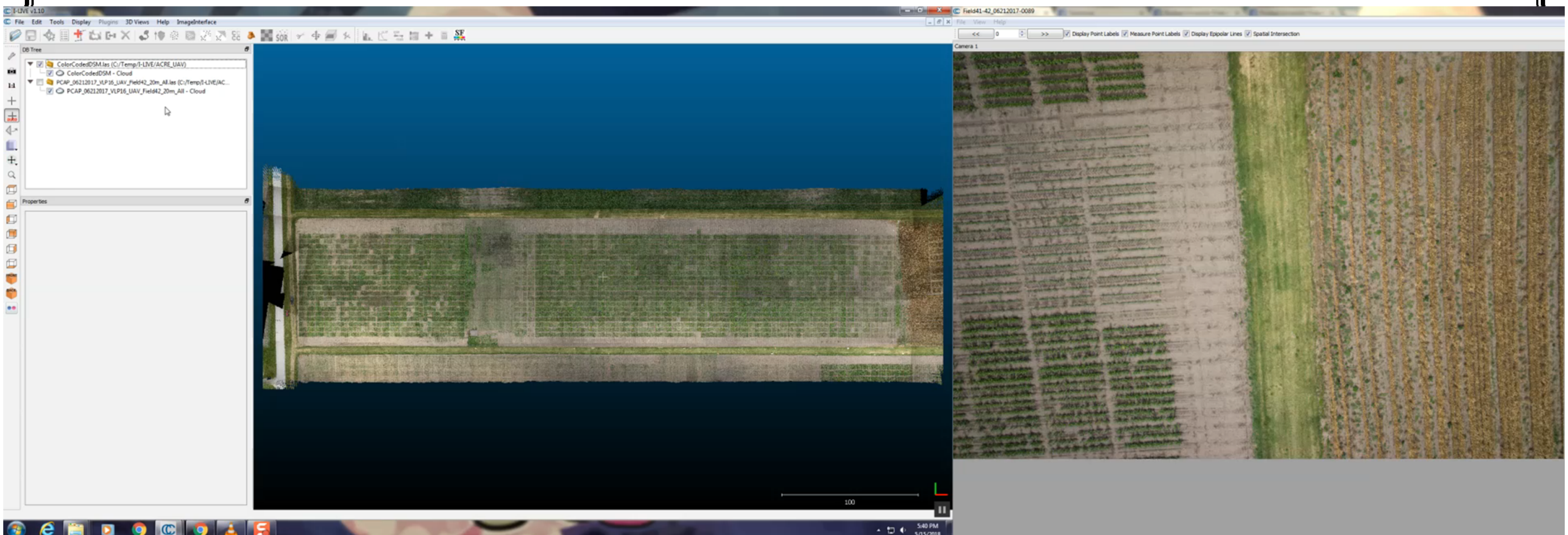
UAV Multi-Date Data Alignment



UAV Multi-Date Data Alignment

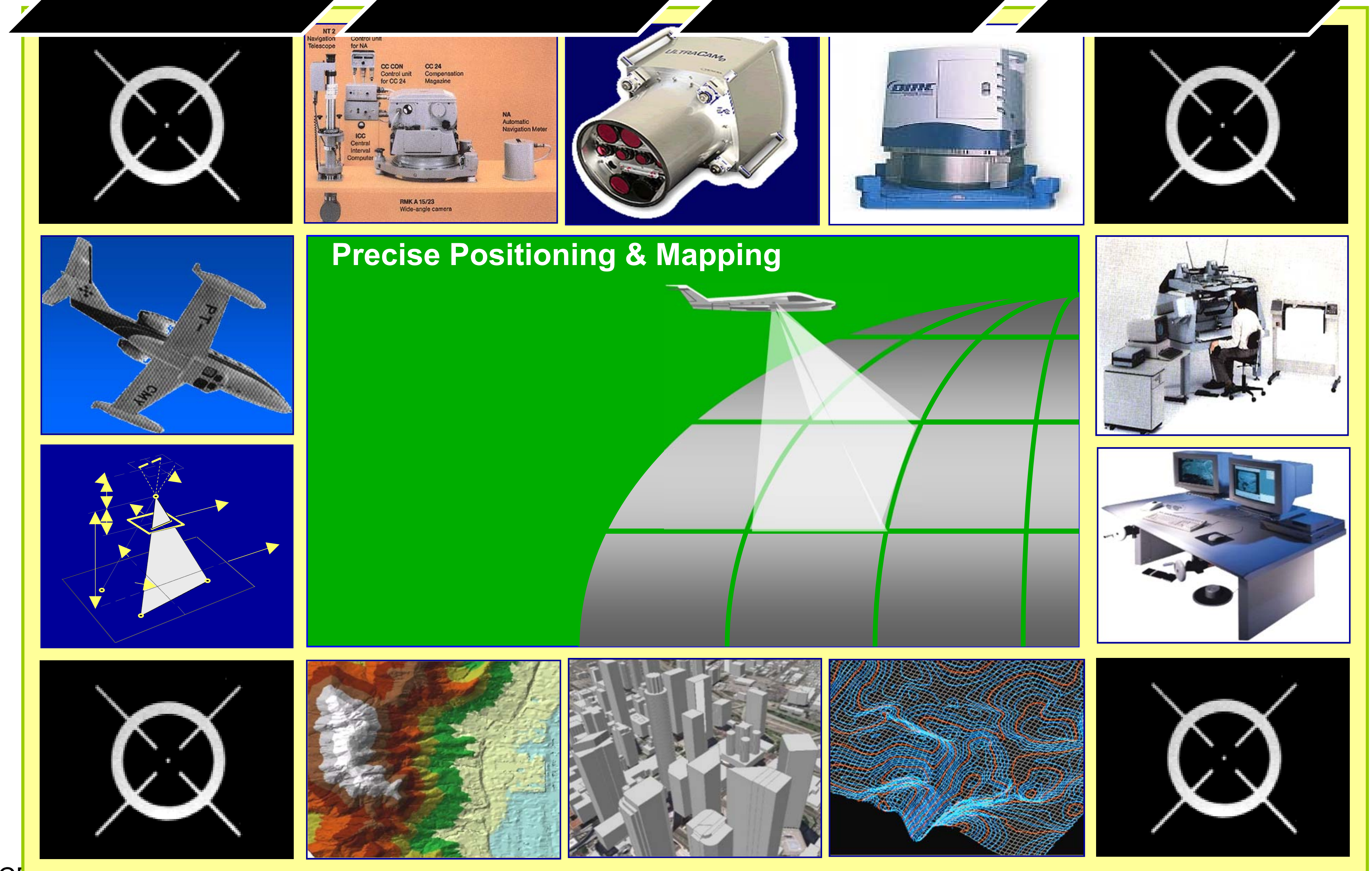
UAV Data Visualization

Image-LiDAR Interactive Visualization Environment (I-LIVE)



Precise Positioning & Mapping

Sensor → **Platform** → **Data Processing** → **Applications**

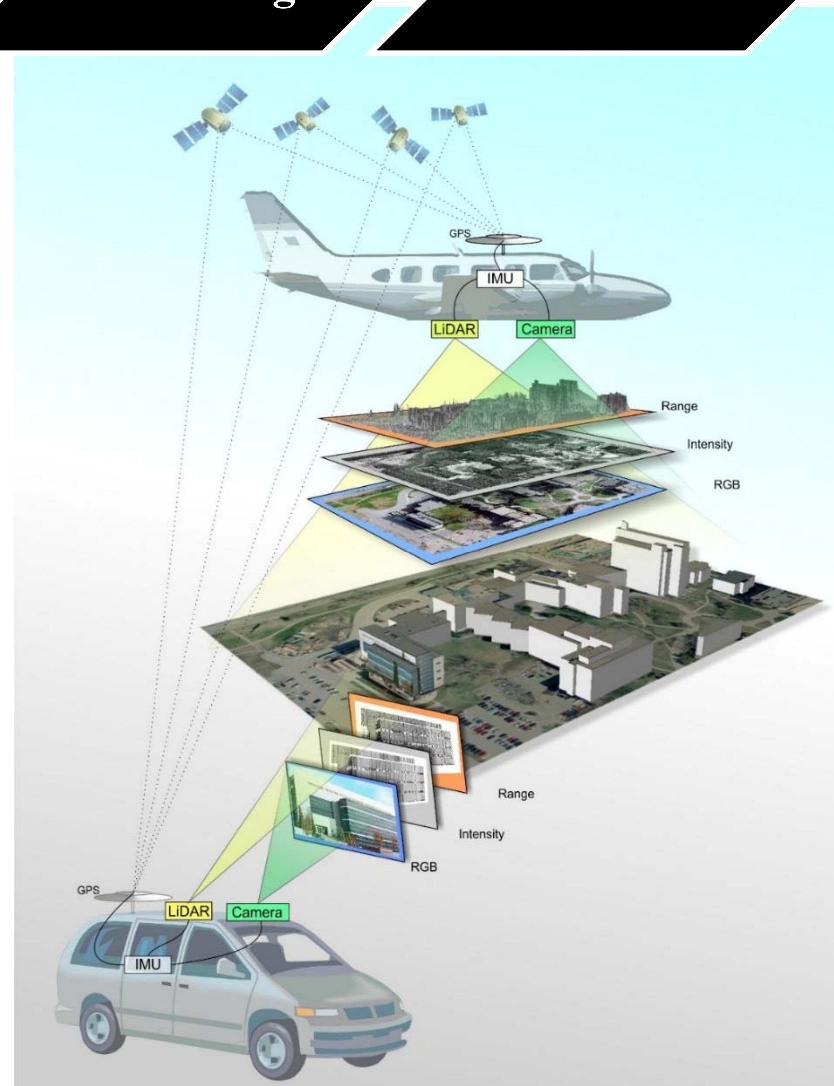


Precise Positioning & Mapping

Sensor → **Platform** → **Data Processing** → **Applications**

Multi-platforms & Multi-Sensor Systems:

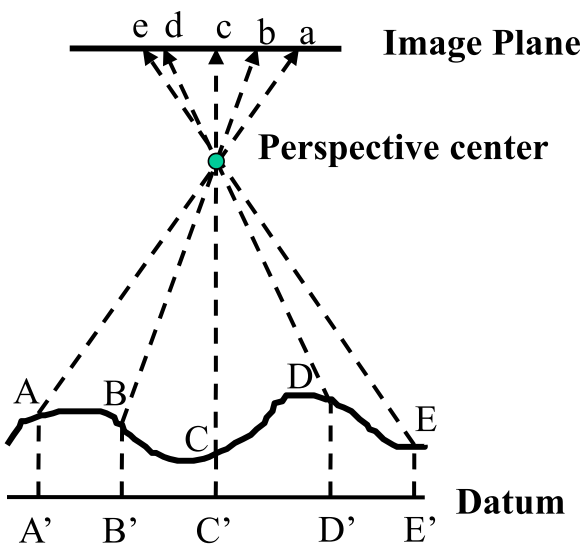
Motivating Diverse Applications



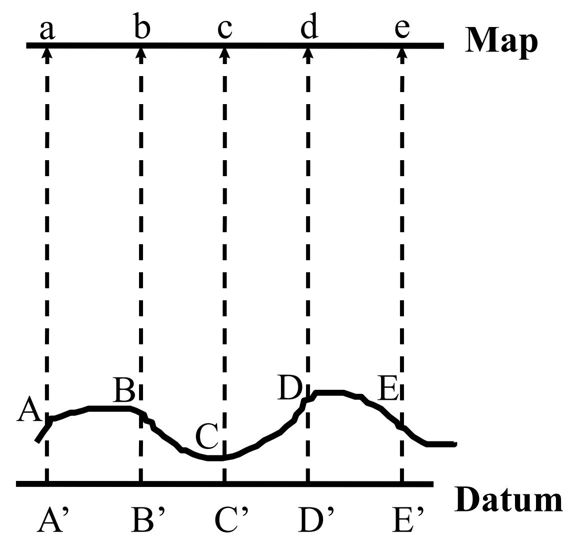
Photogrammetry

What are we trying to do?

An Image Versus a Map

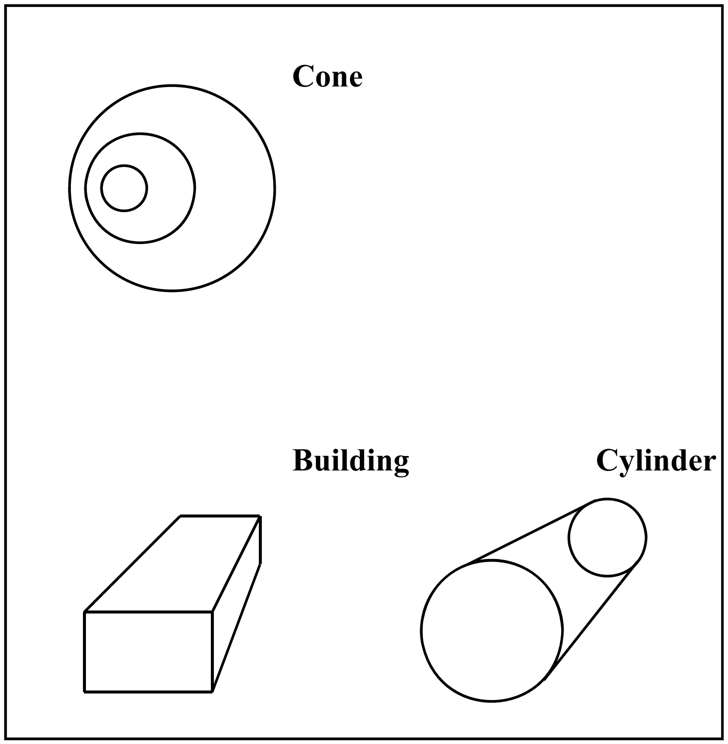


Image

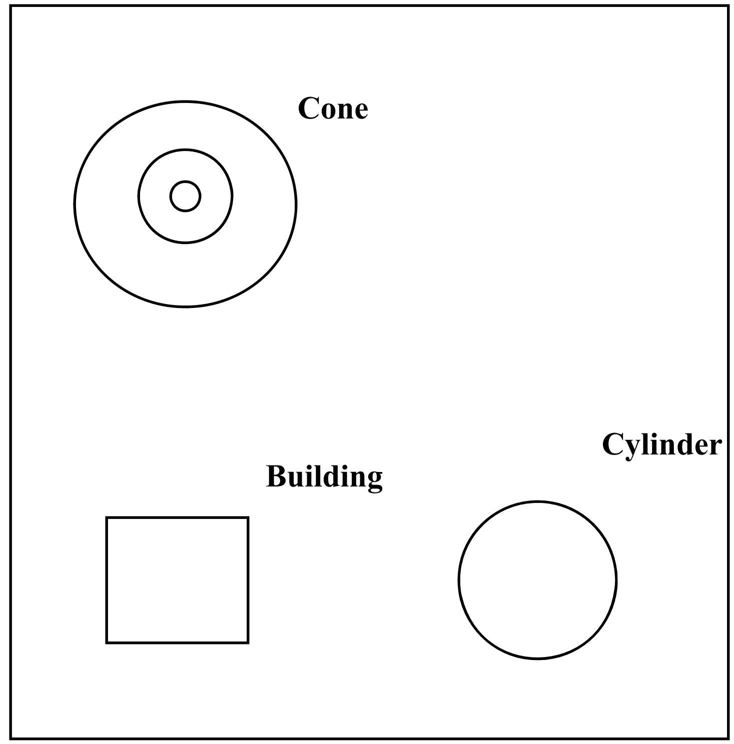


Map

Perspective Versus Orthogonal Projection



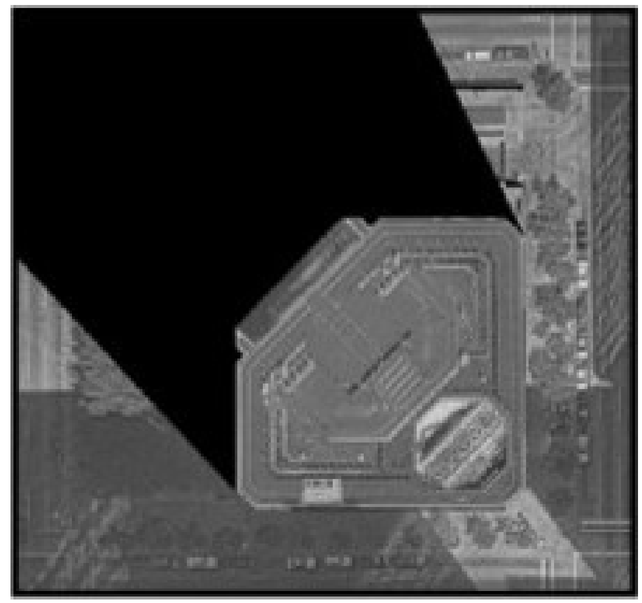
(A) Perspective Projection



(B) Orthogonal Projection

Perspective Versus Orthogonal Projection

Perspective Projection



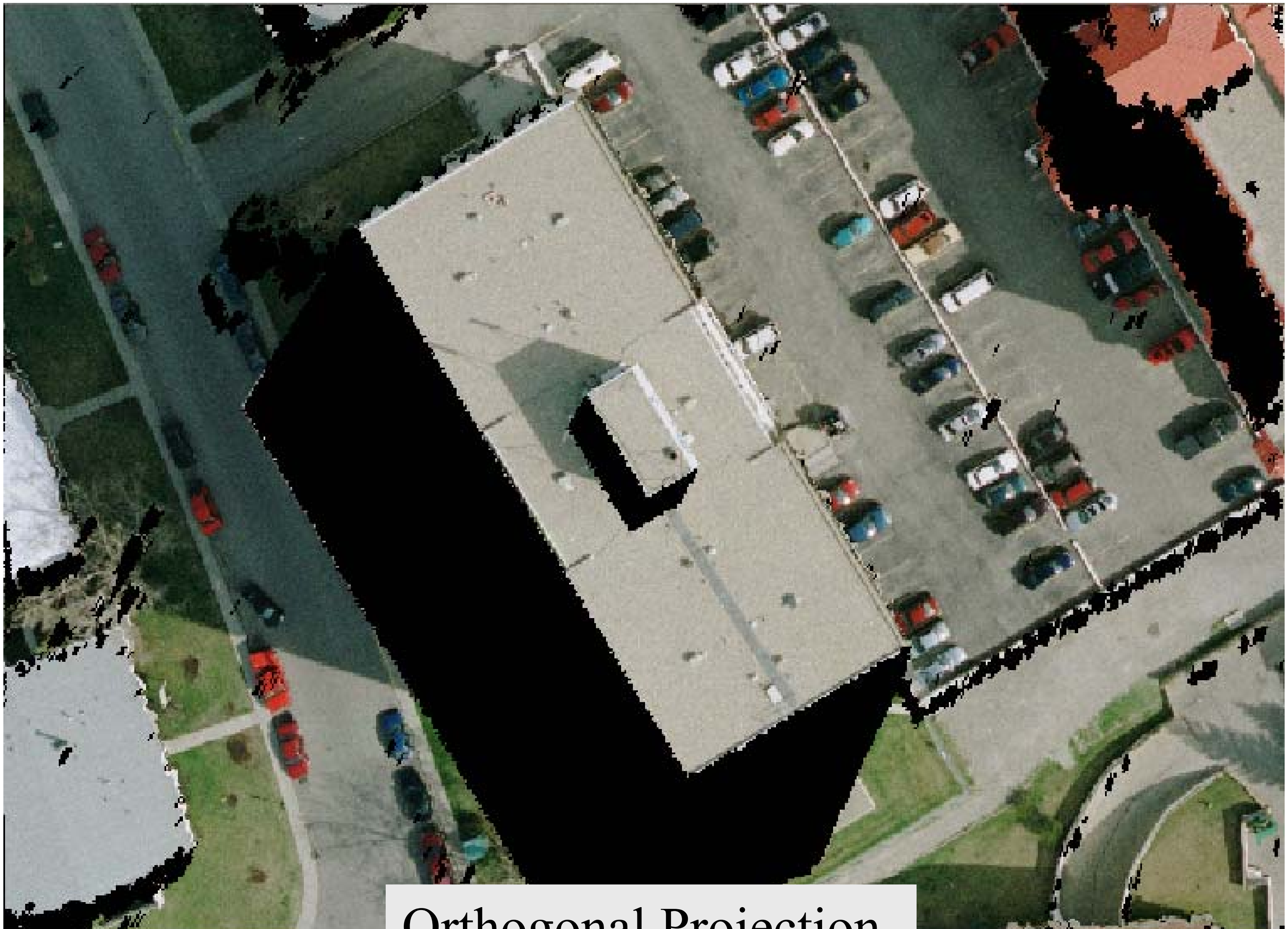
Orthogonal Projection

http://www.e-topo.com/etoposite/pages/ortho_photography.aspx

Perspective Versus Orthogonal Projection

Perspective Projection

Perspective Versus Orthogonal Projection



Orthogonal Projection

Perspective Versus Orthogonal Projection

Perspective Projection

Orthogonal Projection

Perspective Versus Orthogonal Projection

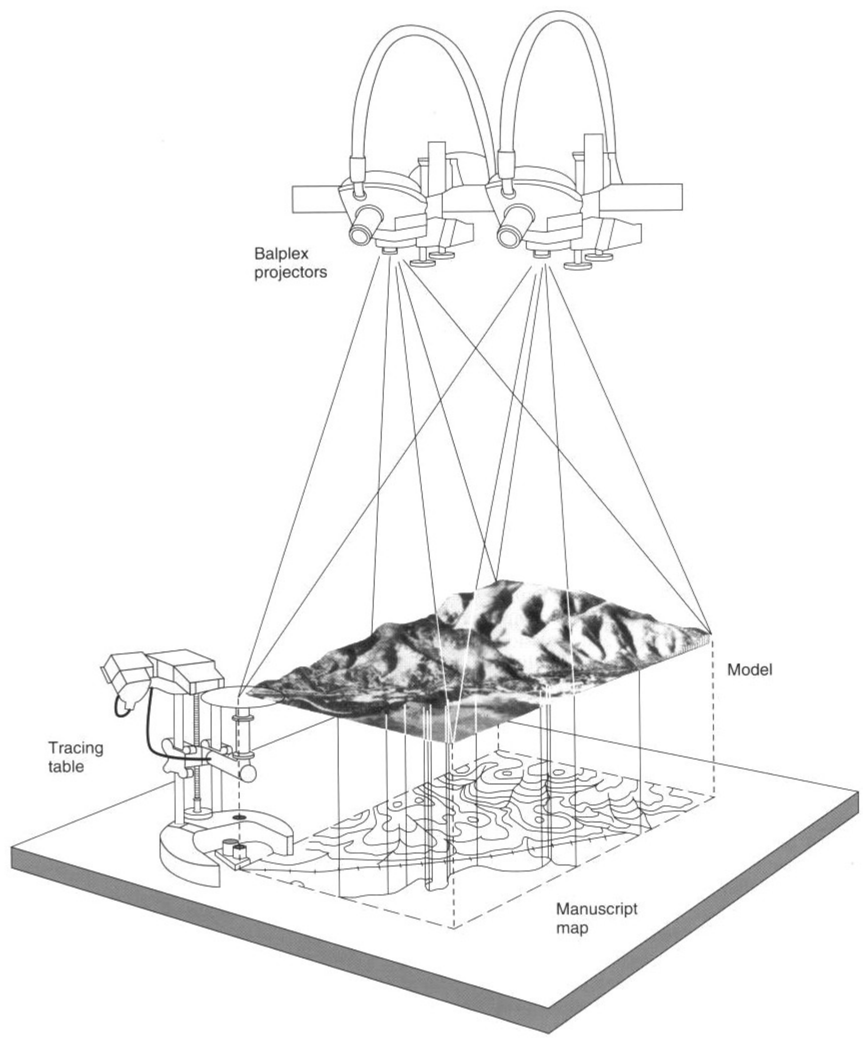
- Perspective Projection
- Orthogonal Projection

http://www.swisstopo.admin.ch/internet/swisstopo/en/home/products/images.html

An Image Versus a Map

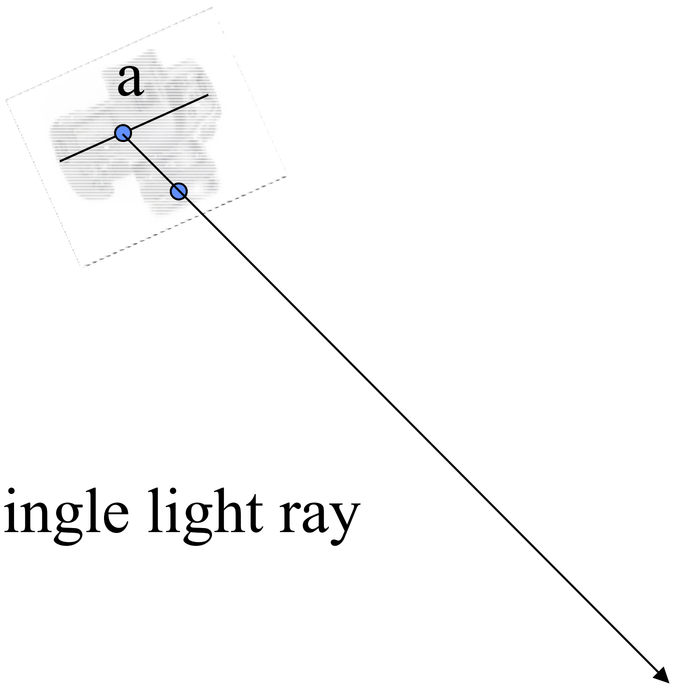
- Images have the following properties:
  - Perspective projection
  - Non-uniform scale
- Maps, on the other hand, have the following characteristics:
  - Orthogonal (parallel) projection
  - Maps have a uniform scale
- Objective of Photogrammetry:
  - How can we obtain orthogonally projected maps from perspective images?
  - How can we recover 3-D information from 2-D images?

Photogrammetry: 2-D → 3-D



Photogrammetric Triangulation

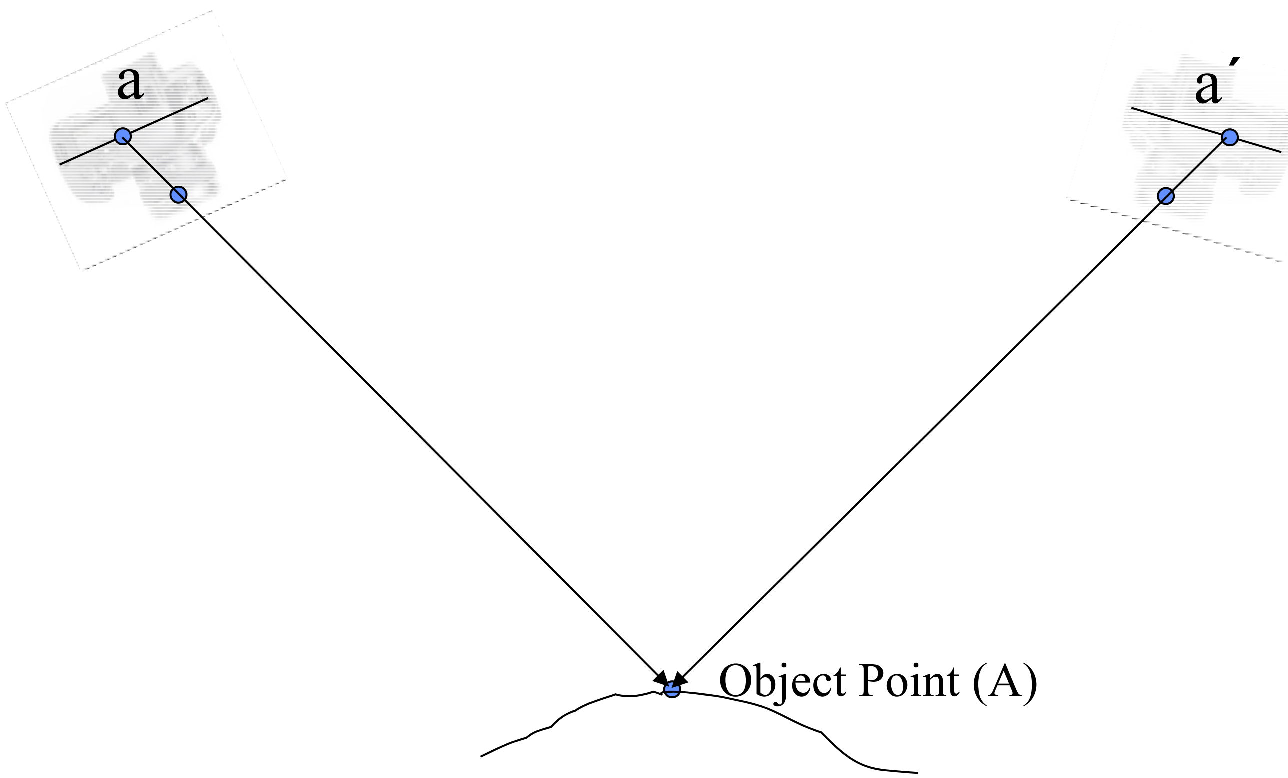
Object Space From Single Photograph



Single light ray

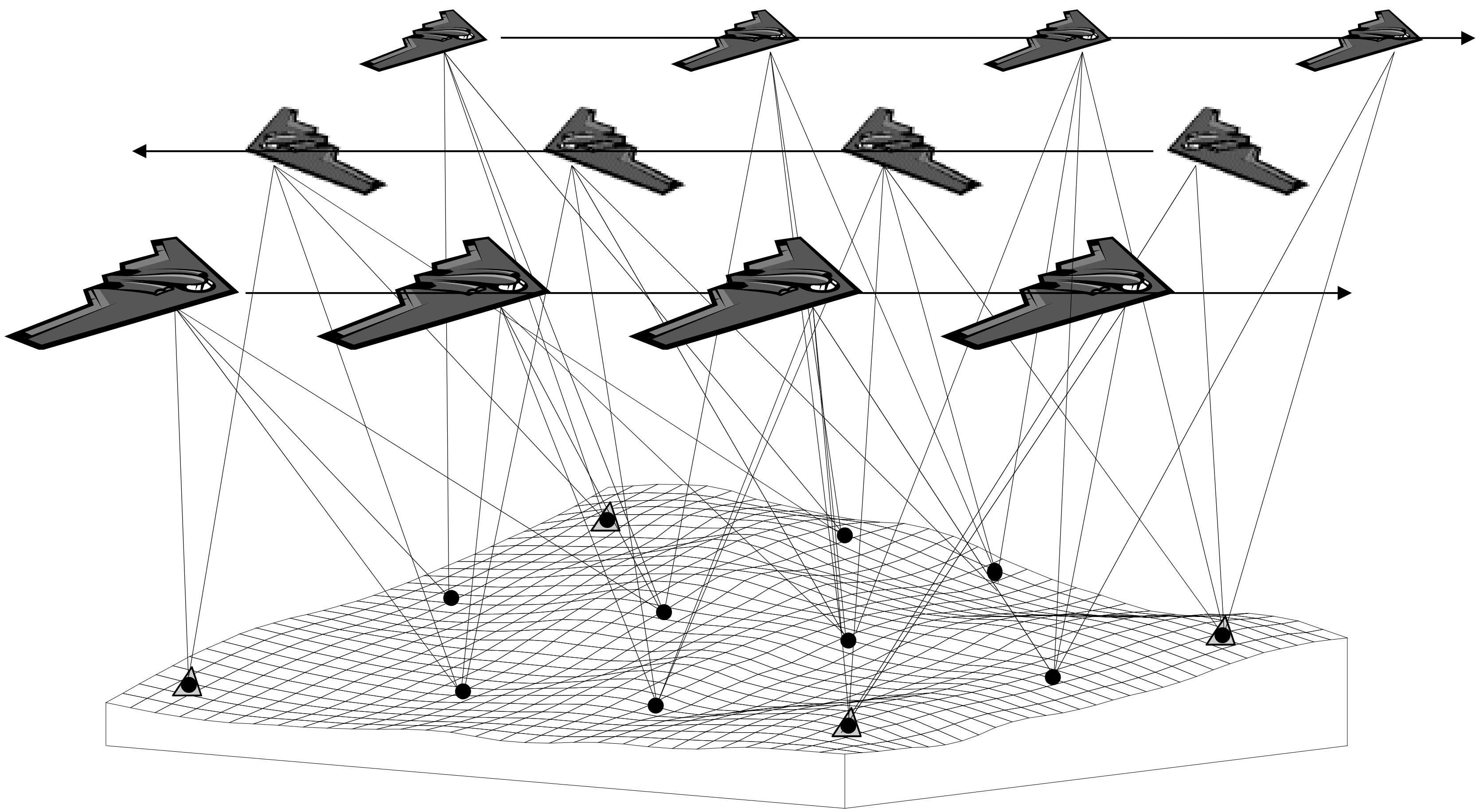
Object reconstruction is not possible

Object Space From Stereo Imagery



Object reconstruction is possible.

Object Space From Block Adjustment



Object reconstruction is possible.

Block of Aerial Images

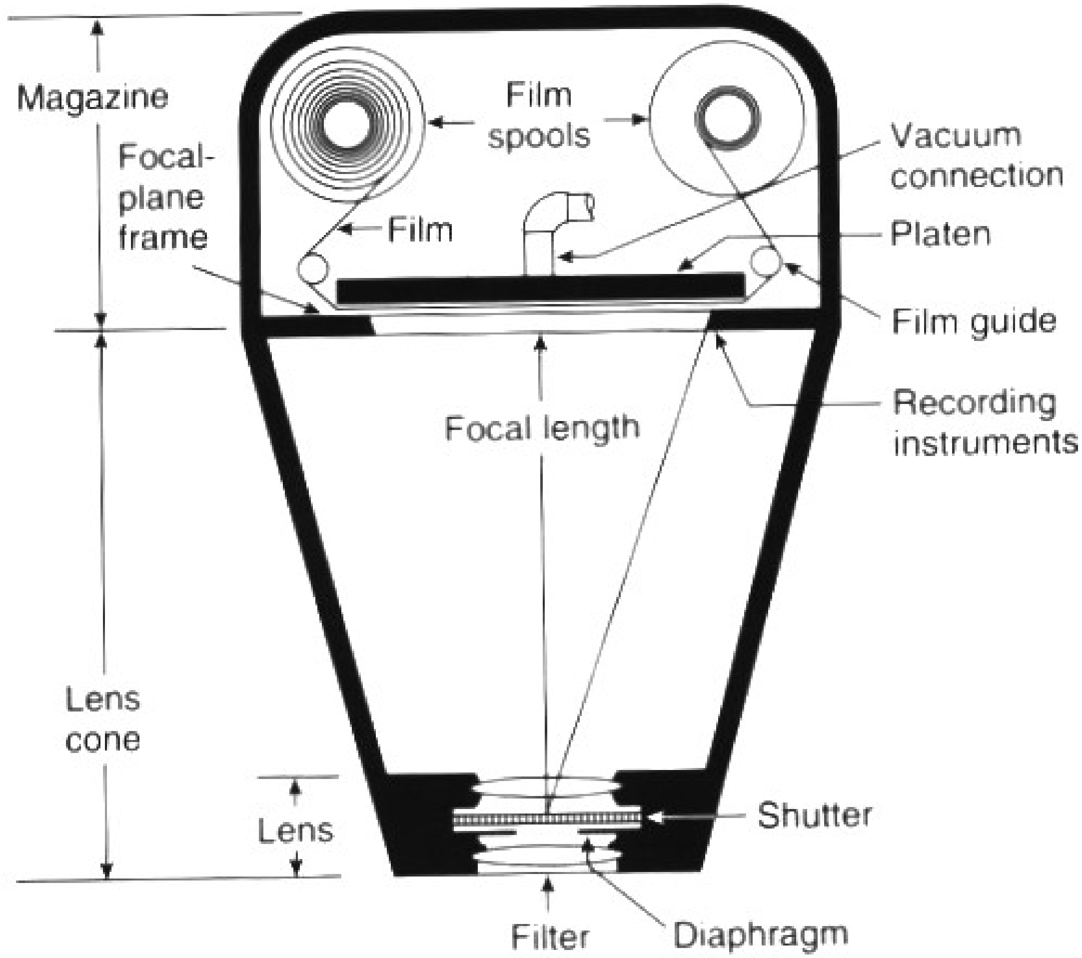
Photogrammetry

Data Acquisition

Basic Components of an Analog Camera

- Lens: collects light and brings it to focus at the image plane
- Aperture: opening that controls the amount of light entering the camera
- Shutter: determines the time period during which the film will be exposed to light
- Film: reacts to incident light to form the latent image
  - For digital Cameras, the film will be replaced by a CCD/CMOS array.
- Body: light proof housing of the camera mechanism

Analog Photogrammetric Cameras

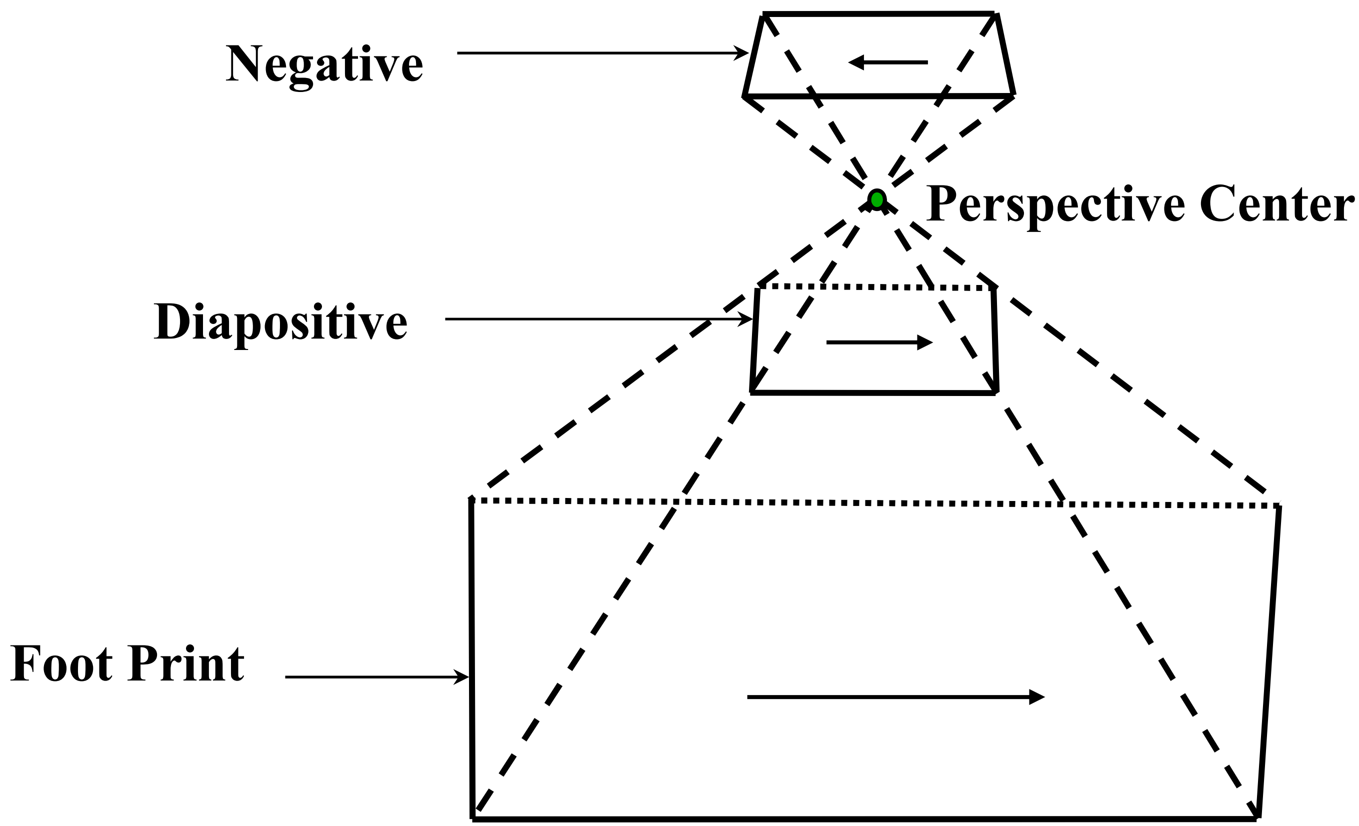


http://cmapspublic.ihmc.us/rid=1235786230204_282179246_24695/Photogramm%C3%A9trie%20-%20Cam%C3%A9ras%20a%C3%A9riennes%20analogiques.jpg

Analog Aerial Camera: RC30

http://www.kasurveys.com/Sensors.html

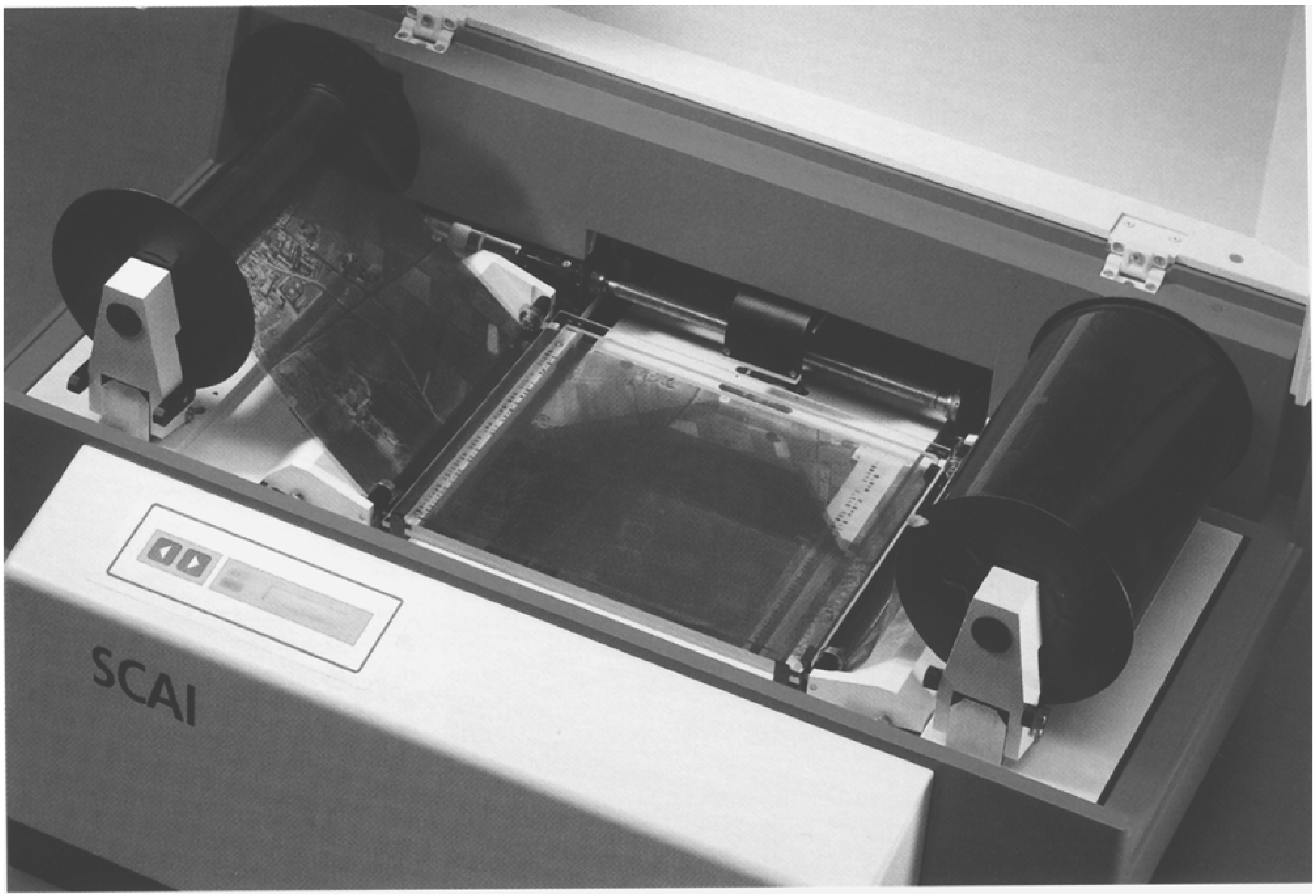
Image Formation



Digital Photogrammetry

- Digital photogrammetry utilizes digital imagery as an input.
- The rapid technological advances in computer hardware and software motivated the shift from analog to digital imagery.
- How can we get digital images?
  - Scanning analog images
  - Using digital camera

Photogrammetric Scanner

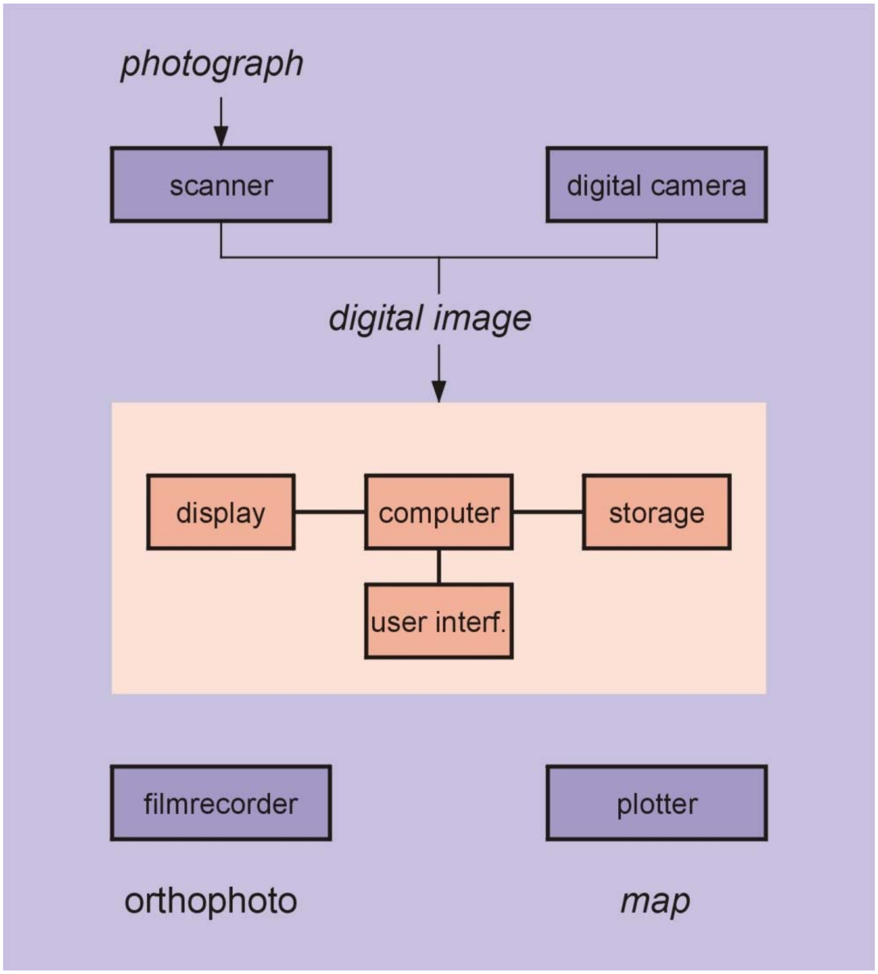


http://cmapspublic.ihmc.us/rid=1J5T5YMZV-15ZNLP5-1JMD/Balayeur%20optique.bmp

Digital Aerial Camera: DMC™

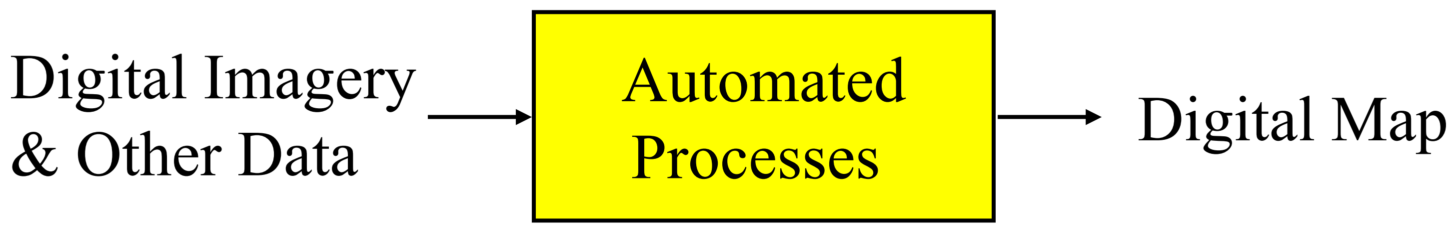
http://cmapspublic.ihmc.us/rid=1235786299998_244221932_24870/Photogramm%C3%A9trie%20-%20cam%C3%A9ras%20num%C3%A9riques.jpg

Digital Photogrammetric Environment



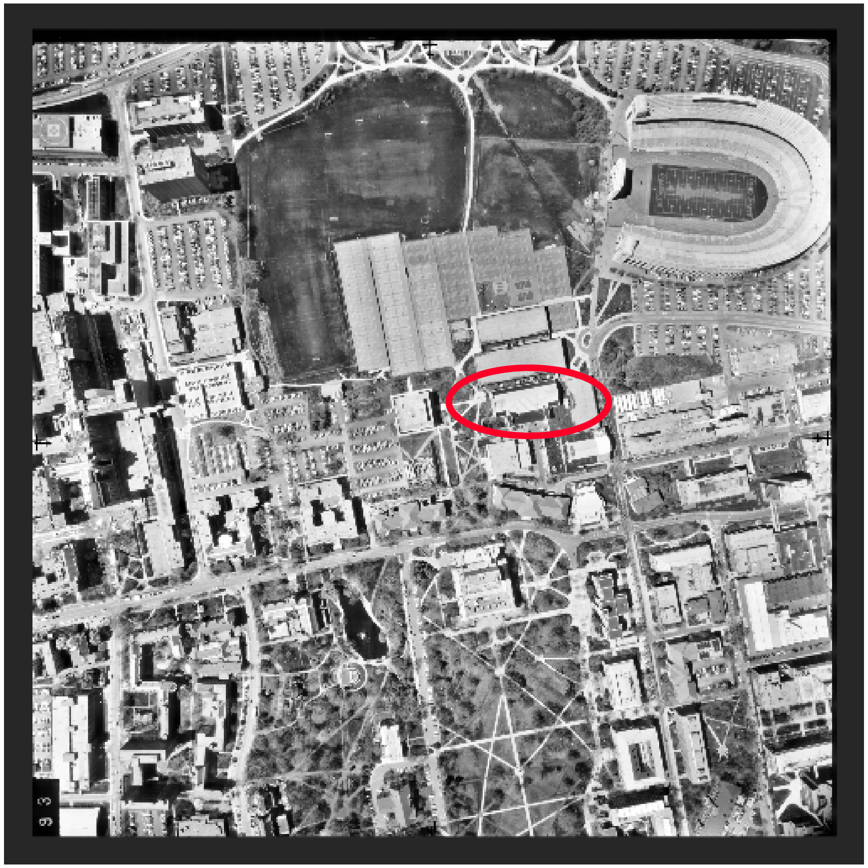
Digital Photogrammetry

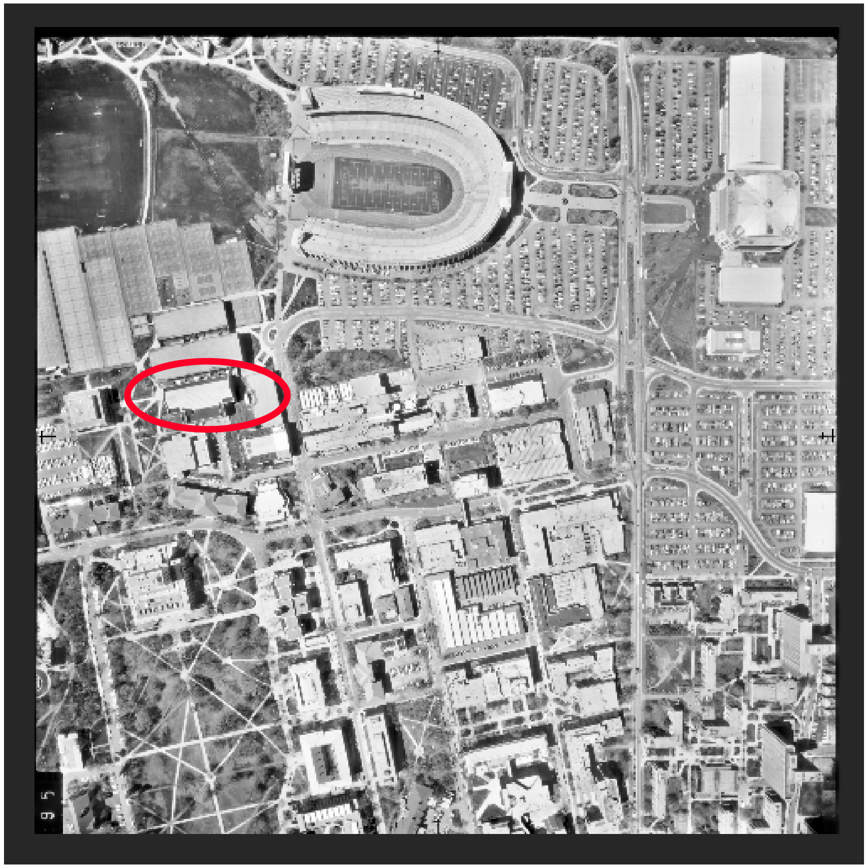
- Ultimate objective:
  - Create a map-making machine



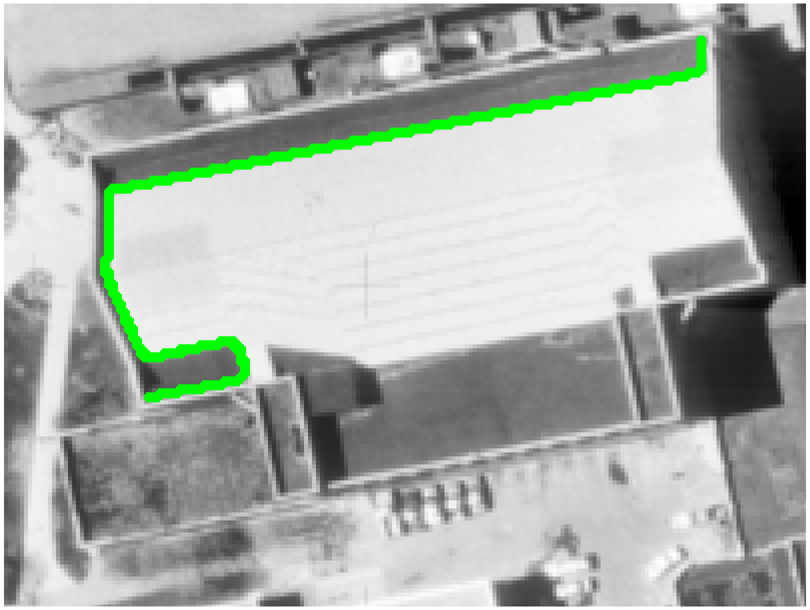
Deriving 3-D Information from 2-D Imagery

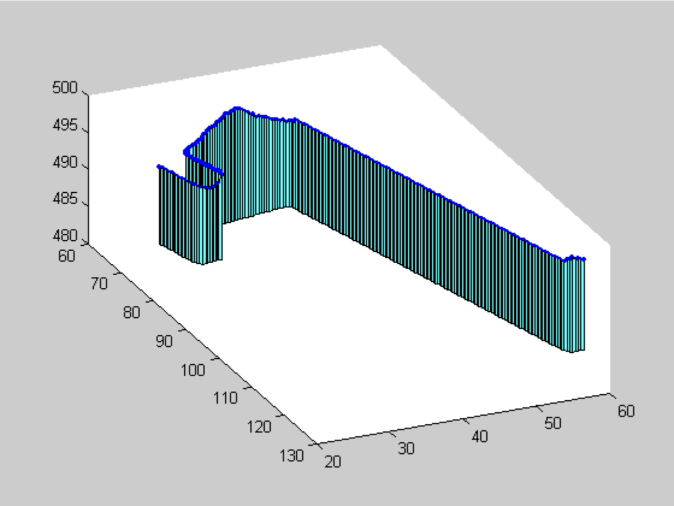
3-D Information from 2-D Imagery



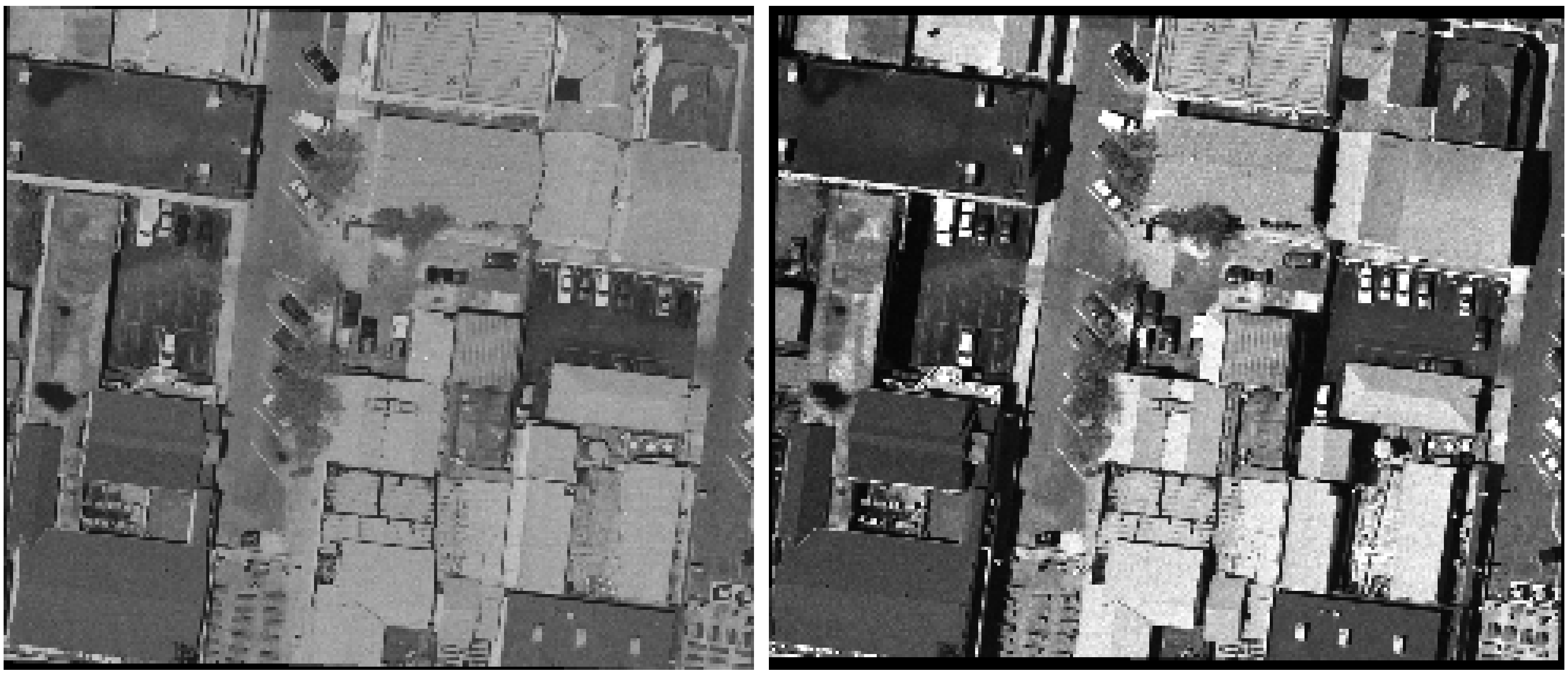


3-D Information from 2-D Imagery



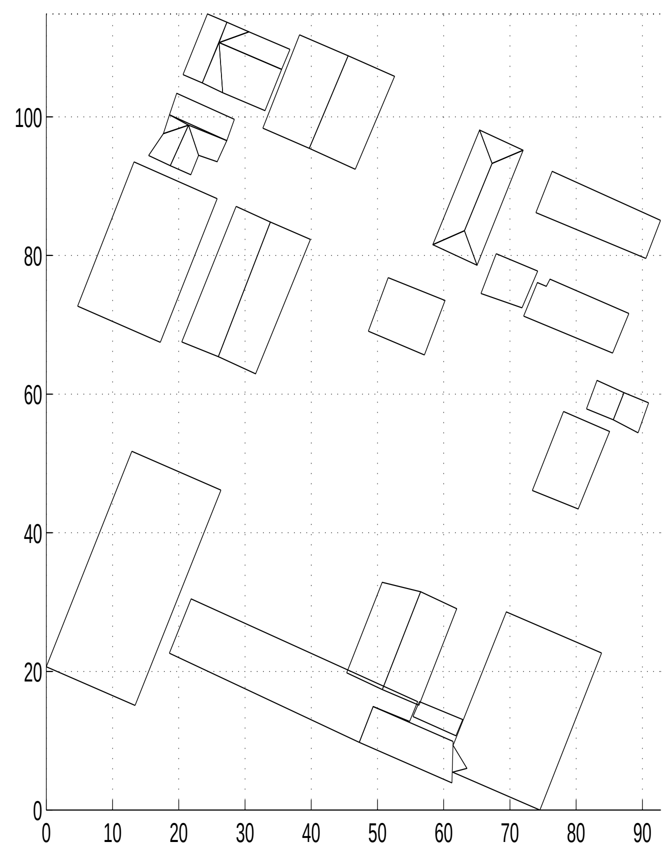


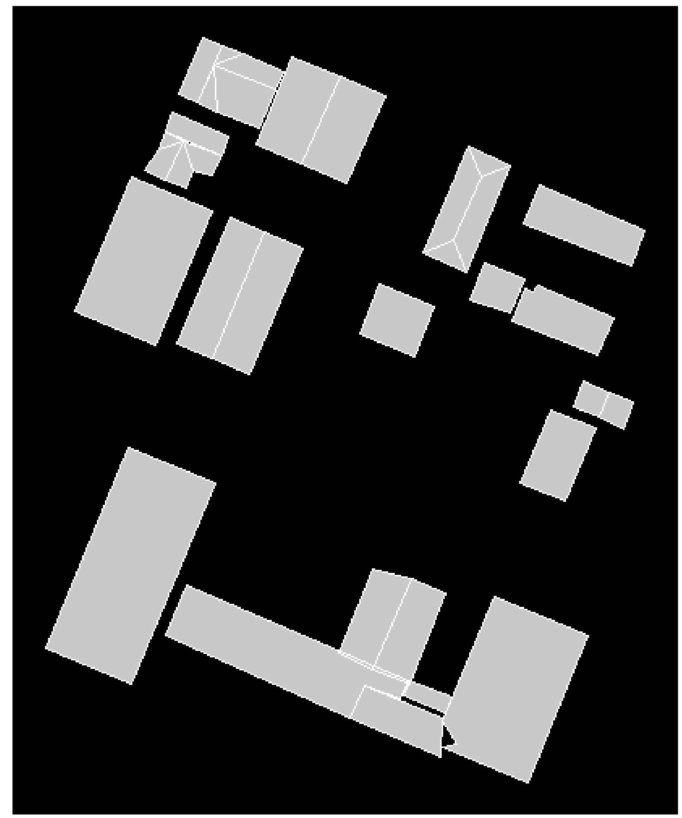
3-D Information from 2-D Imagery



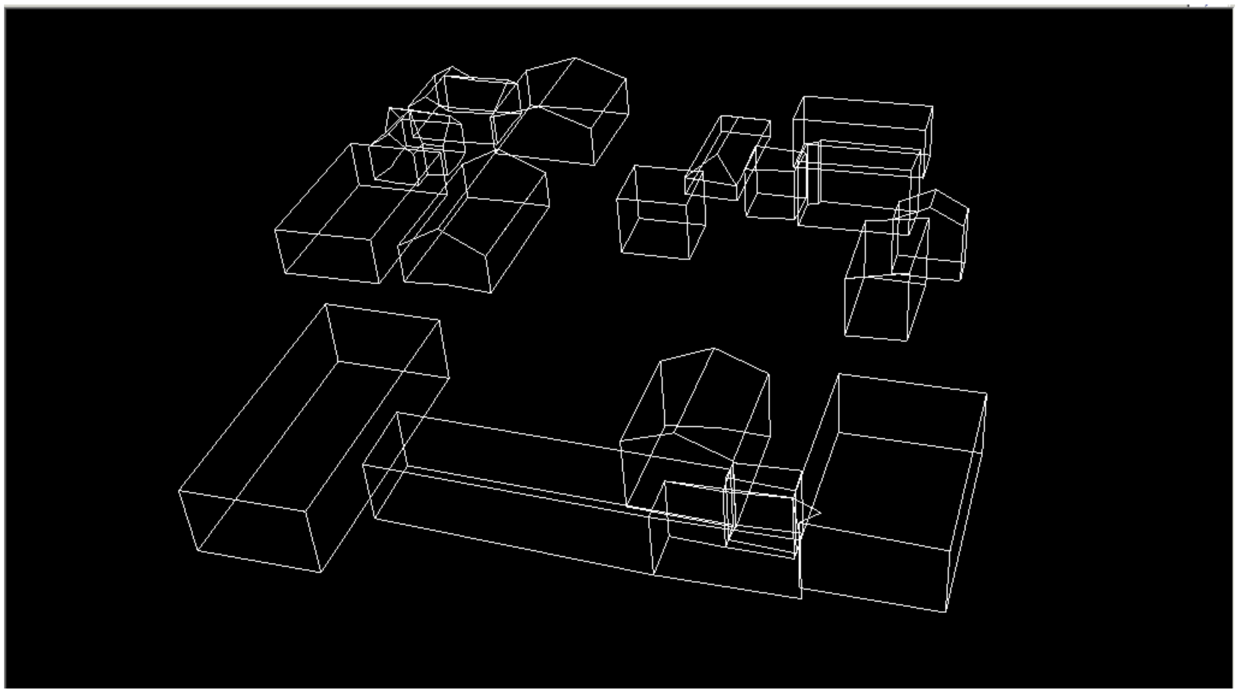
http://www.noobeed.com/nb_ex_image_histmatch.htm

3-D Information from 2-D Imagery





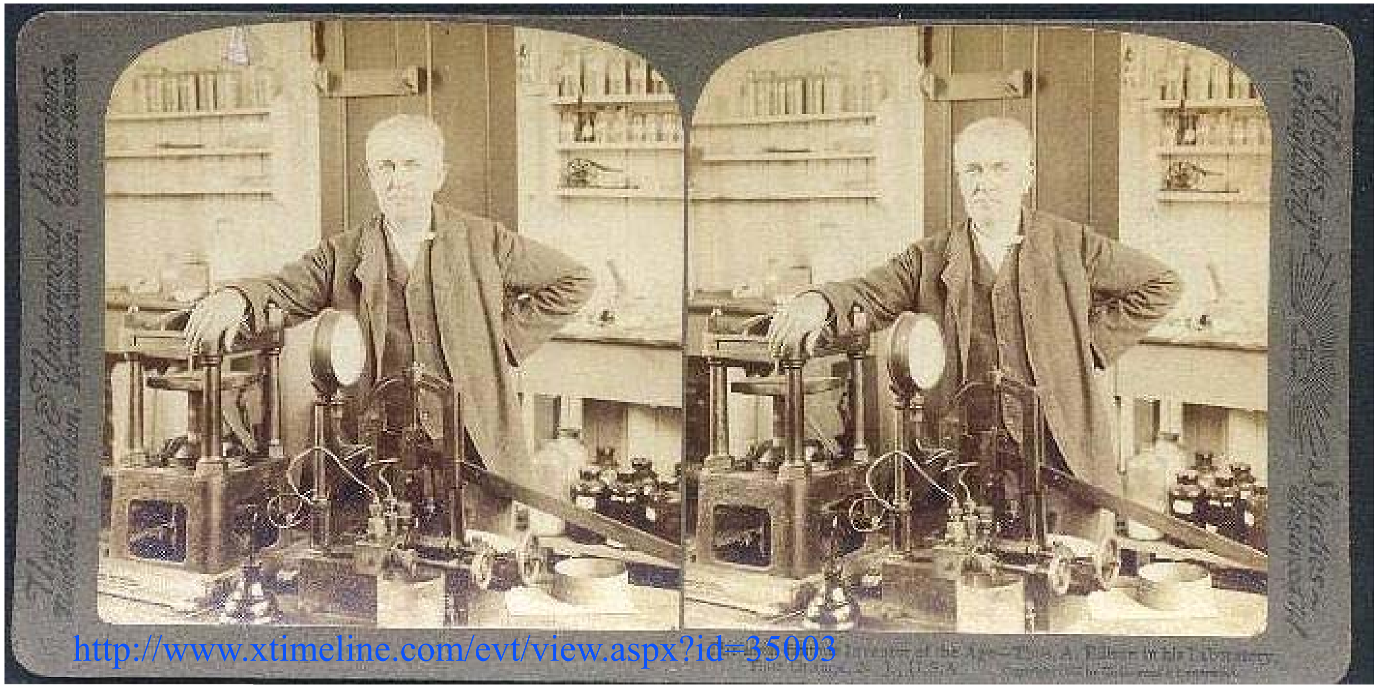
3-D Information from 2-D Imagery



3-D Information from 2-D Imagery: How?

- Requirements:
  - Having at least two images of the object of interest from different locations
  - Align the captured imagery to simulate their position and orientation (attitude) when capturing the imagery
  - For 3-D viewing, we need to allow each eye to see only one image.
    - Photogrammetric plotters
    - Anaglyph glasses
    - Polarized glasses
    - Synchronized eyewear

3-D Viewing Using 2-D Images



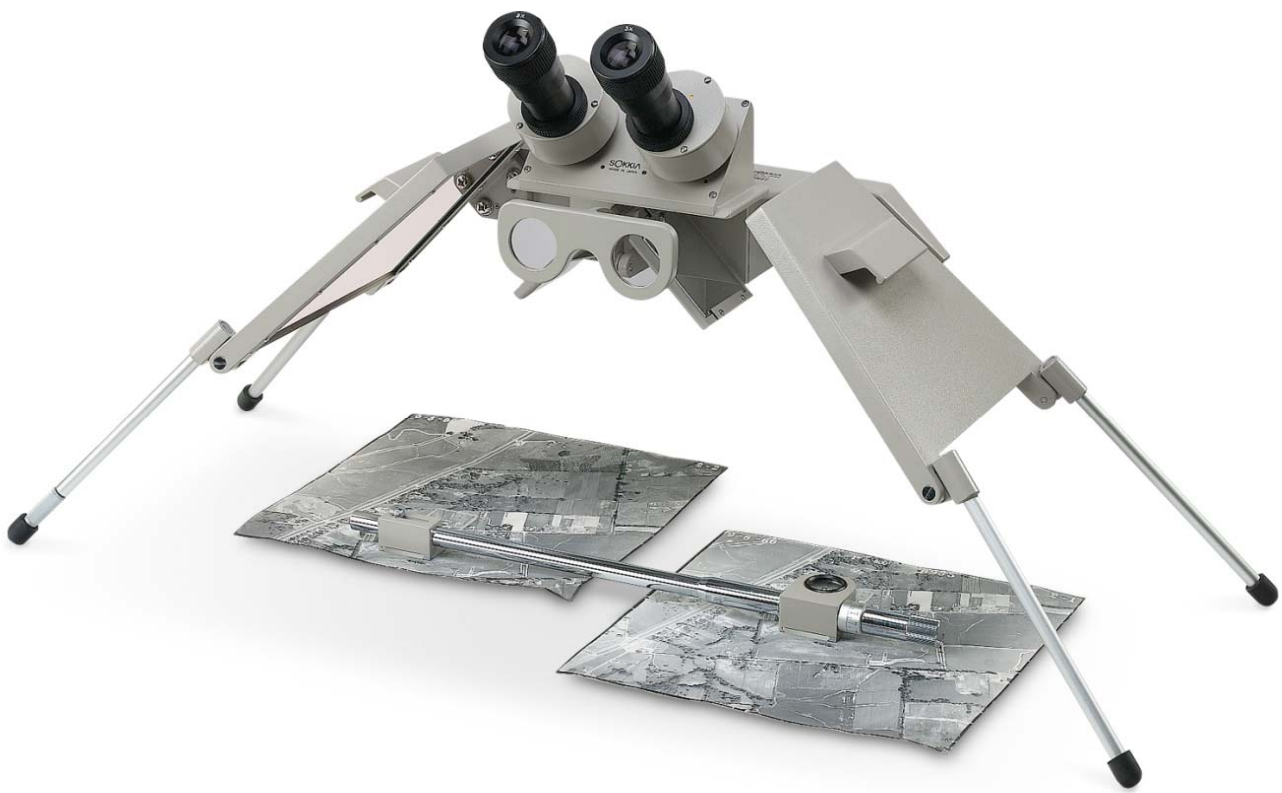
http://www.xtimeline.com/evt/view.aspx?id=35003

Thomas Edison

Pocket Stereo-Scope

http://www.gilai.com/product_810/British-Army-Pocket-Stereoscope-Type-D.

3-D Viewing Using 2-D Images



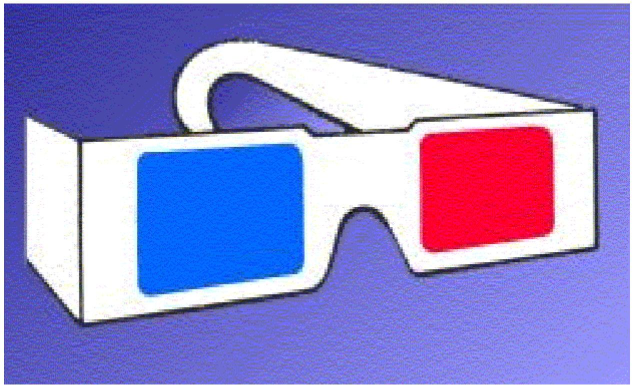
Mirror Stereo-Scope

http://www.forestry-suppliers.com/product_pages/View_Catalog_Page.asp?mi=27851

3-D Information from 2-D Imagery

http://cmapspublic.ihmc.us/rid=1235786206554_857097895_24622/Photogramm%C3%A9trie

3-D Information from 2-D Imagery

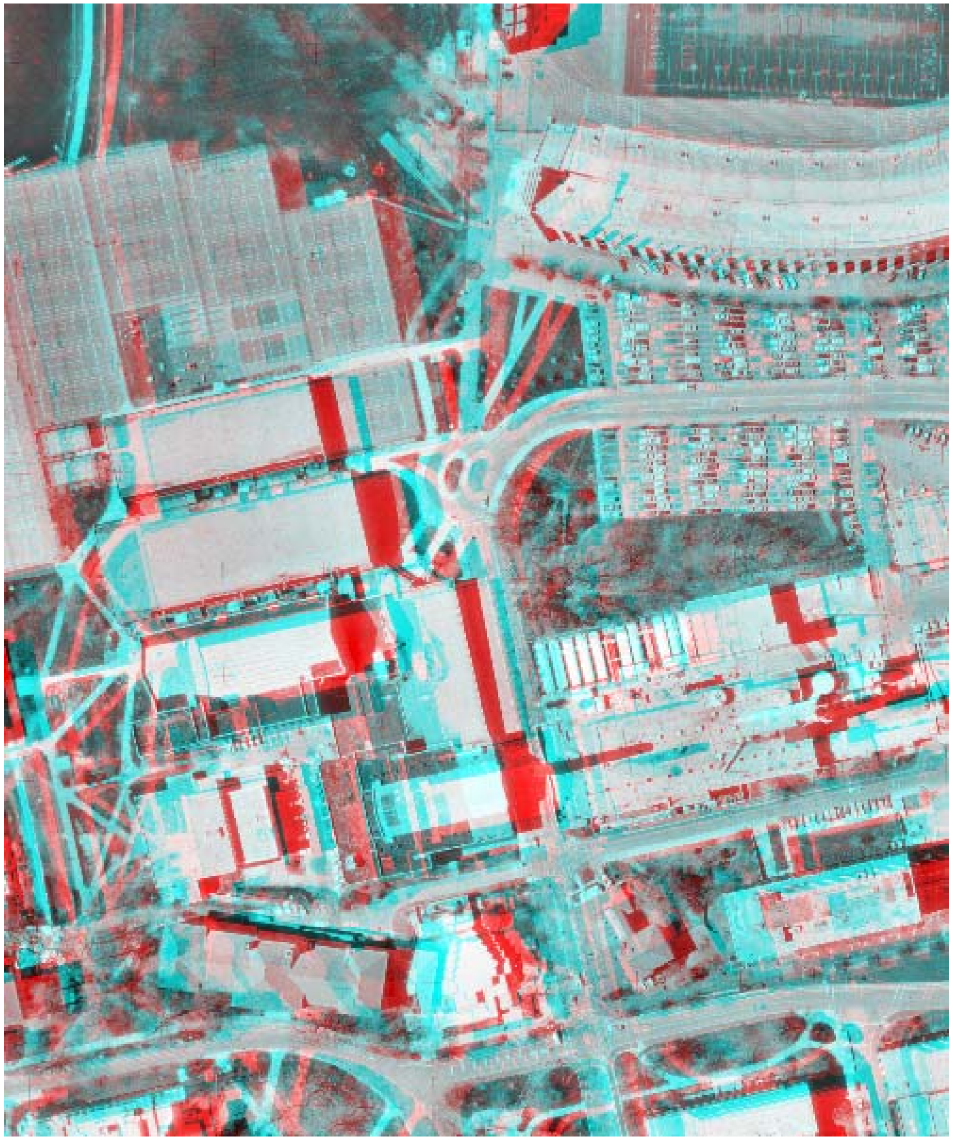


3-D Viewing Glasses

http://cmapspublic.ihmc.us

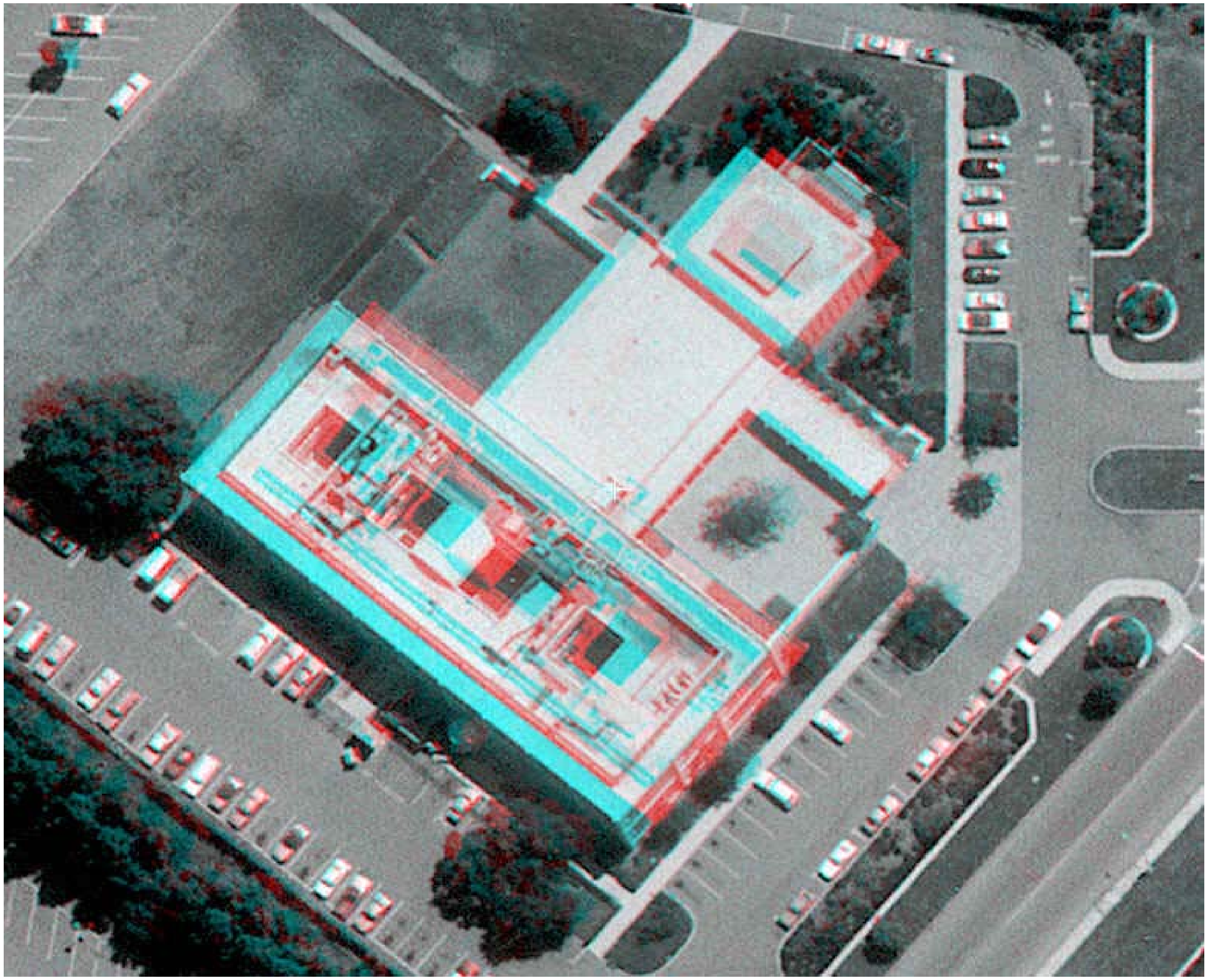
3-D Model

3-D Information from 2-D Imagery



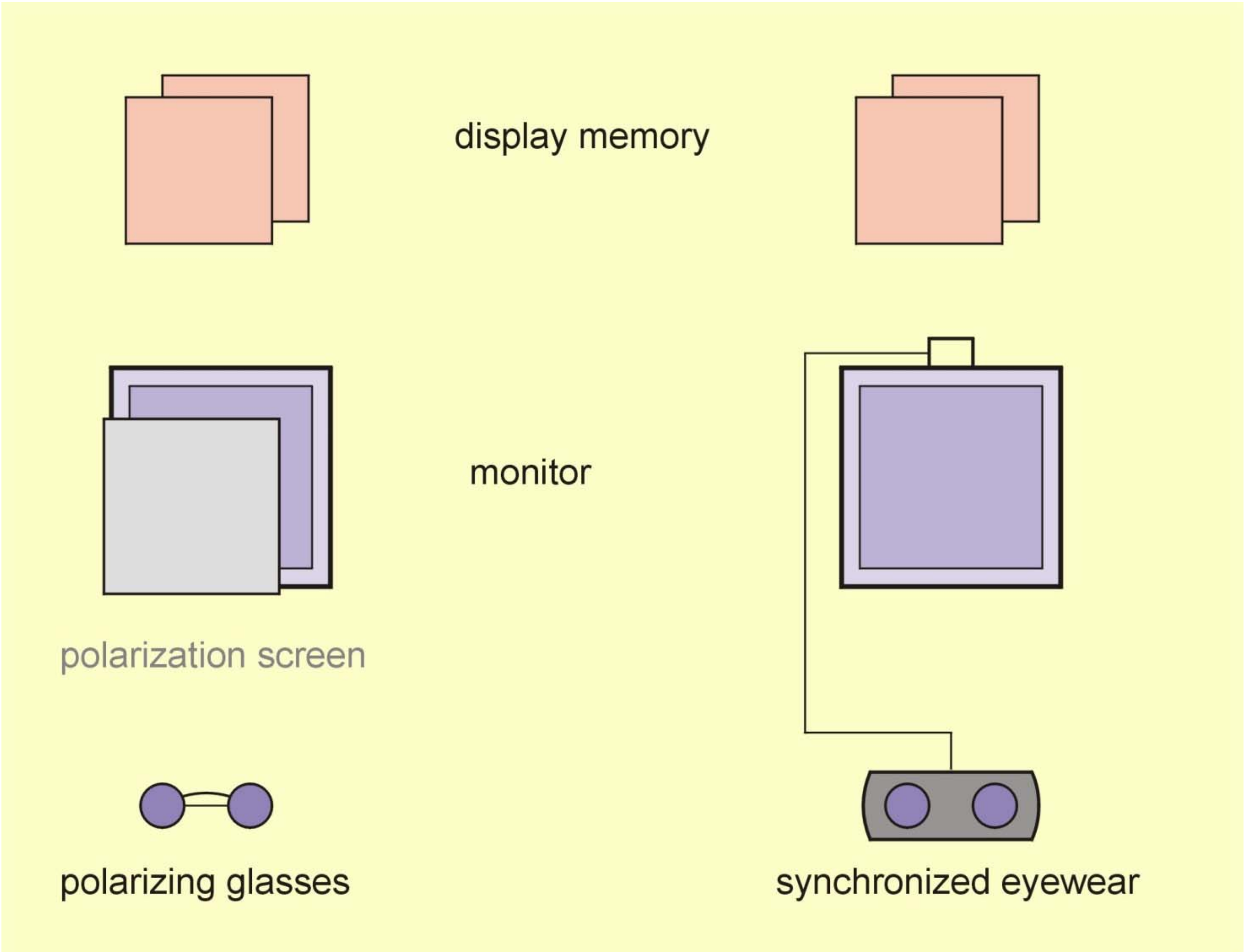
http://cmapspublic.ihmc.us

3-D Information from 2-D Imagery



http://cmapspublic.ihmc.us/rid=1235786356595_1534539563_25009/Reproduction%20st%C3%A9r%C3%A9oscopique%20-%20Anaglyphes.jpg

Stereo Viewing with Temporal Separation



Stereo-Viewing

Polarized Glasses

http://cmapspublic.ihmc.us/rid=1235786467027_1563676685_25243/Reproduction%20st%C3%A9r%C3%A9oscopique%20-%20Filtres%20polaris%C3%A9s.jpg

Stereo-Viewing

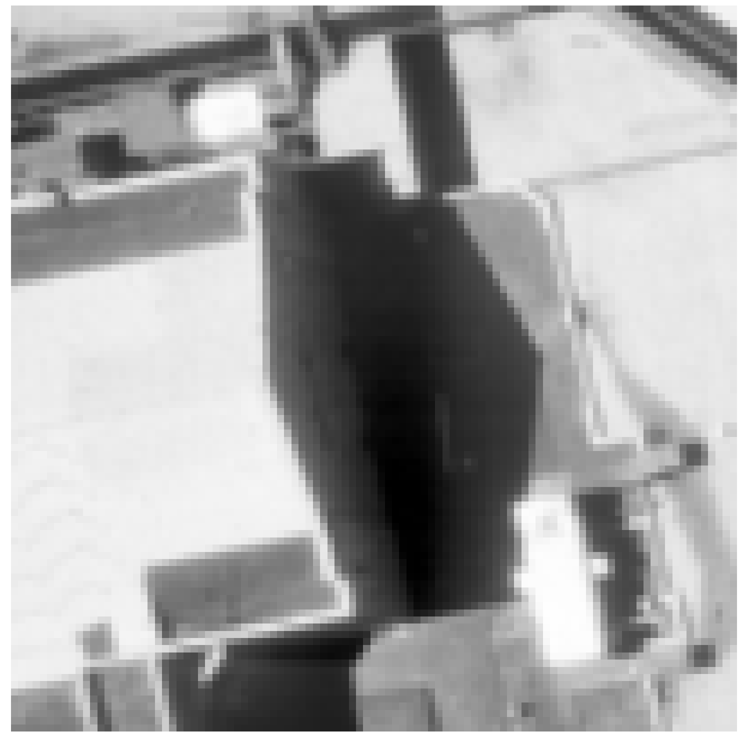
http://cmapspublic.ihmc.us/rid=1235786345425_1692683138_24990/Reproduction%20st%C3%A9r%C3%A9oscopique%20-%20St%C3%A9r%C3%A9o-image%20alternateur.jpg

Synchronized eyewear

Automation in Photogrammetry

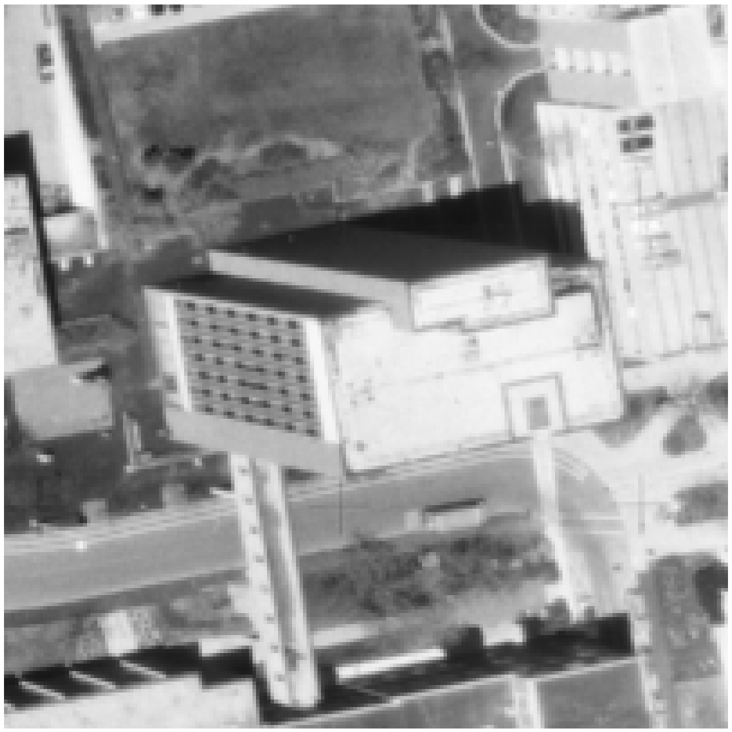
- Current photogrammetric research is focusing on automating the derivation of 3-D information from 2-D imagery.
- The most important task for the automation procedure is:
  - Automatic identification of conjugate points in overlapping images (Matching Problem)
- Solving the matching problem is not a trivial task.
  - Why?

Automatic Derivation of Conjugate Points



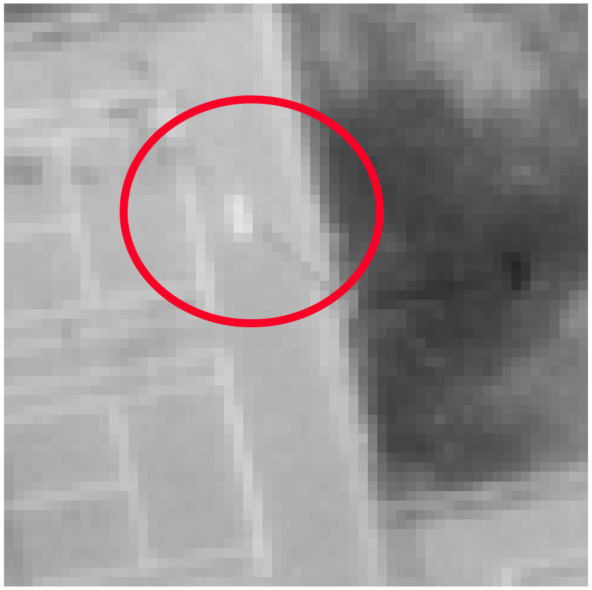
Occlusions

Automatic Derivation of Conjugate Points



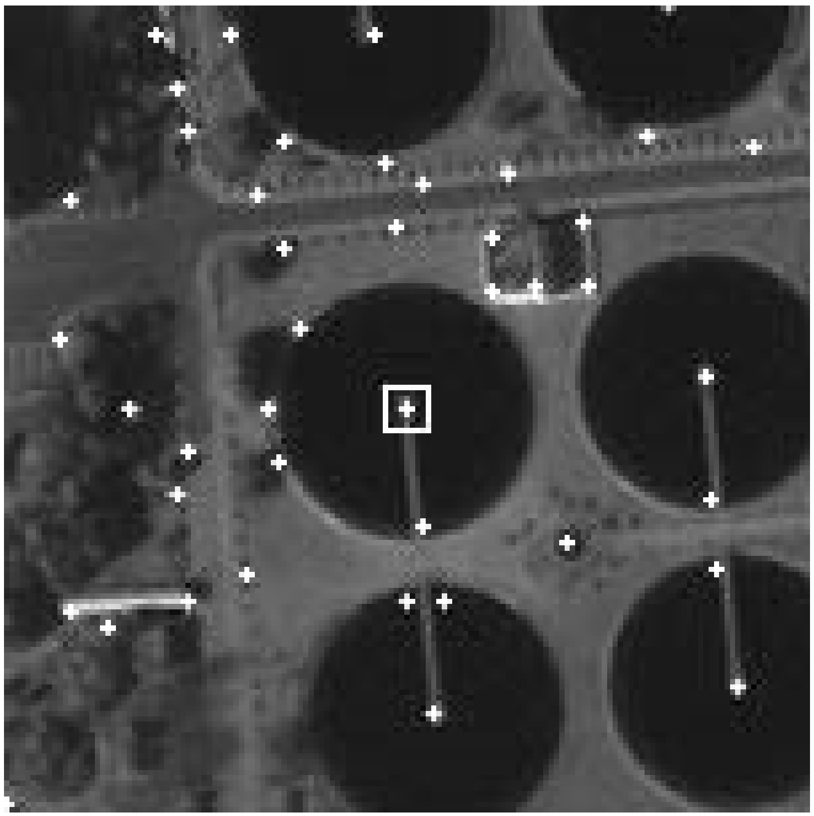
Occlusions & Foreshortening

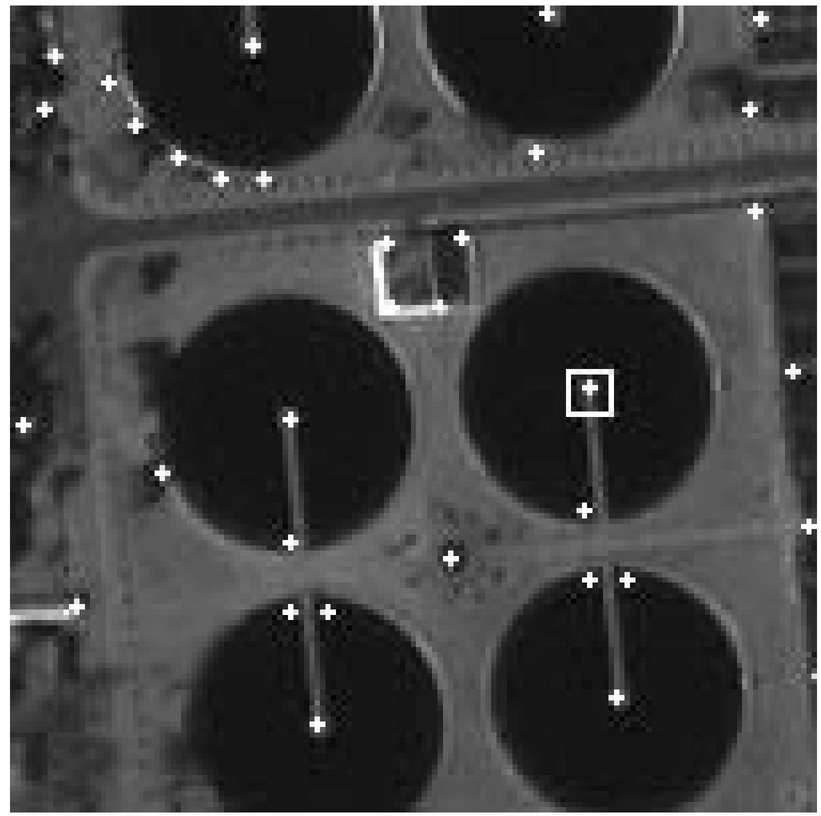
Automatic Derivation of Conjugate Points



Relief displacement (different background)

Automatic Derivation of Conjugate Points





Repetitive Patterns

Necessary Tools

- Understand the image formation process:
  - Electro magnetic radiation (Chapter 2)
  - Optics (Chapter 3)
  - Film development (Chapter 4)
- Understand the necessary image processing techniques:
  - Mathematical principles behind the reconstruction process (Chapters 5-9)
  - Direct geo-referencing (Chapter 10)
  - Photogrammetric products – DEM & orthophotos (Chapters 11 & 12)