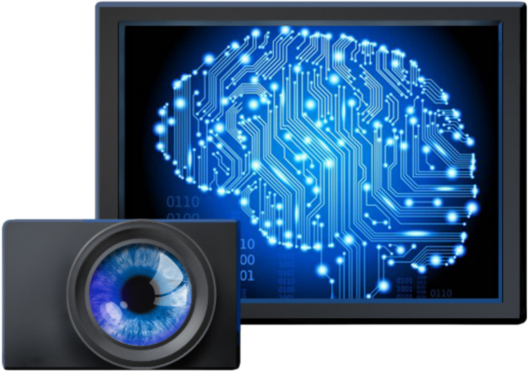
Image Processing

Bachelor Robotics

Technical University of Applied Sciences Würzburg-Schweinfurt



General Information

- E-Learning

  `https://elearning.thws.de/course/view.php?id=25100`

- Lecturer: Volker Willert

  Campus II: 9.1.08

  e-mail: `volker.willert@fhws.de`

  phone: 09721-940-8598

- Office hours: by appointment

Schedule of Lecture

Combined Lecture & Exercise

Schedule

- Start: Today Wednesday, 11. 10. 2023
- End: Wednesday, 24. 01. 2024
- Duration: 14 Weeks (excluding bank holidays)
- Number: 28 Lectures, 1,5 hours each
- Timeslot: Wed 8:15-09:45, Campus I: 5.1.01
- Timeslot: Fri 10:00-11:30, Campus II: 9.E.26

Exam

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Type of exam and examination-relevant material

- Slide contents are relevant for the exam
- Exercise contents are relevant for the exam
- Blackboard notes are relevant for the exam
- Type of examination: written
- Exam date: to be announced!
- Exam duration: 90 minutes
- Resources: formlary as hand-out

Motivation of the course

Here we go ...

www.leben-lieben-wachsen.com

How do machines see our world?

Richard Hamilton

I am not yet convinced that it will one day be possible to build a computer for image processing that is equal to the brain of Velázquez, ...

Quote: Richard Hamilton, Malen nach Zahlen, 2007.

How do machines see our world?

Diego Velázquez

I am not yet convinced that it will one day be possible to build a computer for image processing that is equal to the brain of Velázquez, ...

Quote: Richard Hamilton, Malen nach Zahlen, 2007.

Motivation of the course

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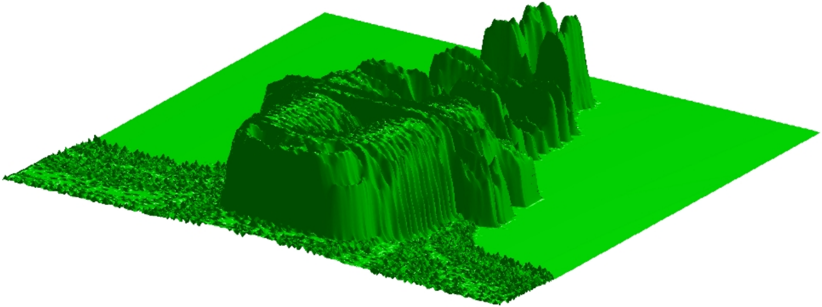
Five Questions

1. What information is contained in an image?
2. How is an image processing system structured?
3. What is the core problem of image processing?
4. How is an image processing problem solved?
5. Why does a roboticist need image processing?

Motivation of the course

What do you see?



Motivation of the course

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What information is contained in an image?

Qualitative features

&

Quantitative features

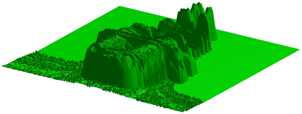
...

...

- Type of information?
- Type of representation?

- Solving recognition tasks

- Solving measurement tasks



- e.g. automation of visual inspection processes

- e.g. non-contact, dimensional metrology

Motivation of the course

What information is contained in an image?

An image contains information about the

- shape (contours, edges), the
- appearance (textures, colours) and the
- lighting (reflexions, shadows)

of the scene, including the background and objects.

Most of the information is contained in the relationships between neighboring values and not in the individual absolute values of the pixels themselves.

The information of an image can be used to solve

- 2D & 3D measurement tasks and
- 2D & 3D pattern recognition tasks

simultaneously.

Motivation of the course

What information is contained in an image?

Compared to other sensors(Lidar [60-300 KByte/sec], Radar [300 KByte/sec]), cameras [47-61 MByte/sec] are

- very high-resolution and can therefore show
- details of complex scenes

Only radar works in fog!
. In heavy rain all sensors fail ...

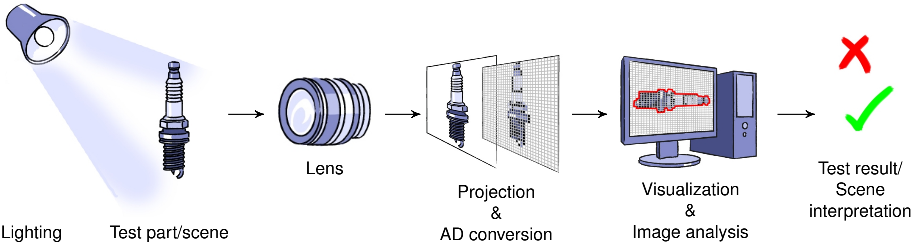
... moreover, they are inexpensive.

Source: Ammon Shashua CVPR 2016 (Mobile Eye)

Source: www.cbcity.de

Motivation of the course

Components of an image processing system



Complex dependencies between

- environment
- test part / scene
- hardware
- software

▶▶▶ Large number of influencing variables

▶▶▶ Many different realization possibilities

Motivation of the course

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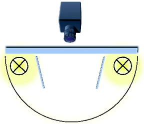
Lighting - highlight features

Optimal contrast

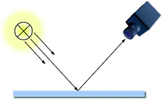
- illumination type & wavelength range of light source
- light sensitivity of camera
- reflection & absorption of test part

Transmitted light



Diffuse lighting

Incident light



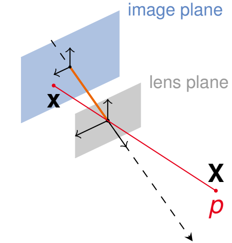
Bright field illumination

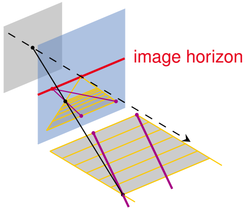
Motivation of the course

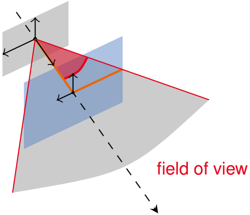
Projection - loss of information

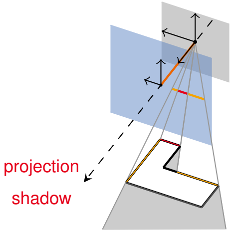
Considering geometry:

- distance
- angle
- field of view
- occlusions
- depth of field
- distortions etc.



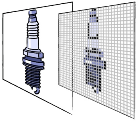






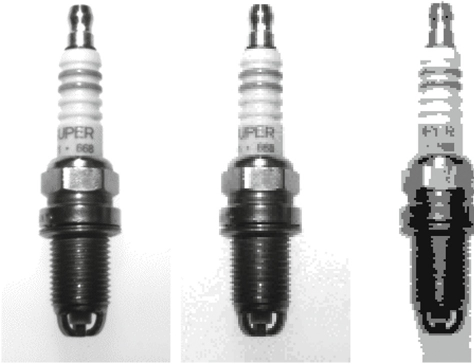
Motivation of the course

AD conversion - loss of information



Considering signal theory:

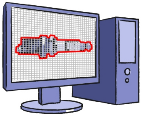
- averaging intensity
- sampling
- location limitation
- sampling theorem
- quantization theorem

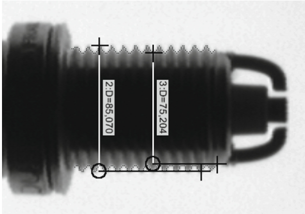


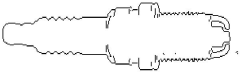
The distance between two pixels must be no more than half the size of the smallest relevant detail in the image
Sonka, 2008.

Motivation of the course

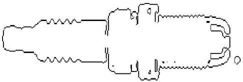
Image analysis - possibilities



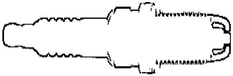




gradient based



curvature based



morphological

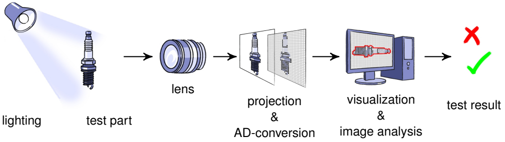
Motivation of the course

Image processing chain - conclusion

Quality assurance requirements for image processing

Image processing must be able to extract features

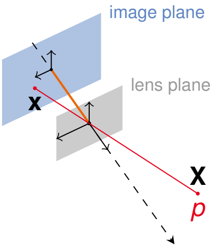
- under the existing environmental constellations,
- for all permissible variants of test parts,
- reproducible, stable over time and statistically significant,
- at a test speed adapted to the production cycle.



Motivation of the course

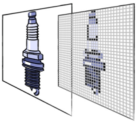
What is the core problem?

Task
To extract information about the captured 3D scene from 2D projections = inverse problem



Problem: loss of information via

- projection and
- A/D-conversion



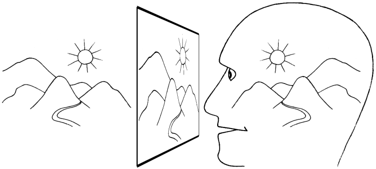
Consequence
Image data alone are almost never unambiguous = ill-posed, inverse problem

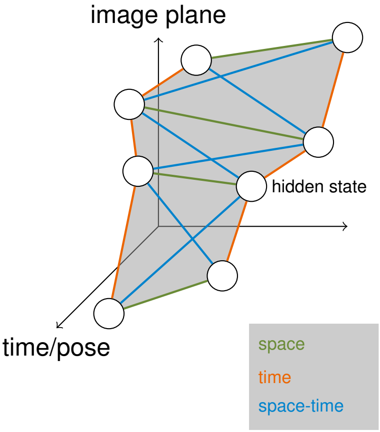
Motivation of the course

How to solve an image processing problem?

Mathematical models for

- geometry and physics of the world
- dependencies between image data and hidden states
- dependencies between hidden states





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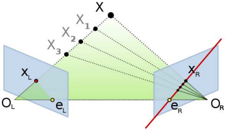
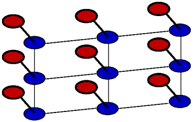
How to solve an image processing problem?

raw image data

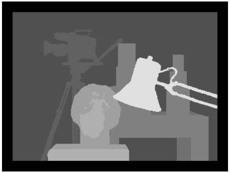
epipolar geometry



local smoothness



true depth



pure measurement

+ prior knowledge

Motivation of the course

How to solve an image processing problem?

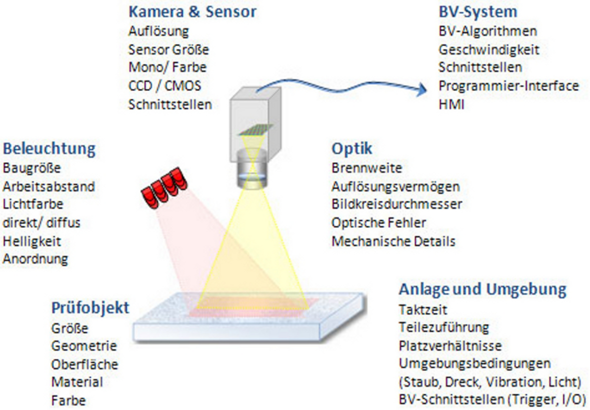
There are different approaches and solutions ...
the constraints are decisive

- controlled or uncontrollable environment
- passive or active camera system
- offline or online application
- recognition, discrimination or measurement task

Motivation of the course

How to solve an image processing problem?

Industrial applications:
Setting is almost
fully controllable!



www.vision-doctor.de

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Why does robotics need image processing?

General utility:

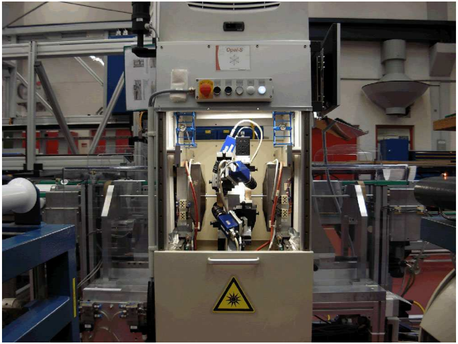
- perception of the robot’s environment
- perception of the state of the robot

Applications:

- inspection, quality control
- production, recovery
- photogrammetry
- visual driver assistance
- medical technology
- etc.

Potential by far not exhausted

Contactless inspection of surfaces



Surface inspection of pipes and bars

- detection of texture and geometry defects.
- Barcode reader for automated documentation of inspection results.
- Ring-shaped arrangement of six cameras.
- Linear feeding of the workpieces without inherent rotation enables high inspection speeds and high precision for metallic surfaces.

Source: Fraunhofer IIS

Applications

Contactless inspection of surfaces

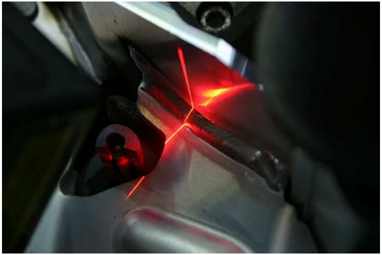
Industrial quality assurance of wood laminate foils.

- Inspection of patterned, colored surfaces in real time.
- Speed of up to several meters per second.
- Recorded data from line scan cameras are evaluated in networked standard PCs.

Source: Fraunhofer IIS

Applications

Active inspection of surfaces



Testing of weld seams of the rear axle beam of the Daimler C-Class

- Laser light sectioning method: Semiconductor laser projects a line onto the weld seam.
- High-speed camera captures this line as a height profile.
- Via relative movement of sensor and object a three-dimensional image of the weld seam surface is gradually generated.

Source: Vitronic

Applications

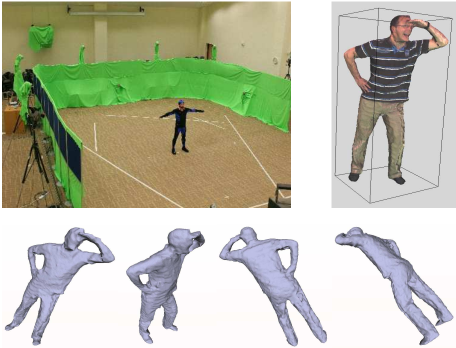
Contactless identification

Identification, position and orientation detection of parts

- Subpixel accurate contour extraction of arbitrary freeform shapes based on contour-based geometry models.
- detection of touching or overlapping parts.
- detection of objects of arbitrary scale and rotational position.

Source: Isra Vision AG

Contactless 3D reconstruction



Create a 3D model from different views

- Removing the known background to get the siluette of an object from different views.
- Calculating depth profiles of the siluettes.
- Merging the depth profiles to a 3D model.
- Cameras are calibrated and object-free environment is completely known.

Source: ICCV 2009, Kyoto University

Applications

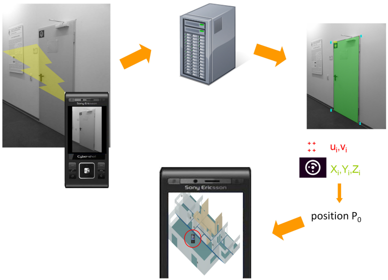
Visual driver assistance

Capture and analysis of traffic scenes

- lane detection (product)
- Traffic Sign Recognition (Product)
- signal detection and status reporting: Traffic lights, barriers, etc. (development)
- Driver attention/status detection (development, research)
- Automatic blind spot monitoring (especially for trucks) (product)
- Vehicle detection and classification (product, development, research)
- Pedestrian detection (development, research)
- Scene classification: traffic participants, drivable areas, background/obstacles. (research) item etc.

Applications

Image processing for smart phones



Acquisition of environmental information by means of the camera data of a mobile device (and possibly additional sensor data)

- Augmented reality = visually supported extension of the perception of reality. e.g., display of distances
- Location-based services e.g. indoor navigation
- Information retrieval e.g. data set comparisons, detections, classifications
- etc.

Applications

Robotics

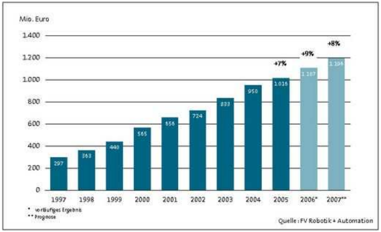
... now it's your turn ...

Sales development

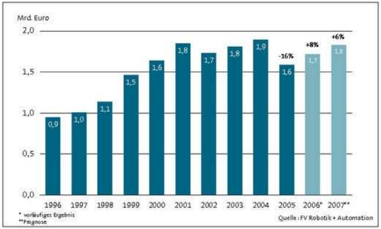
Industrial image processing

VDMA-Fachverband Robotik und Automation 2006

Image processing



Comparison: Robotics



Sales increases/decreases in 2007

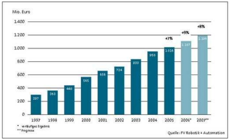
- +45% for configurable systems (systems consisting of cameras, computer and software that can be put into operation with little effort and can also be reconfigured for other tasks).
- -3% for specialized, application-specific systems.

Sales development

Industrial image processing

VDMA-Fachverband Robotik und Automation 2016

Image processing



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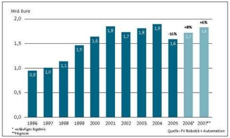
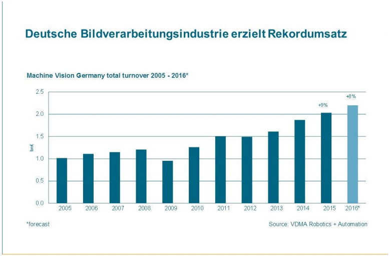
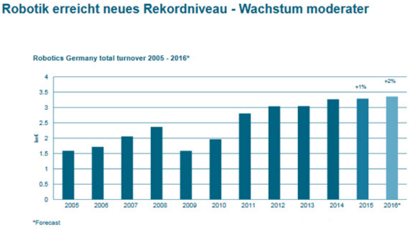


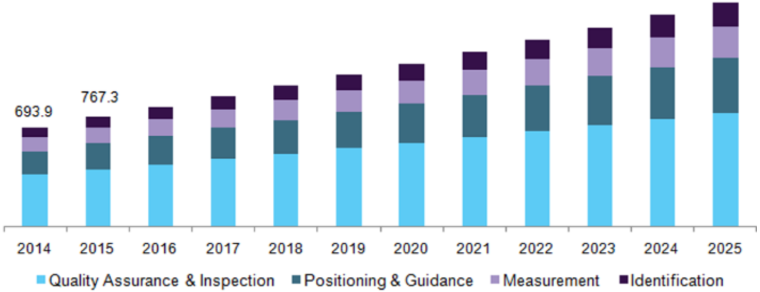




Sales development

Future prospects

Market shares of different machine vision segments



Source: https://www.grandviewresearch.com/industry-analysis/machine-vision-market

Sales development

Future prospects

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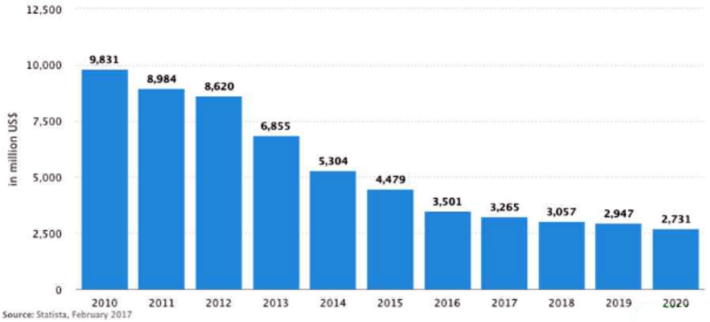
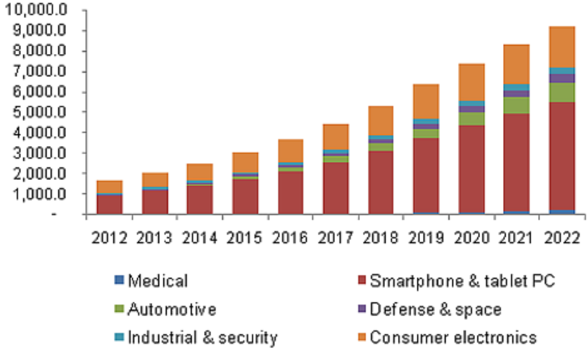
Sales development of classic cameras



Sales development

Future prospects

Sales development for cameras in different industries



Content of course

Camera & Geometry Basics

1. Introduction
2. 2D and 3D geometry
3. Projective geometry
4. Camera calibration
5. Optics, lens
6. Lighting
7. 2D camera systems

Image analysis

1. Image decomposition
2. Correlation analysis
3. 2D filtering
4. Geometric transformations
5. Image statistics
6. Edge & line detection
7. Corner detection & structure analysis

Variety of Terms

Generic term: Visual Computing

The evaluation and generation of visual data is called with the generic term Visual Computing. This includes the areas of image editing, image processing, photogrammetry, machine vision (computer vision), computer graphics and virtual reality. Many methods in these areas are being advanced by the multimedia industry to open new markets in the areas of, video games, film, multimedia communications, etc.,. But also for the solution of engineering tasks cameras are increasingly used. Especially for the solution of measuring and automation engineering tasks, methods are required mainly from the fields of photogrammetry, image processing and machine vision.

Relevant disciplines

The entire field of computer vision is highly interdisciplinary and requires diverse knowledge from areas of physics, mathematics, computer science, engineering, and biology.

- Optics
- Lighting technology
- Signal theory
- Systems theory
- Numerical mathematics, optimization, statistical methods
- Pattern recognition, machine learning
- Automation engineering, control engineering
- Software engineering, algorithmics

Motivation of the course

What are the main points?

Focus on content

- Geometric and signal theoretical basics
- Tools of image processing for solving automation tasks

Goals of the lecturer

- Clearly explain basic approaches
- point out advantages and disadvantages
- Evaluate application possibilities and areas of use

Purpose of Exercises

- Consolidation of the lecture material
- Efficient implementation in algorithms
- Training for exam

Relevant literature

In-depth study of the lecture content

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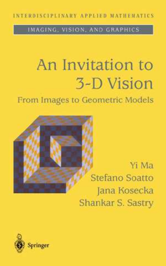
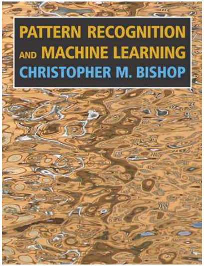
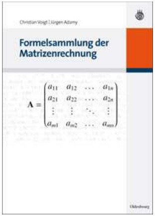


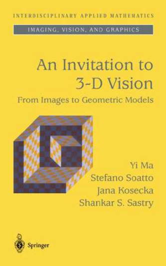


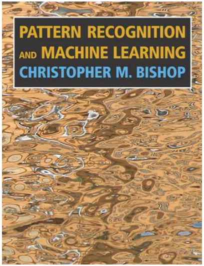


1. Yi Ma, Stefano Soatto, Jana Kosecka und Shankar S. Sastry, *An Invitation to 3-D Vision - From Images to Geometric Models*, Springer, 2003.
2. Bernd Jähne, *Digitale Bildverarbeitung*, Sechste Auflage, Springer, 2005.
3. Christopher Bishop, *Pattern Recognition and Machine Learning*, Erste Auflage, Springer, 2006.
4. Christian Voigt und Jürgen Adamy, *Formelsammlung der Matrizenrechnung*, Oldenbourg Verlag, 2007.

Relevant literature

Websites





1. *An Invitation to 3-D Vision - From Images to Geometric Models*
   `http://vision.ucla.edu/MASKS/`
2. *Pattern Recognition and Machine Learning*
   `http://research.microsoft.com/en-us/um/people/cmbishop/prml/`
3. *Industrielle Bildverarbeitung*
   `http://www.vision-doctor.de/`

Further reading

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1. Richard Hartley, Andrew Zissermann, *Multiple View Geometry in Computer Vision*,Second Edition, Camebridge University Press, 2004.
2. Karl Kraus, *Photogrammetrie*, Siebte Auflage, de Gruyter Lehrbuch, 2004.
3. Rafael Gonzalez, Richard Woods, *Digital Image Processing*, Third Edition, Pearson Education, 2008.
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