A machine vision system for scanner-based laser welding of polymers

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LASER World of PHOTONICS

Laser Polymer Welding – Recent results and future prospects for industrial applications in a European research project

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Motivation

- Benefits of **laser technology**
  - Facility to implement ***on-line process control systems***.
  - Increase of ***process repetitiveness***.
  - Reduction of the ***heat affected zone***.
  - Implementation of ***non-contact joining*** technologies.

- Benefits of laser **scanners**
  - Facilitate the ***increase of productivity.***
  - Combine ***design flexibility and high speed***.

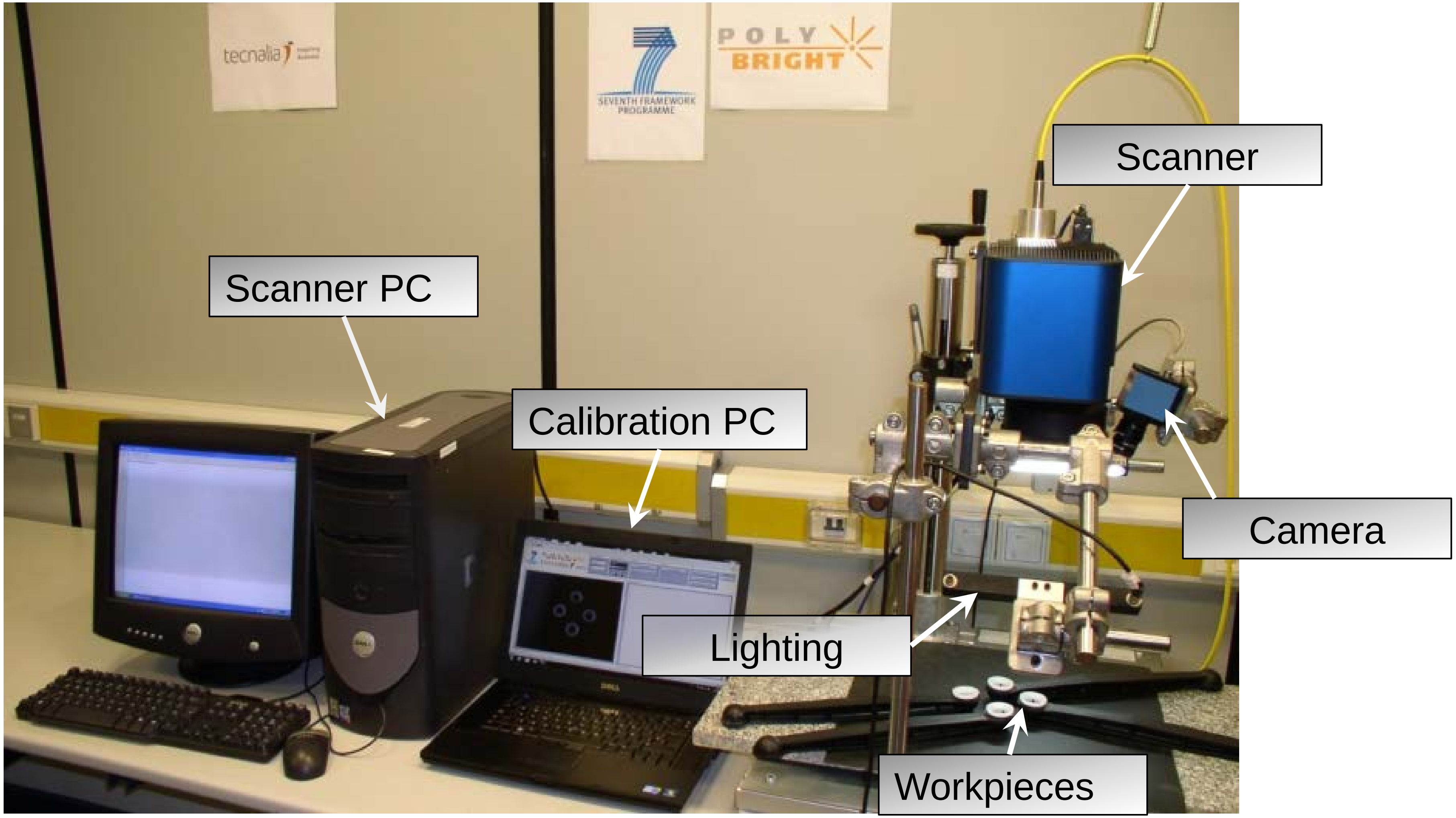
- **Problem**
  - ***Expensive clamping devices are required*** in order to obtain a precise automatic positioning of the laser beam relative to the workpiece.
- **Solution**
  - ***Vision cameras*** allow to ***correct the laser beam position in a non-intrusive way***.

Objectives

- Develop a ***machine vision system for scanner-based laser welding*** with ***automatic calibration*** that allows precise welding of polymers.

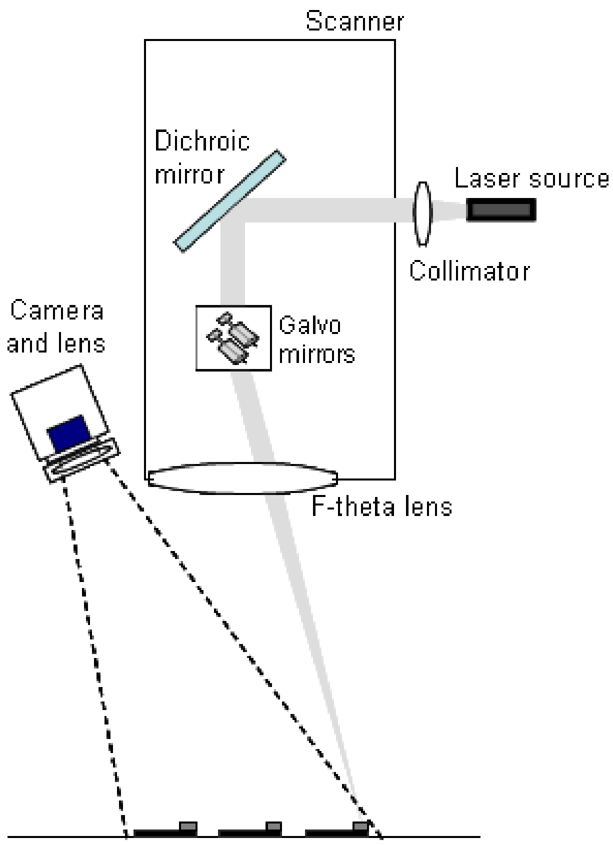
- With this system it is intended to:
  - ***reduce the complexity of the clamping devices***
  - allowing some uncertainty when presenting the workpieces to the laser radiation
  - calibrate only once and non-stop laser welding

System overview

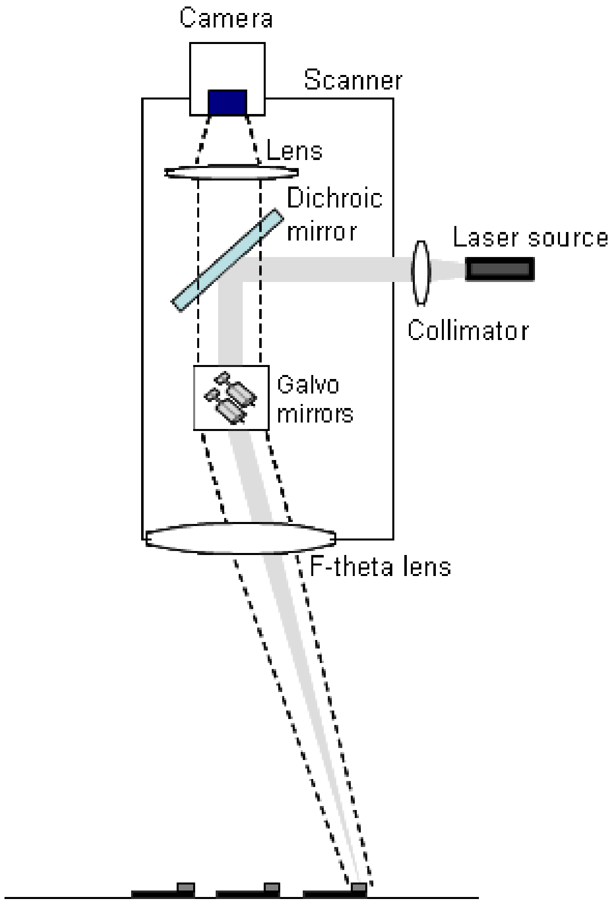


System configuration

External camera



Coaxial camera



External camera - Calibration

Mapping function from camera to scanner

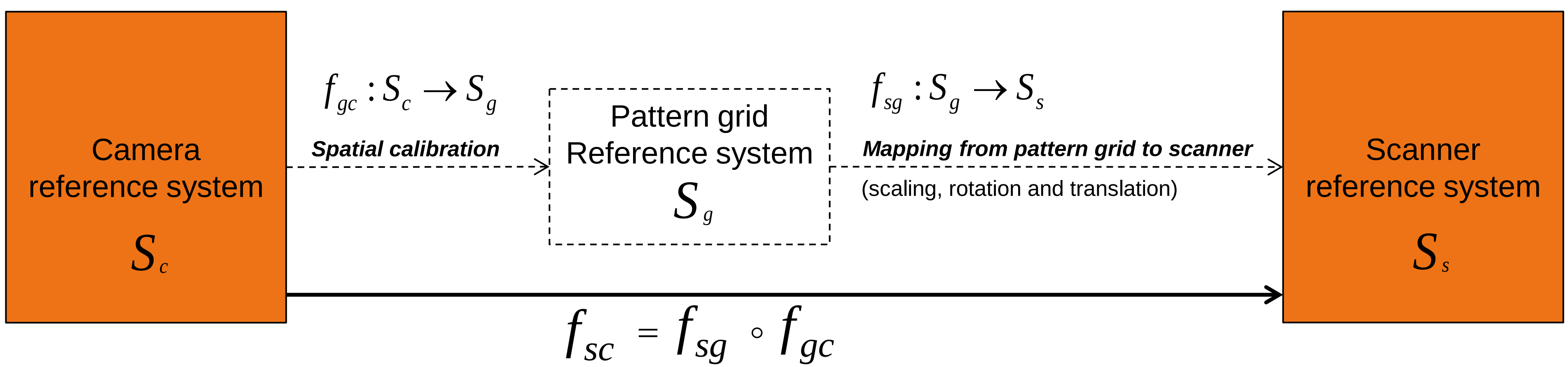
Two basic reference systems:

- Camera reference system.
- Scanner-laser reference system.

An extra reference system is defined by the use of a ***pattern grid***:

- Composed of dots with a known relationship between them.

System calibration is defined as the ***composition of mapping functions between the extra and the basics reference systems***.



External camera - Calibration

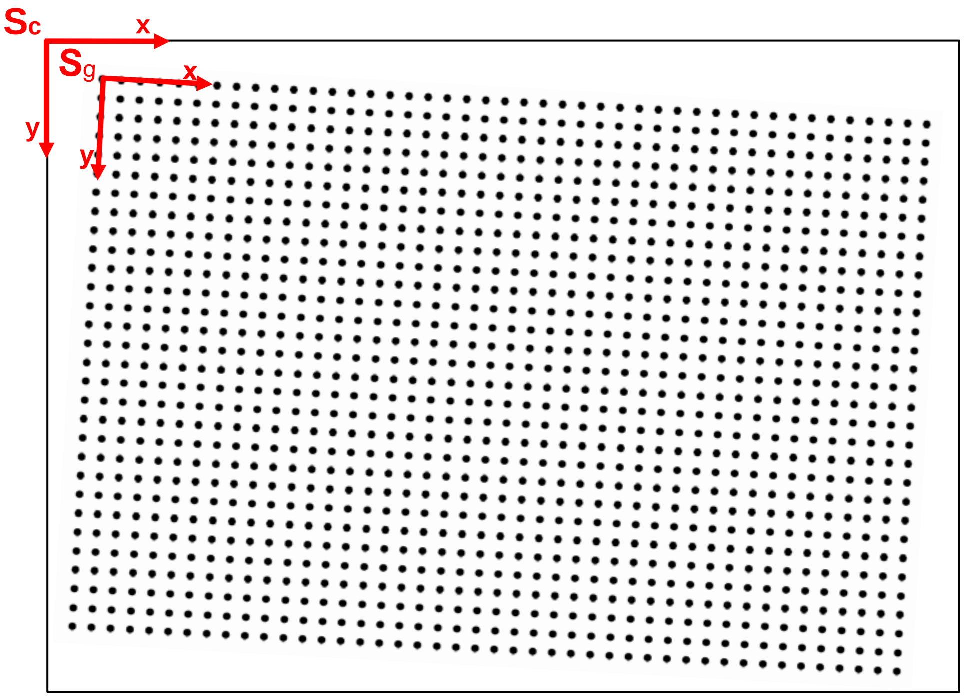
Spatial calibration

It relates points in the camera image to points in the pattern grid

$$f_{gc} : S_c \rightarrow S_g$$

Camera view of the pattern grid

Pattern grid size	200 mm x 200 mm.
Distance between dots centers	4.5 mm.
Dots diameter	1 mm.

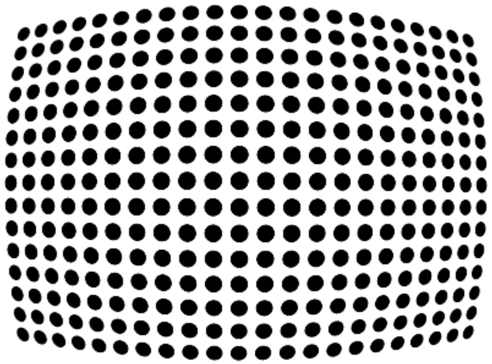


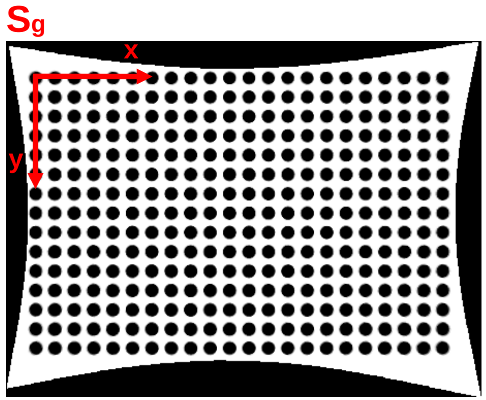
External camera - Calibration

Spatial calibration

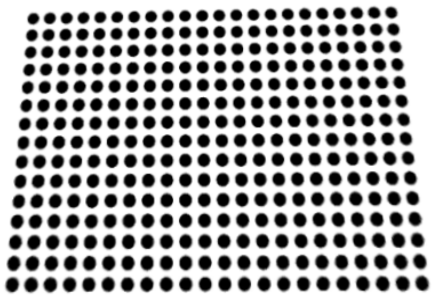
We used the machine vision library
IMAQ of National Instruments

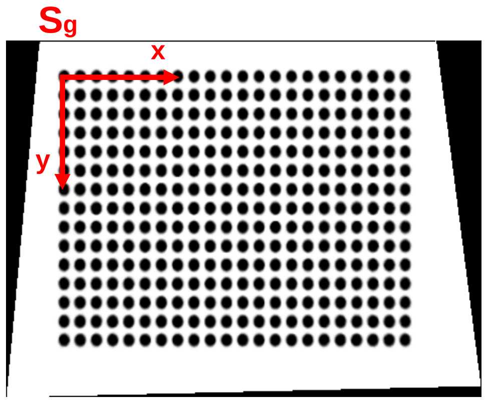
Estimation of image distortion





Estimation of perspective projection





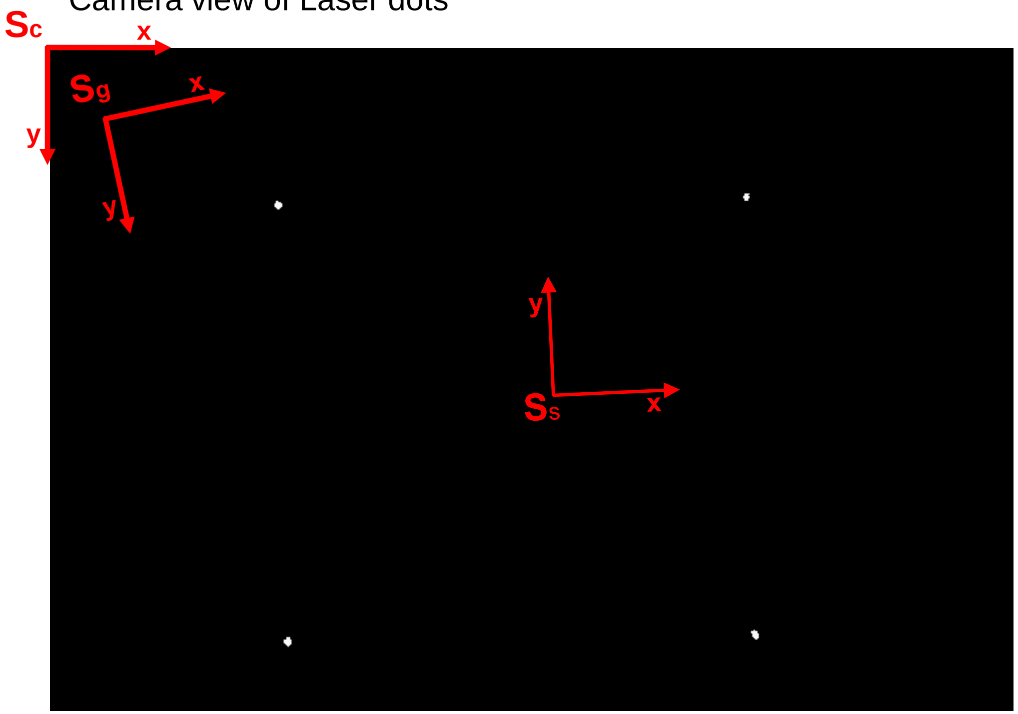
External camera - Calibration

Mapping from pattern grid to scanner

Mapping function is obtained by ***correlating positions of dots in*** S_s ***and*** S_g .

$f_{sg} : S_g \rightarrow S_s$ (scaling, rotation and translation)

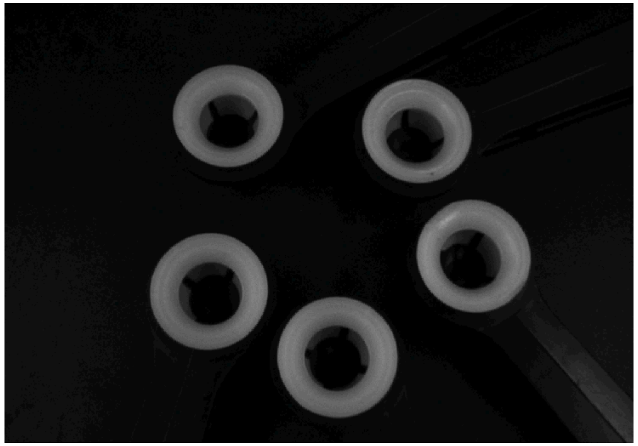
Camera view of Laser dots



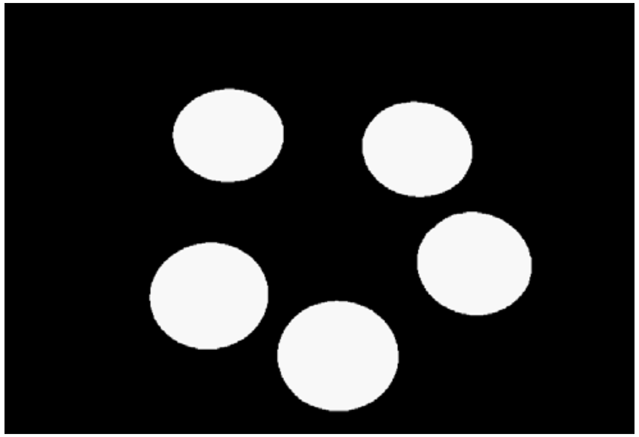
- Position of dots in S_s is known.
- Position of dots in S_g is obtained by using the spatial calibration.

External camera - Workpieces detection

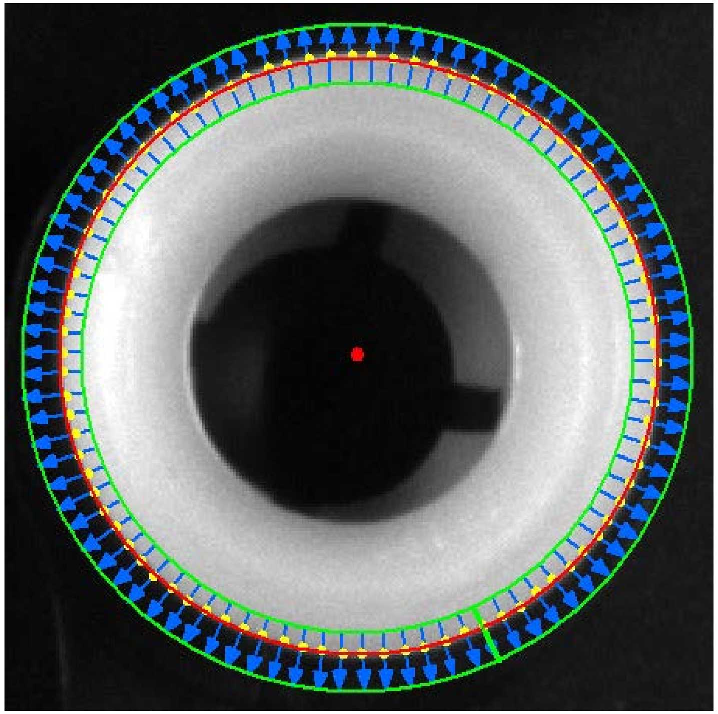
Raw image



Shapes detection



Fine border detection



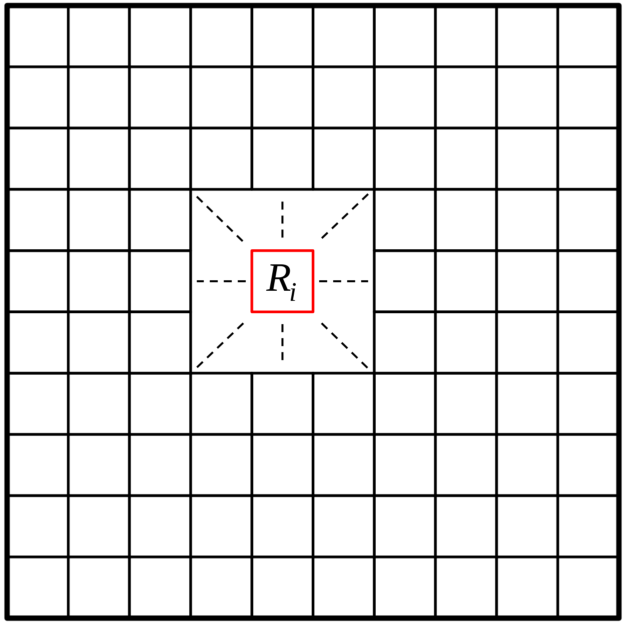
Coaxial camera - General strategy

The general strategy when working with the coaxial camera is to:

- Divide the workspace in regions (each of them smaller than the camera field of view).
- Calibrate each region.

Workpieces detection

- Scan the workspace and take an image of each region.
- Correct each image by using the calibration data.
- Construct a global image by correcting and joining the region images.
- Search workpieces in the global image.



Working area: 150x150 mm^2
Camera view: 14x16 mm^2 approx.
Region area: 10x10 mm^2

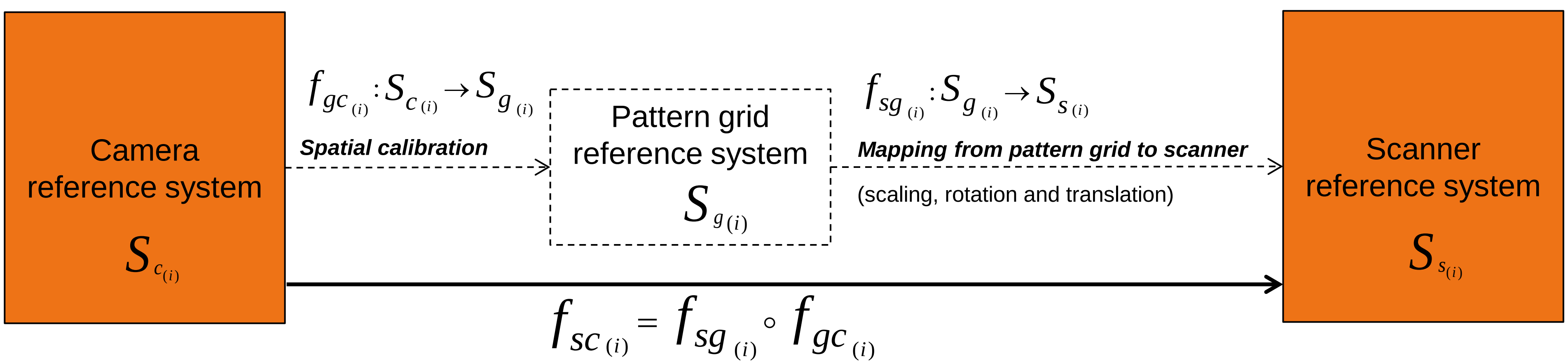
Coaxial camera - Calibration

Mapping function from camera to scanner for each region (i)

Two basic reference systems:
- Camera reference system.
- Scanner-laser reference system.

An extra reference system is defined by the use of a ***pattern grid***:
- Composed of dots with a known relationship between them.

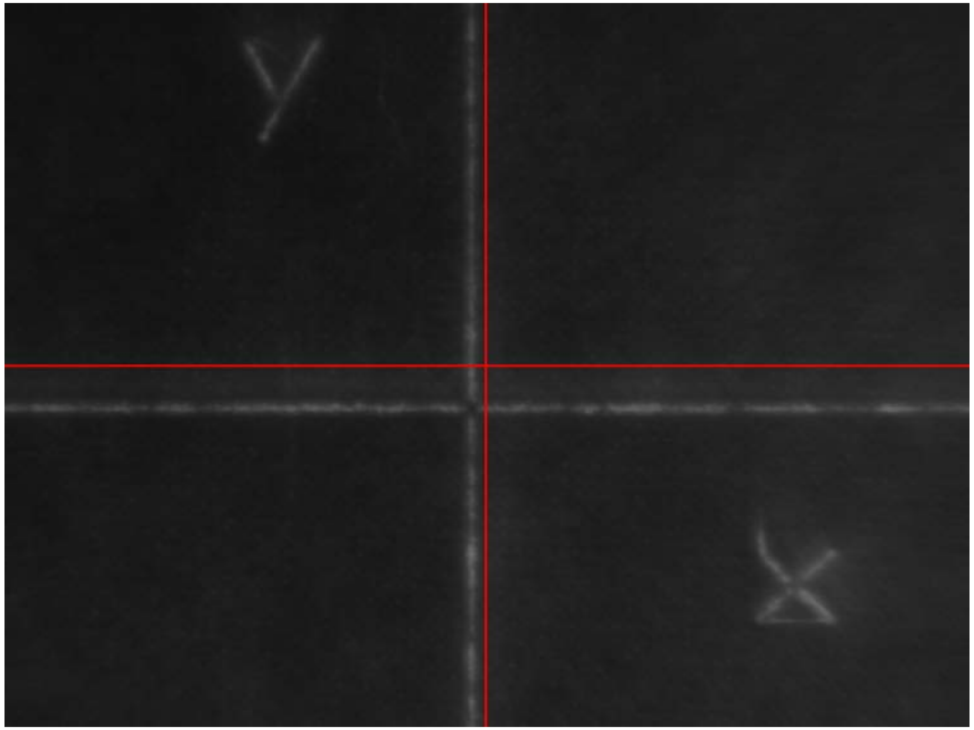
Calibration of region (i) is defined as the ***composition of mapping functions between the extra and the basics reference systems***.



Coaxial camera - Calibration

Camera alignment

- ***Mark the scanner axes*** on a blank target.
- ***Move the scanner to its origin***.
- ***Manual alignment of the camera*** to the scanner reference system.



Coaxial camera - Calibration

Spatial calibration

- Pose the ***scanner at the centre of region*** (i) with the pattern grid on the workspace.
- ***Take an image and improve quality***.
- ***Perform spatial calibration of region*** (i).

$$f_{gc_{(i)}} : S_{c_{(i)}} \rightarrow S_{g_{(i)}}$$

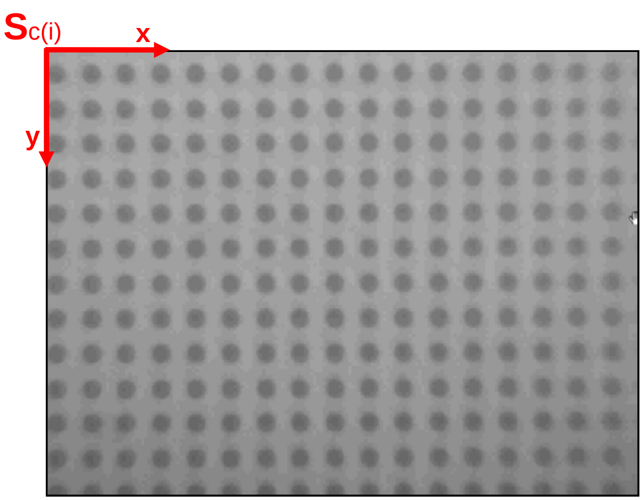
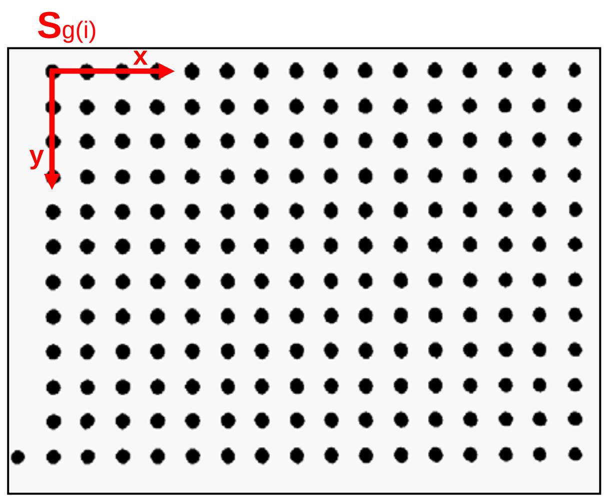


Image of the pattern grid at the scanner origin



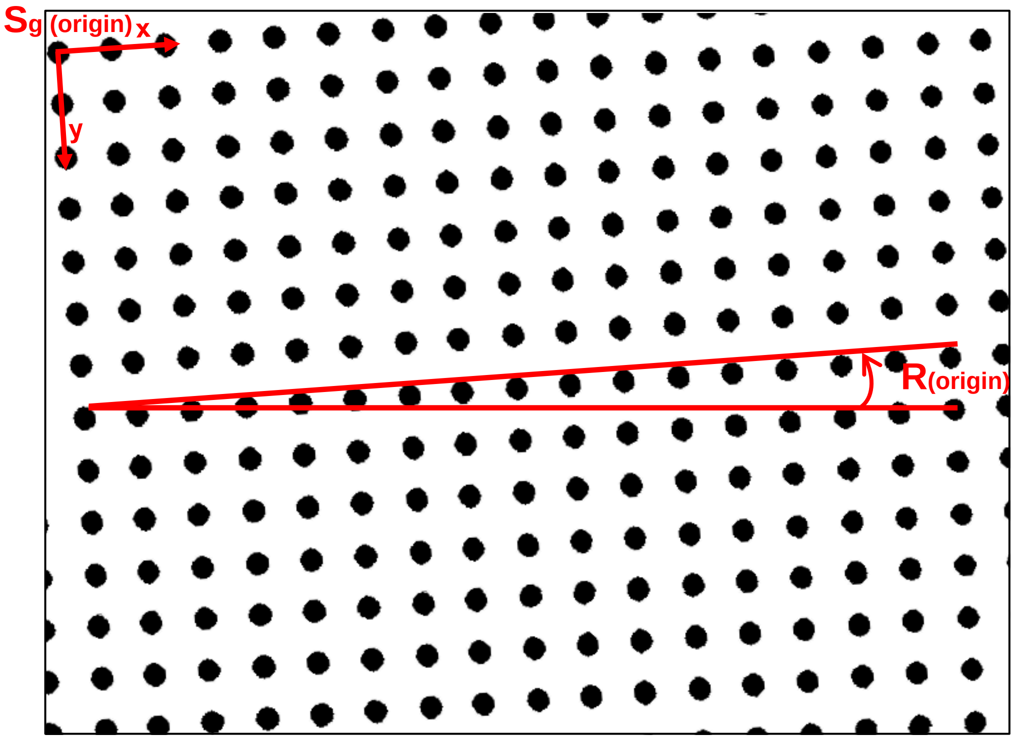
Processed image of the pattern grid at the scanner origin

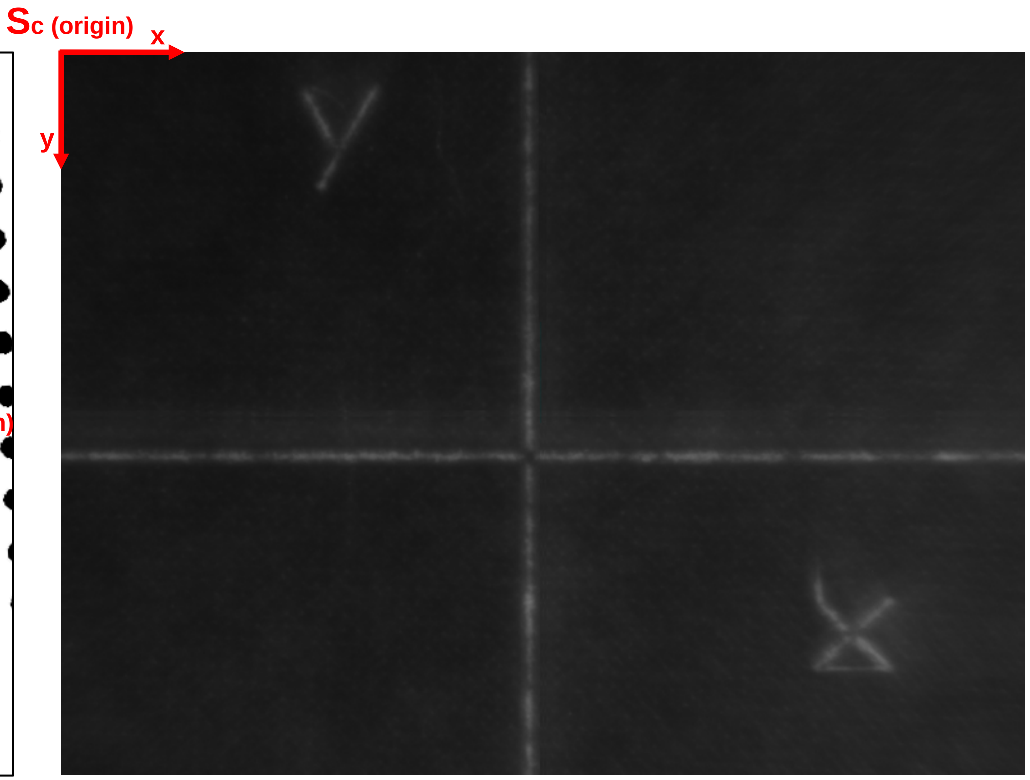
Pattern grid size	200 mm x 200 mm.
Distance between dot centers	1 mm.
Dots diameter	0.5 mm.

Coaxial camera - Calibration

Mapping from pattern grid to scanner

- ***Mark the scanner axes*** on a blank target at the origin.
- ***Obtain rotation*** $R_{(origin)}$ between the pattern grid orientation and the scanner axes.

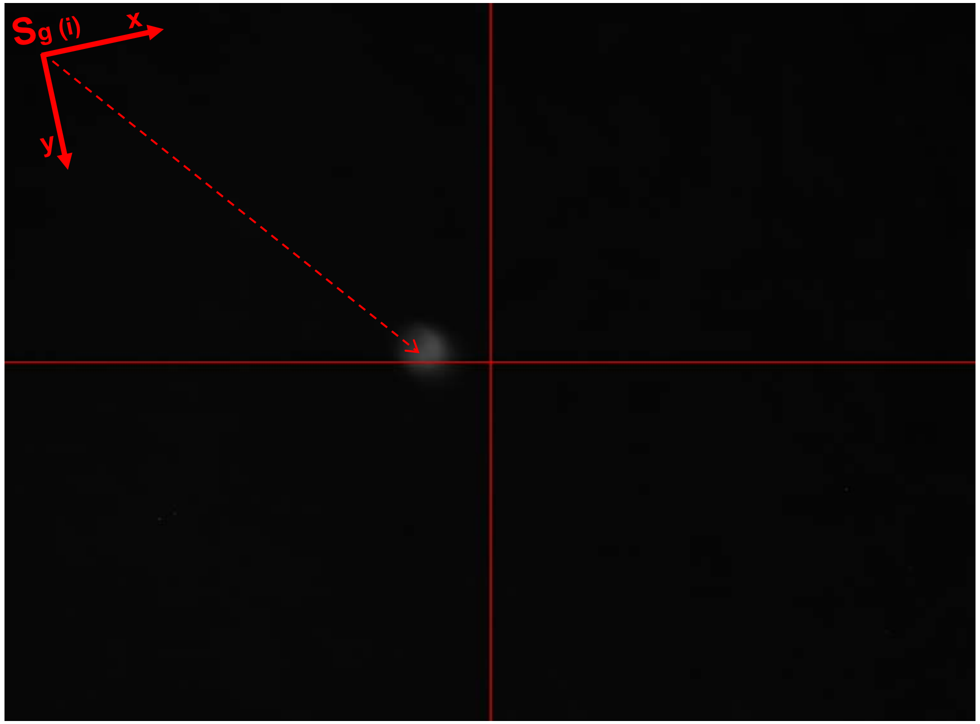




Coaxial camera - Calibration

Mapping from pattern grid to scanner

- ***Mark a dot*** at the centre of each region (i) on a blank target.
- ***Obtain translation*** T_i between the pattern grid and the dot.



- Position of dot in $S_{s_{(i)}}$ is known.
- Position of dot in $S_{g_{(i)}}$ is obtained by applying the spatial calibration.

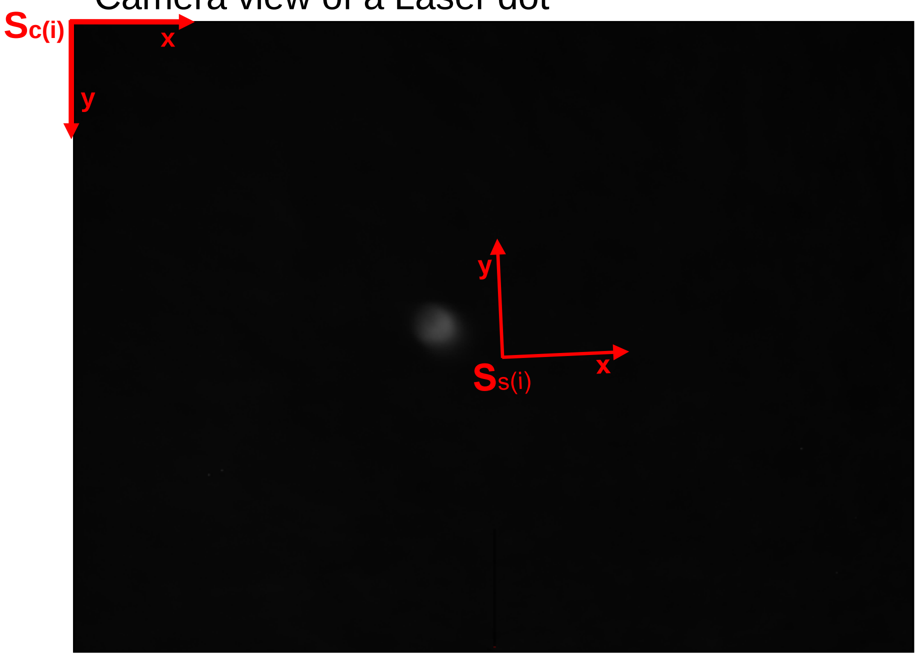
Coaxial camera - Calibration

Mapping from pattern grid to scanner

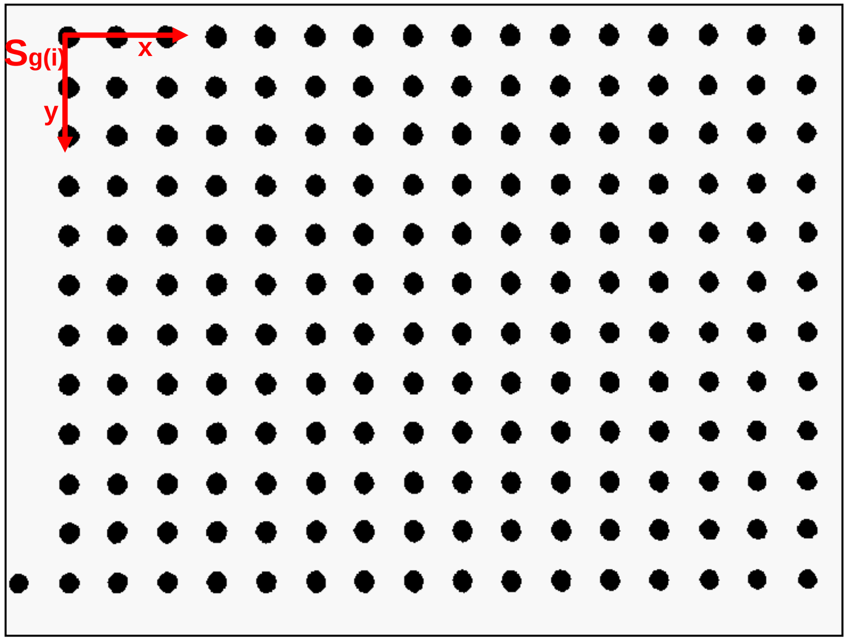
Construct the mapping function at region (i) by ***applying rotation*** $R_{(origin)}$ ***and translation*** T_i.

$$f_{sg_{(i)}} : S_{g_{(i)}} \rightarrow S_{s_{(i)}}$$

Camera view of a Laser dot

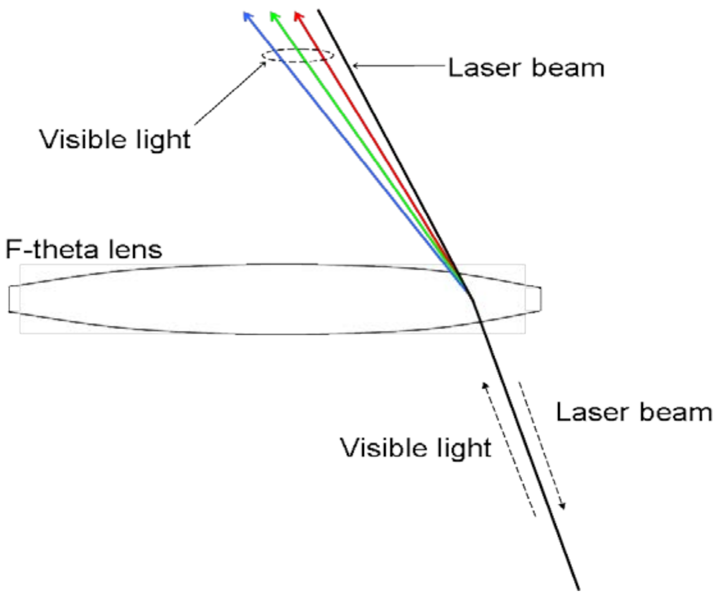


Camera view of the pattern grid

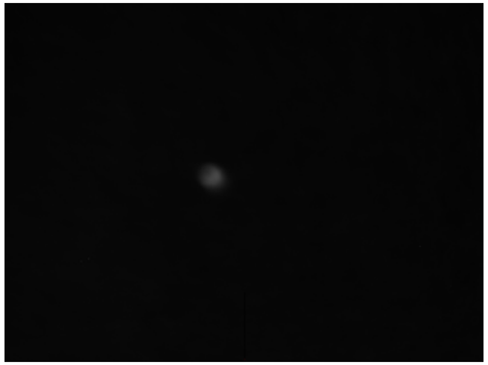


Coaxial camera - Calibration

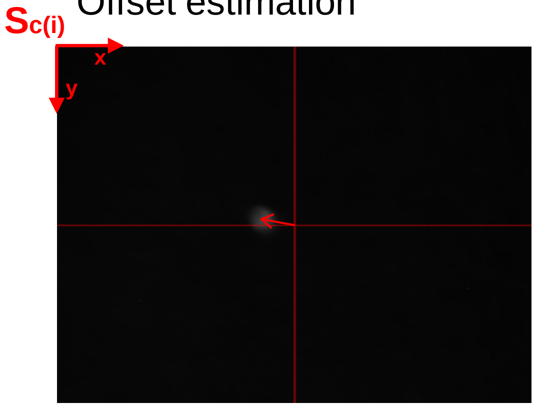
Chromatic aberration



Dot mark



Offset estimation

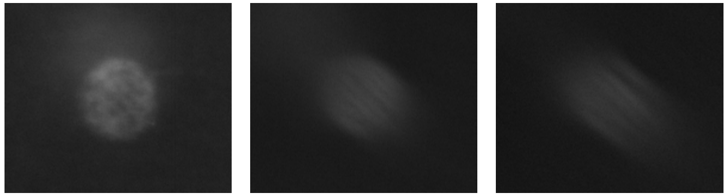


Coaxial camera - Calibration

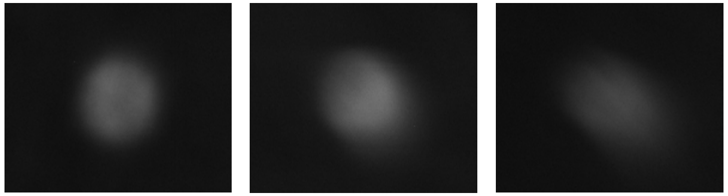
Spot detection

Blurring of the image increases as the scanner position goes away from the origin

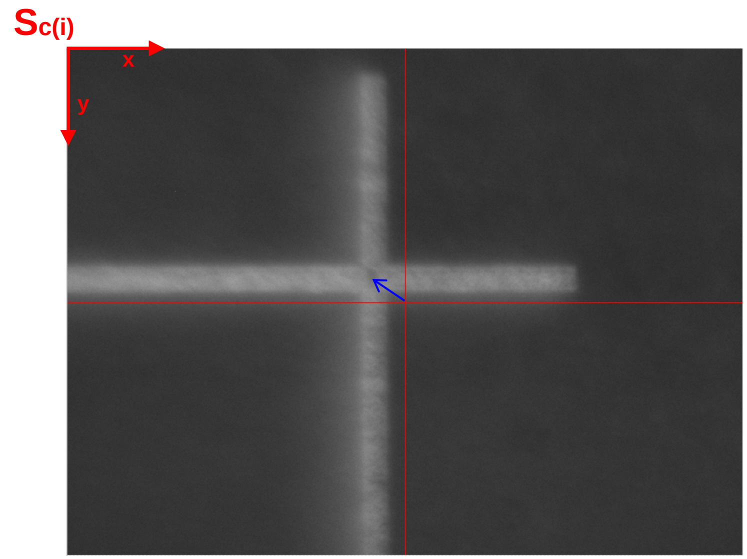
Using white lighting



Using red lighting



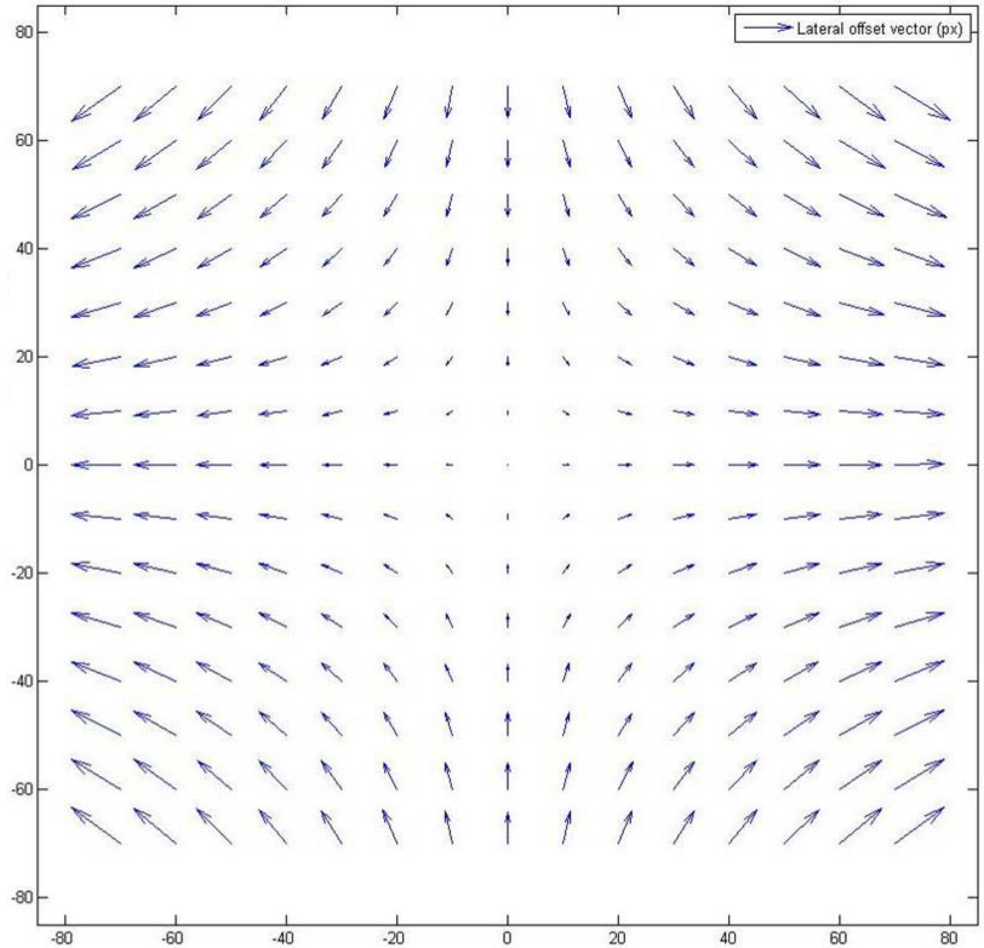
A cross-shaped mark improves detection when using white lighting



Coaxial camera - Calibration

Spot detection

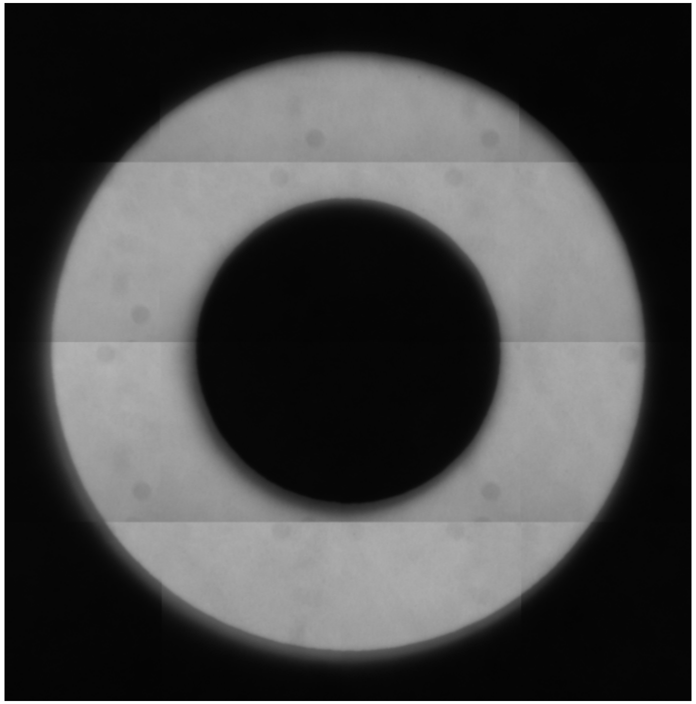
Offset map using white lighting



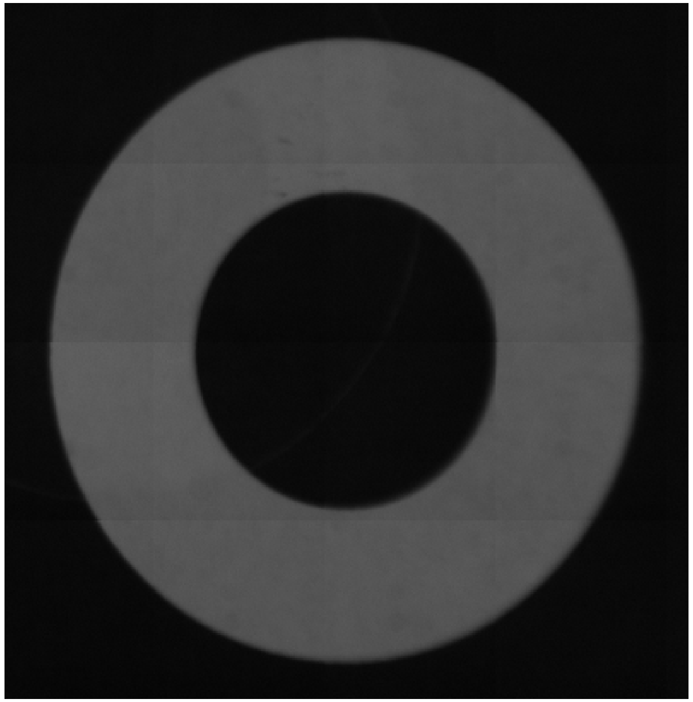
Coaxial camera - Workpieces detection

Images joining

White lighting



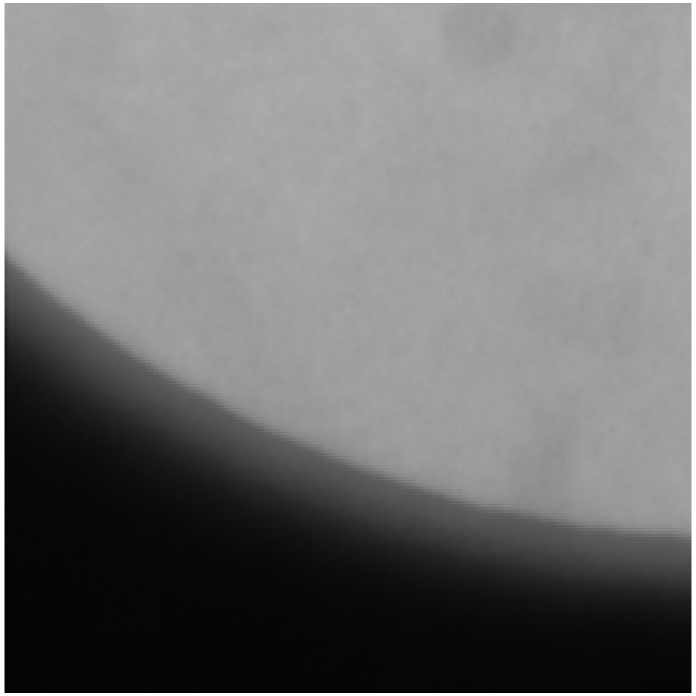
Monochromatic red lighting



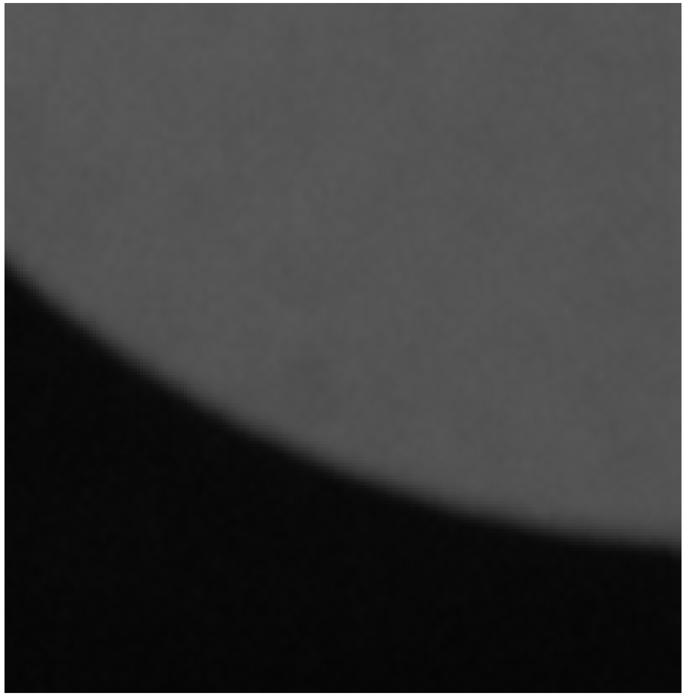
Coaxial camera - Workpieces detection

Workpiece Border

White lighting

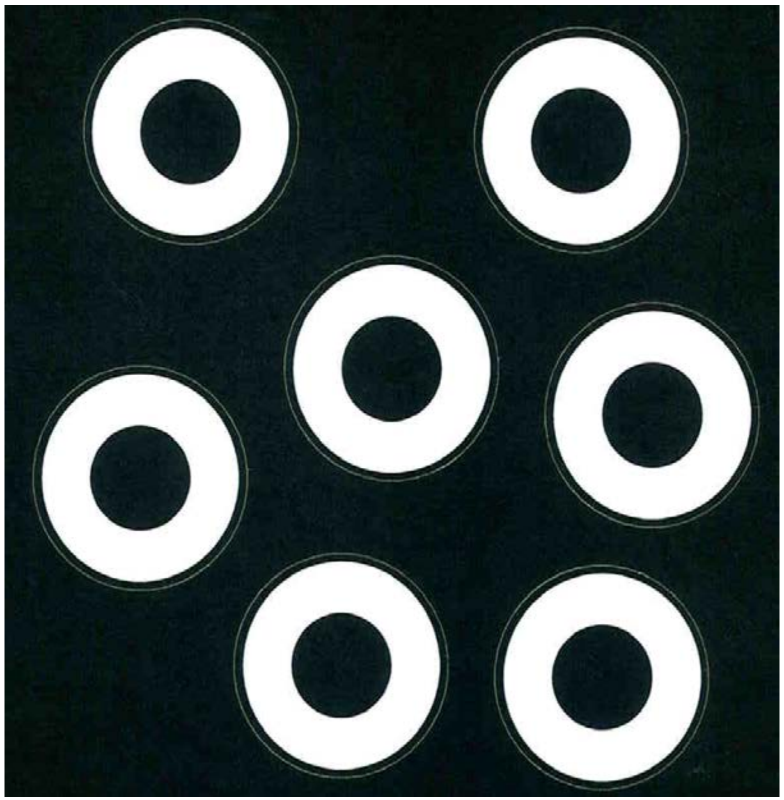


Monochromatic red lighting

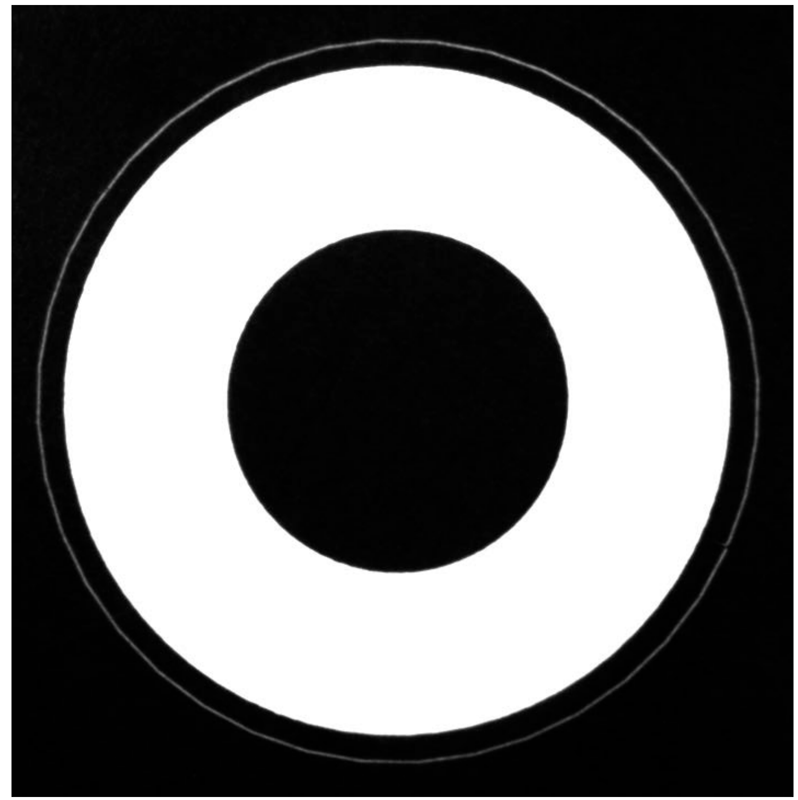


Experiments

Detecting and marking printed workpieces (by ink evaporation).



Measuring the distance between the centroid of the ring-shaped draw and the centroid of the circle mark.



Experiments

Results – Positioning accuracy

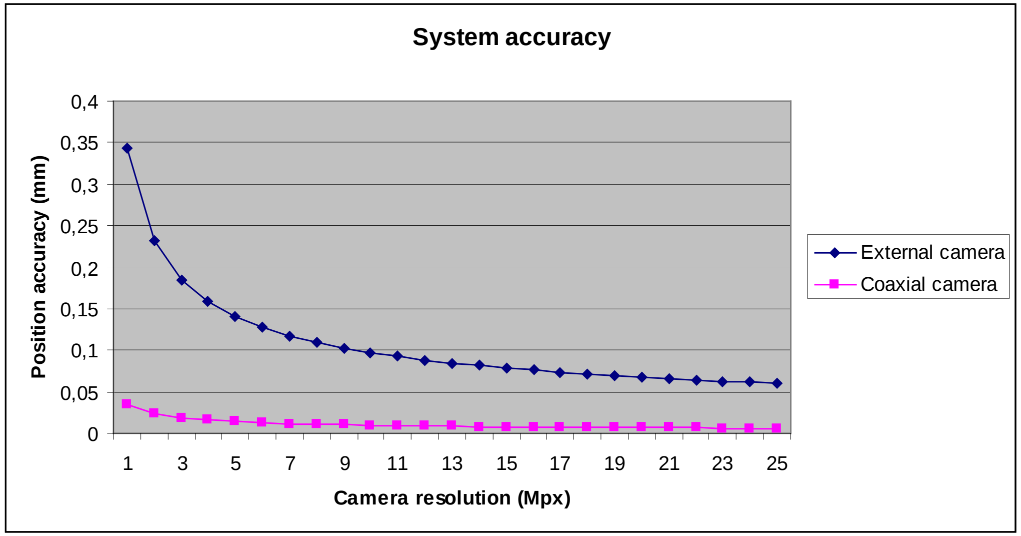
External camera		Working area (mm²)
		150x150
White light	Mean error	0.12
	Max. error	0.33

(errors are expressed in mm)

Coaxial camera		Working area (mm²)		
		50x50	100x100	150x150
White light	Mean error	0.03	0.06	0.12
	Max. error	0.03	0.09	0.49
Red light	Mean error	0.03	0.03	0.05
	Max. error	0.03	0.06	0.16

(errors are expressed in mm)

External/coaxial cameras comparison



Experiments

Results – Cycle time

External camera

- Average image processing time =15 ms.
- Cycle time = 15 ms + (welding time).

Image processing
Computer: Dell Precision M4500.
Processor: Intel Core i7-Q740 (1.73GHz).
Memory: 4 GB RAM.
Operating system: Windows 7 (32 bits).

Experiments

Results – Cycle time

Coaxial camera

Scanning the whole workspace and joining images
(Image processing in sequence)

Working area (mm^2)	**Cycle time**
50x50 (25 images)	***13 s + (welding time)***
100x100 (100 images)	***50 s + (welding time)***
150x150 (225 images)	***112 s + (welding time)***

→ ~13 s/workpiece (~ 500 ms/image) + welding time.

Images correction: ***180 ms/image***.
Global image composition: ***350 ms/image***.
Workpieces detection in the global image: ***10 ms/image***.

Cycle time is excessive when scanning and joining images.

Image processing
Computer: Dell Precision M4500.
Processor: Intel Core i7-Q740 (1.73GHz).
Memory: 4 GB RAM.
Operating system: Windows 7 (32 bits).

Experiments

Results – Cycle time

Coaxial camera

Possible cycle time reduction with a global image

-Optimize image processing algorithms.

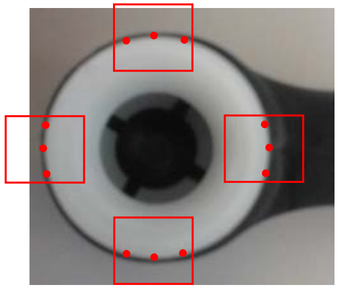
-Image multiprocessing.

Alternatives to processing a global image (avoiding images correction)

-Clamping device with predefined positions.

-An external camera detects workpieces position and then a coaxial camera improves accuracy.

→ Analyze some regions of interest to obtain the workpiece position.



~ 15ms/image

If 4 regions of interest are need for each workpiece → Cycle time
60 ms/workpiece + welding time

Conclusions

External camera Vs. Coaxial camera

	External camera	Coaxial camera
Integration	Easy integration	Adaptor and special optics
Calibration	Easy calibration	Calibration through special optics
Light attenuation	No attenuation of visible light	Attenuation of visible light through the optics (It could be compensated by high power lighting)
Interferences	Camera should be as much perpendicular to the surface as possible	No interferences between camera and workspace
Camera focus	Working distance must be kept constant	In 2-D scanners: working distance must be kept constant In 3D scanners: working distance can be varied
Supervision	No necessity of camera/scanner movements for medium accuracy	It is necessary to acquire some frames by means of scanner movements
Accuracy	For high accuracy: expensive high-resolution cameras or the use of more than one camera are needed	Order of accuracy: 10 to 10^2 times higher than for the external camera
Cycle time	Fast cycle time (Only one camera shot for various workpieces)	It is necessary to take at least one camera shot per workpiece (It could be necessary to join images and make image correction)

Conclusions

- We have developed a functional prototype of a machine vision system for scanner-based laser welding of polymers with automatic calibration.

- ***External camera configuration***
  - Simple integration.
  - Simple calibration procedure.
  - Light attenuation can be easily corrected by the use of external illumination.
  - Workpieces detection is performed with a fast cycle time.
  - It requires a high resolution camera to obtain high positioning accuracy results.

- ***Coaxial camera configuration***
  - The integration of the camera into a scanner needs an adaptor and special optics (some companies have these components as standard modules).
  - Distortion at the periphery affects the image clearness and therefore reduces the detection accuracy.
  - If it is needed to join images in order to detect features, cycle time is slow.
  - If workpieces are supposed to be in predefined places, cycle time can be fast.

Conclusions

- Comparing the two tested camera configurations, the suitability of either one depends on the cycle time and the accuracy needed.

- While the coaxial configuration allows an accuracy more than 10 times higher than the external one, it requires at least one camera shot per workpiece, in contrast to the single shot required for the external configuration for the whole set of workpieces.

Thank you for your attention!

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