Automated inspection of microlens arrays

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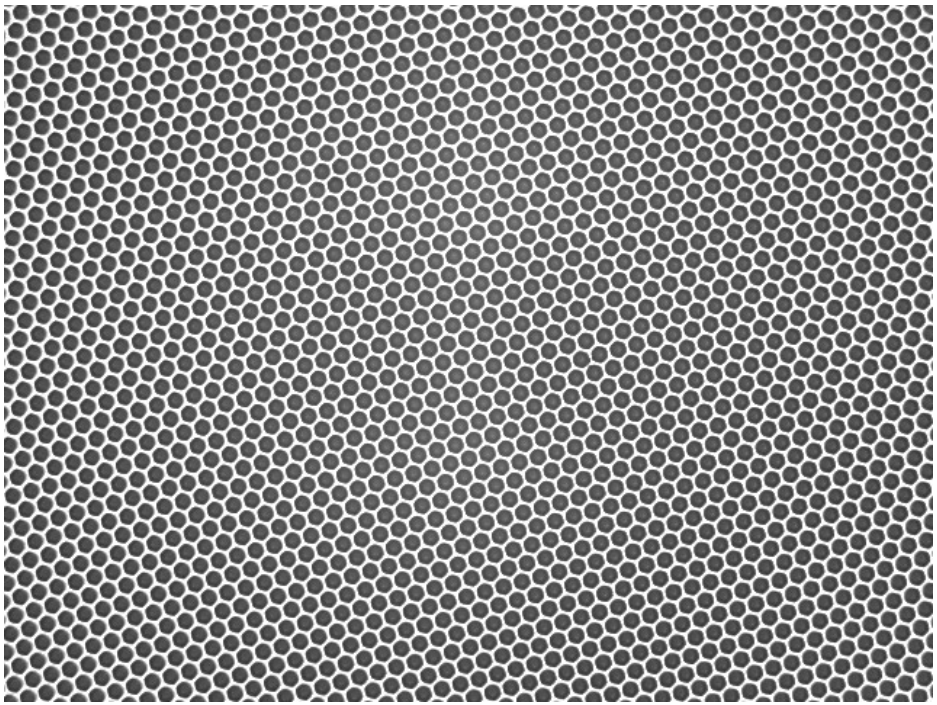
Outline

Outline

Microlens arrays

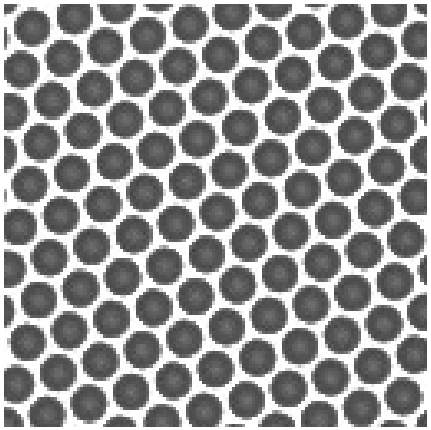
- Optical devices combining many small lenses.
- Used for collimation, illumination, imaging[**?**] ...



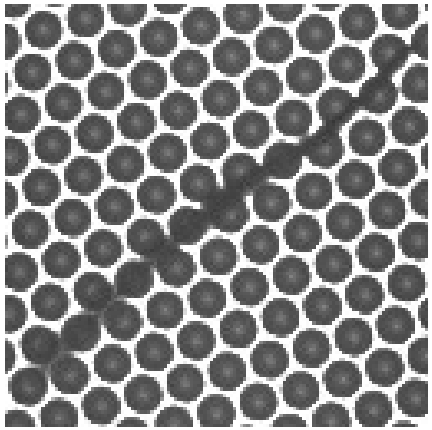
Specificities for this work:

- Small lenses :
  $10 \leq d \leq 50\ \mu m$.
- Gaps coated with metal.
- Device with more than 2000000 lenses!

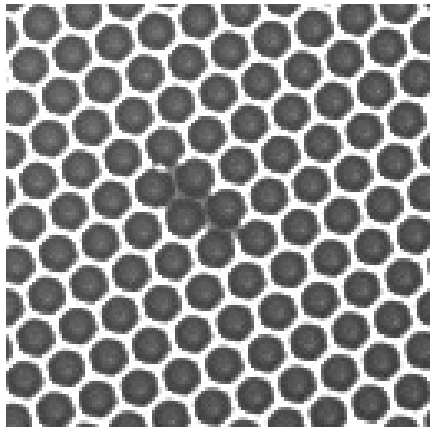
Inspection - Array defects



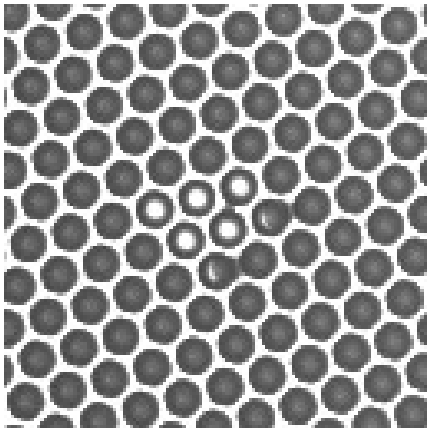
No defect



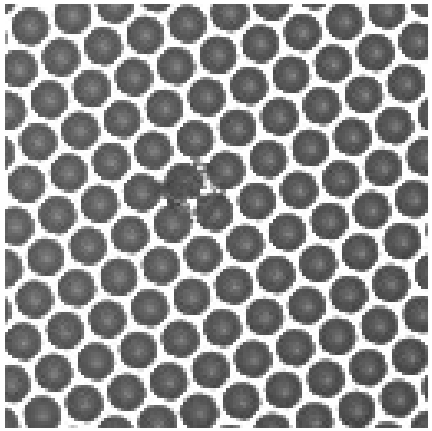
Filament on array



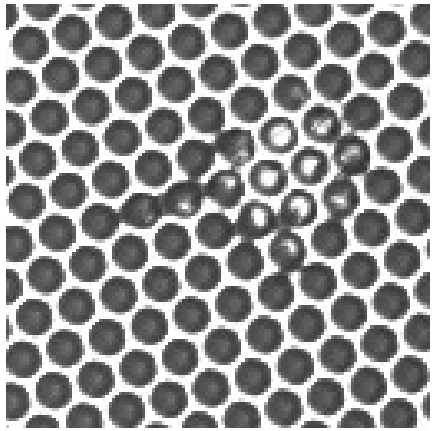
Missing metal



Metal covering

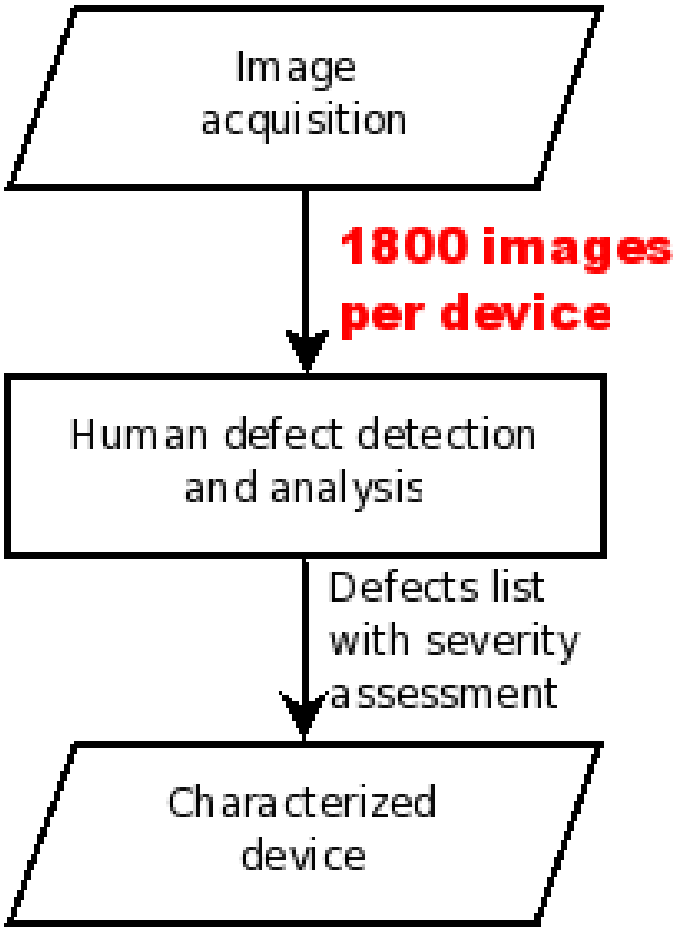


Bad lens



Defects combination

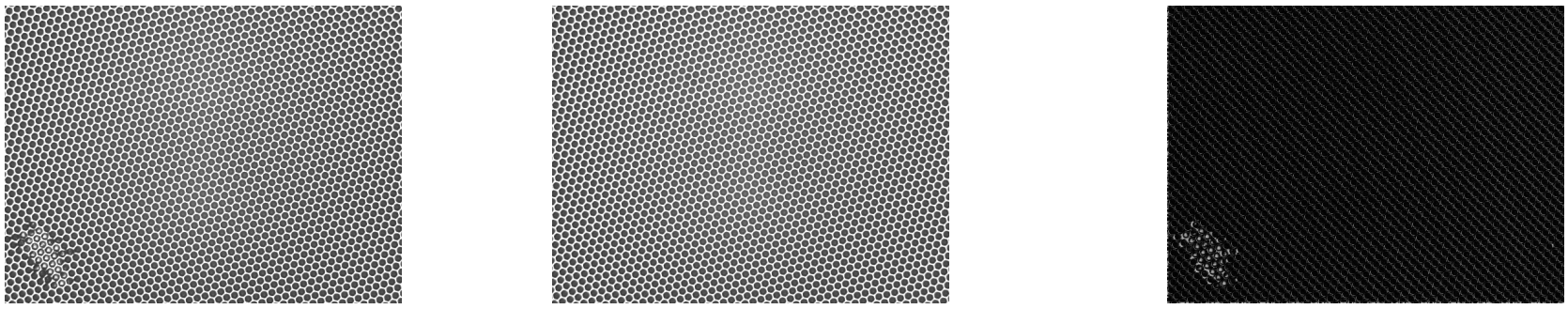
Semi-automated inspection system



- The number of images to inspect is large.
- Human inspection is slow and reliability is low.
- Most images contain no defects.
- Automated defect detection can speed-up the inspection.

Outline

Reference subtraction



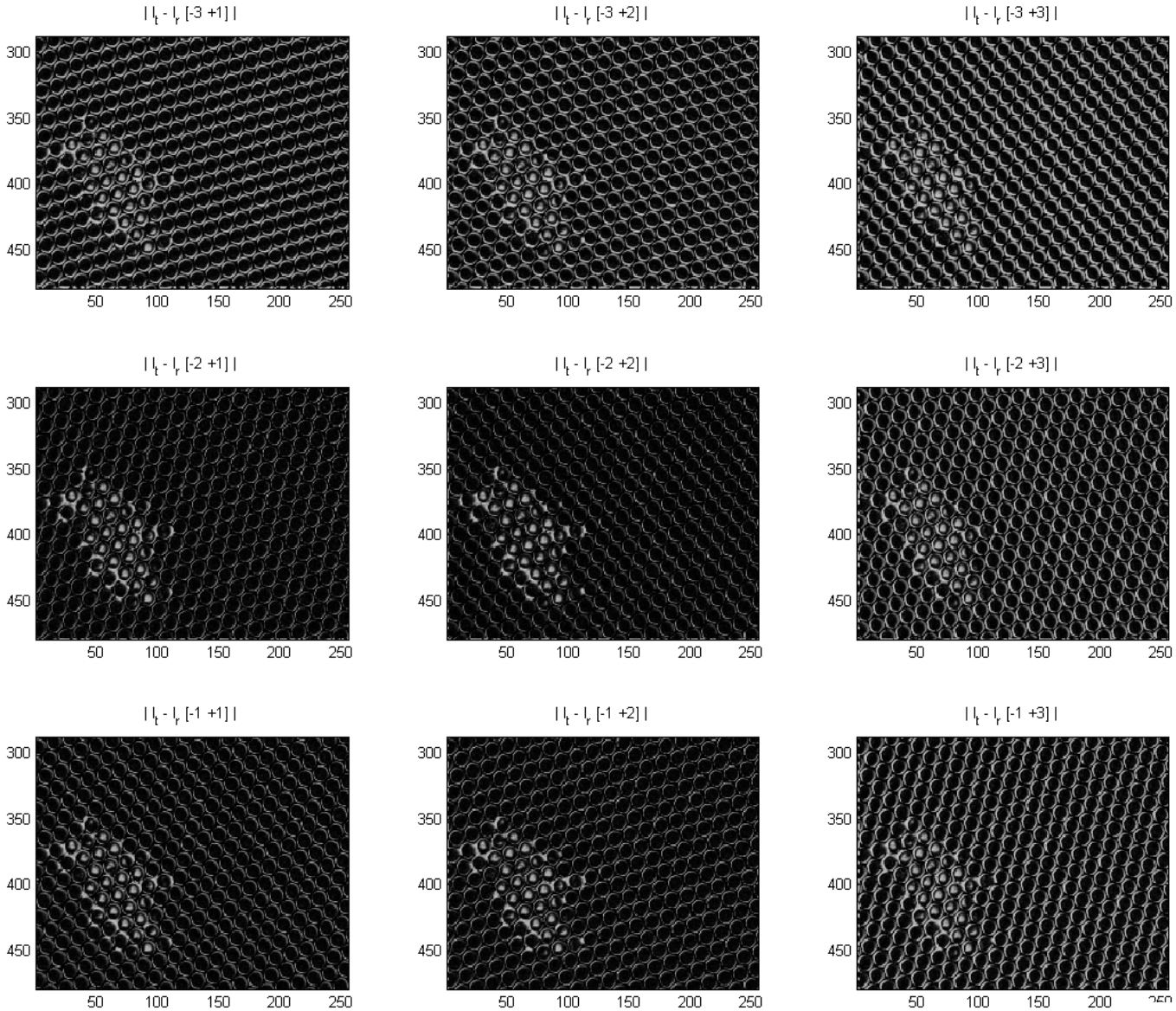
Advantages :

- Short processing time.
- Low memory requirements.

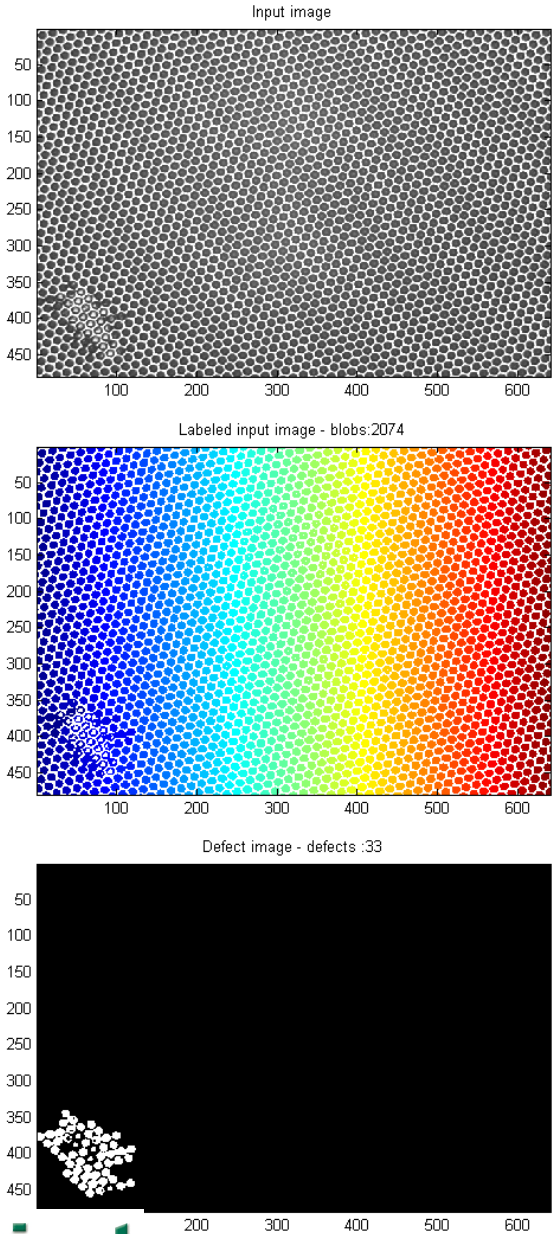
Disadvantages :

- Requires accurate alignment.
- Sensitive to **coarse sampling**.

Alignment and coarse sampling issue



Blob analysis



Advantages :

- Insensitive to alignment and coarse sampling.
- Simple, parametric lens models can be used.
- Easily adapted to new lens array geometry.

Disadvantage :

- Segmentation is critical.

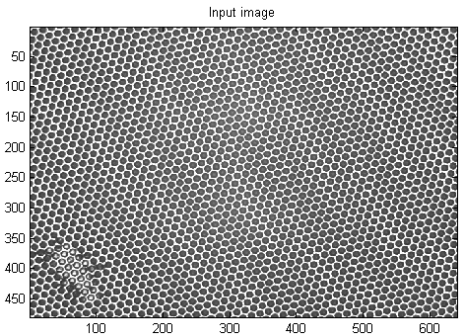
Methods comparison

Challenge	Reference sub.	Blob analysis
Illumination may vary (gradients + vignetting)	$-$	0
No alignment between array lattice and image axes	$--$	$++$
Defects may vary greatly in size and intensity characteristics	$++$	$++$
Short processing time ($< 1\,s$)	$++$	$+$

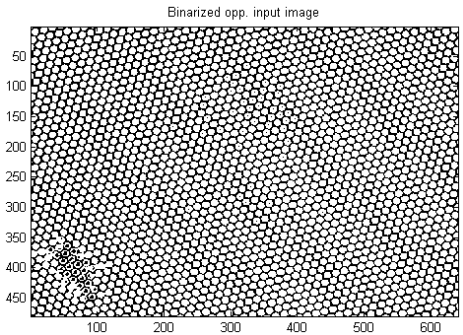
Outline

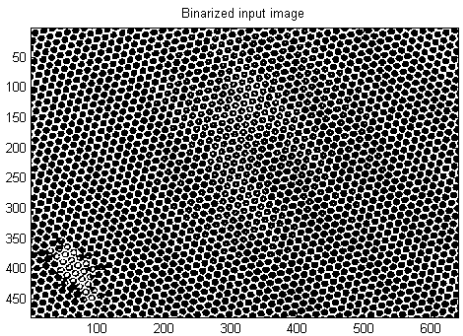
Blob analysis - Process

Input

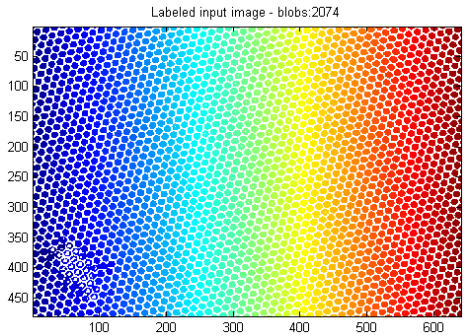


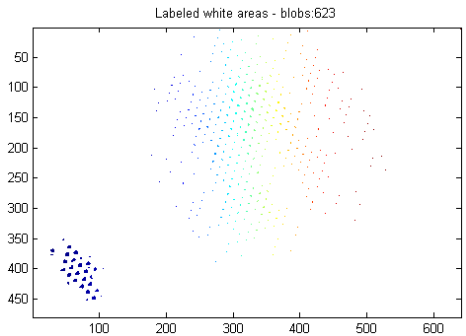
Segmentation



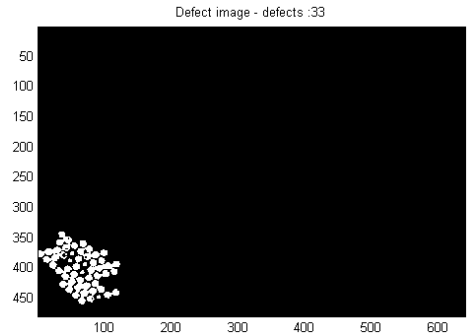


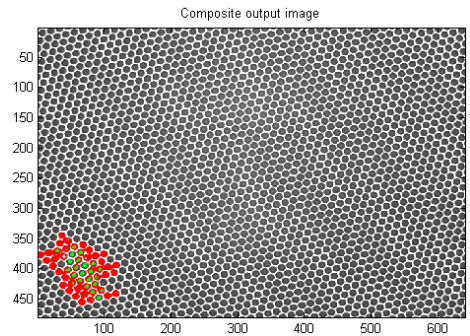
Morphology Labeling



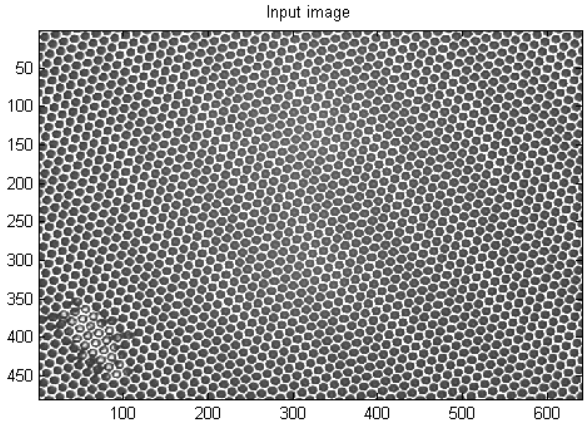


Defect detection

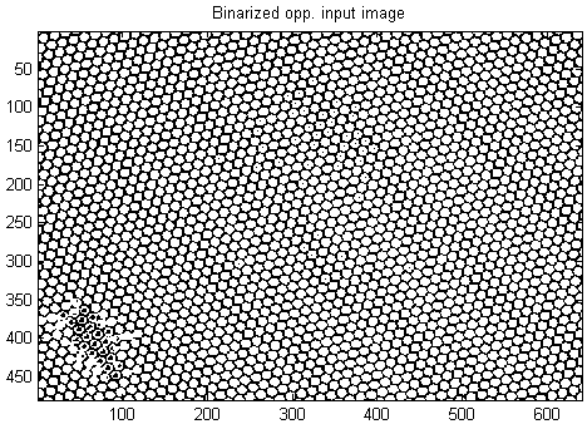




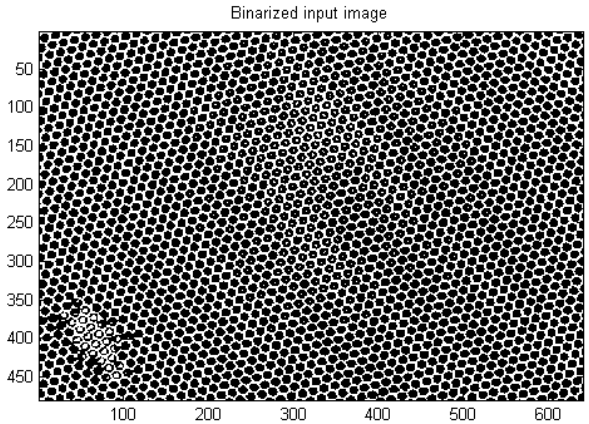
Segmentation



Global threshold θ



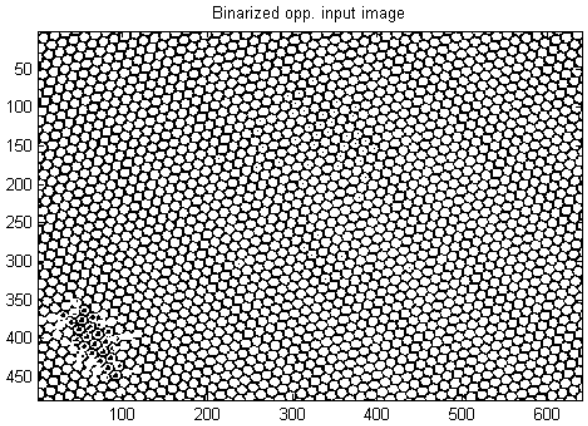
Lens regions



Metal + lens top regions

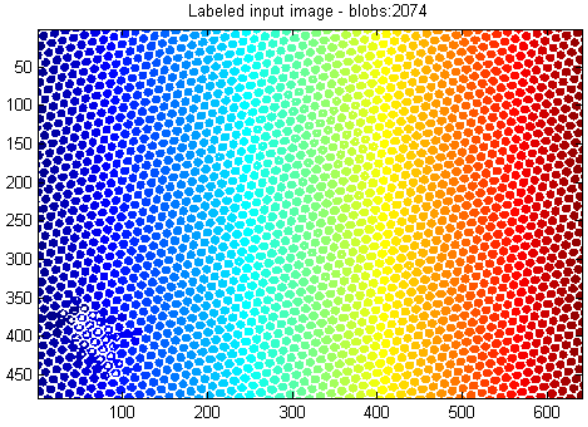
Morphology and labeling

Lens regions



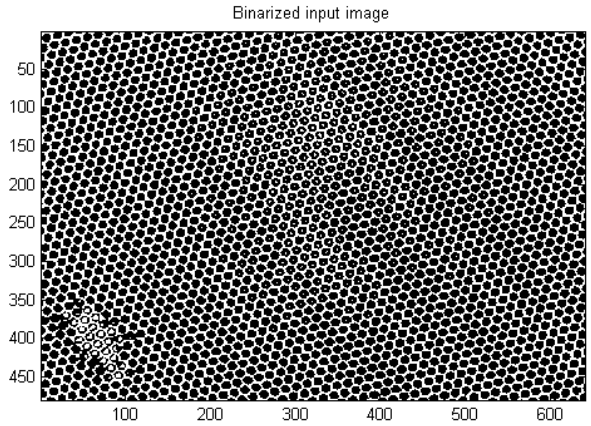
Denoising: Opening with 3x3 kernel

Labeling: V8 connected regions



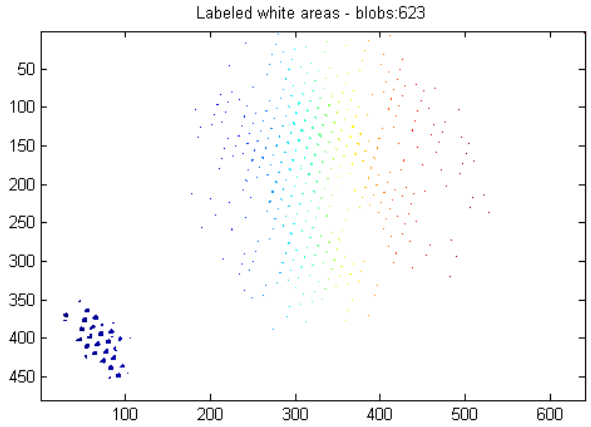
Lens blobs

Metal + lens top regions



Labeling: V8 connected regions

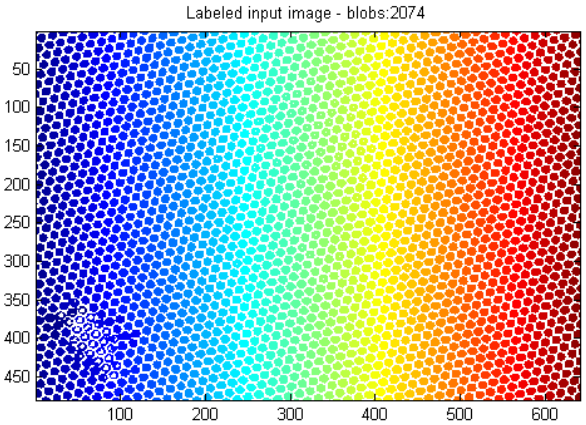
Removal of largest region (metal)



Lens top blobs

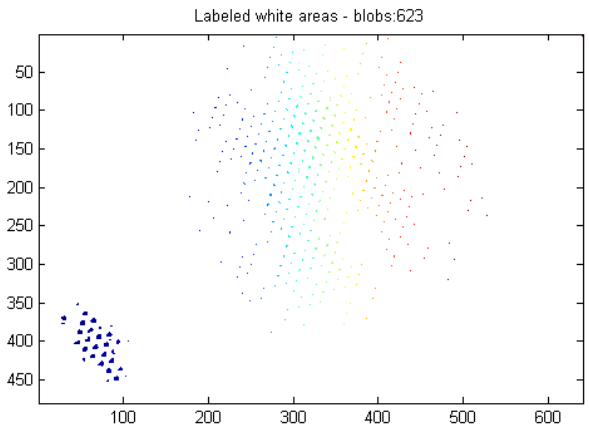
Blob area analysis

Lens blobs

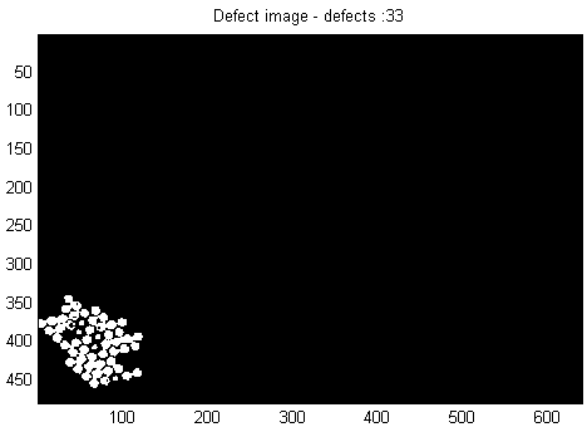


Area check: $A_{min,l} \leq A_l \leq A_{max,l}$

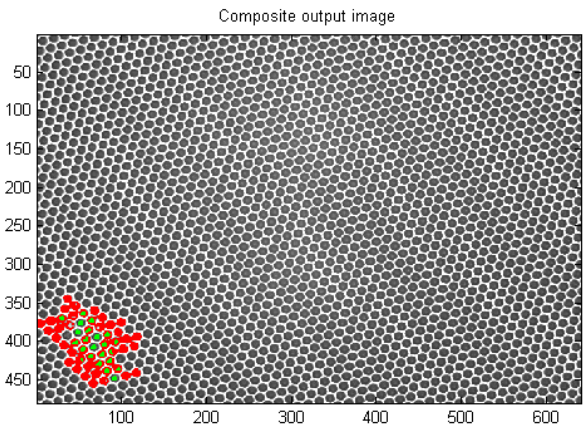
Lens top blobs



Area check: $A_m \leq A_{max,m}$



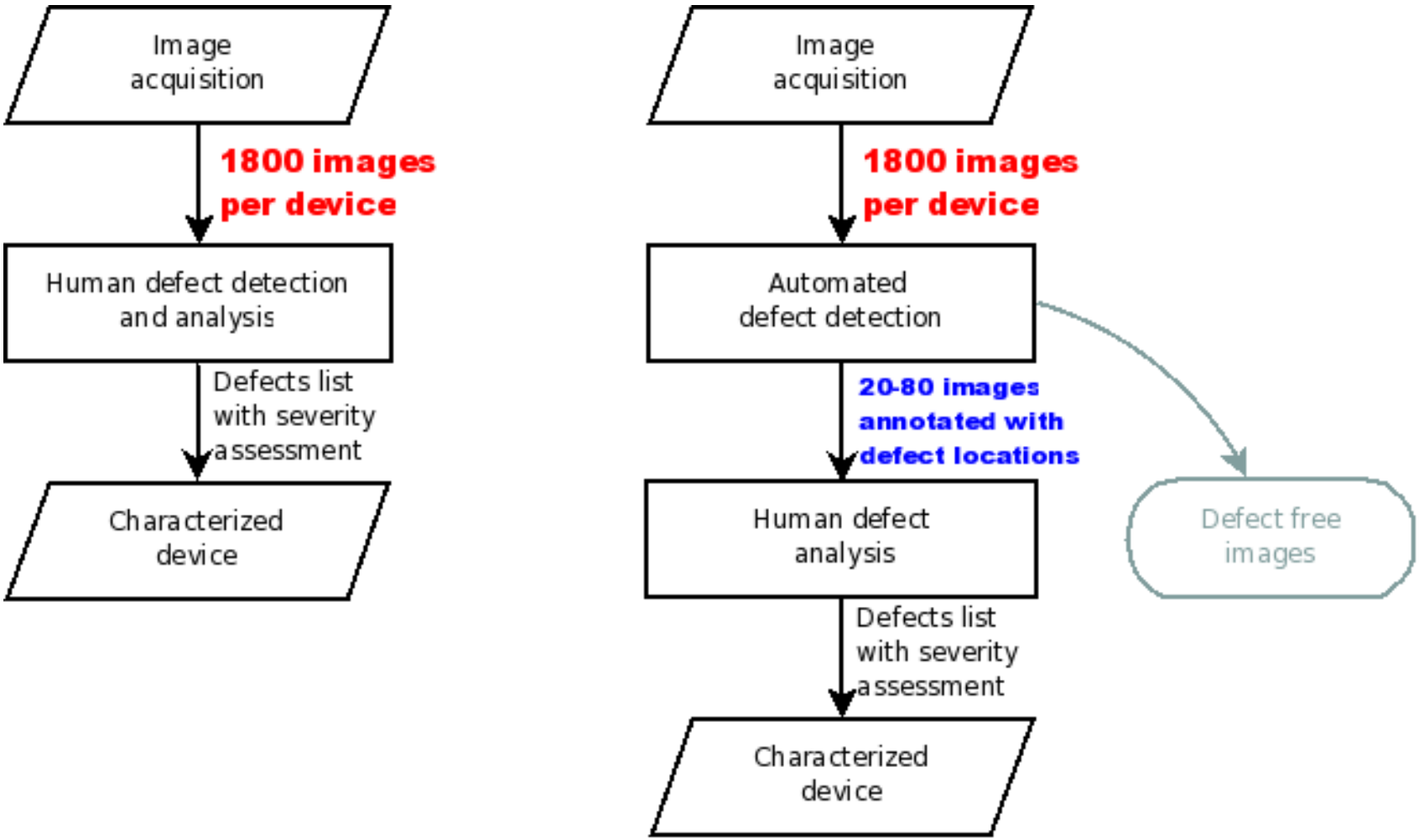
Defects map



Composite output

Outline

Semi-automated inspection system

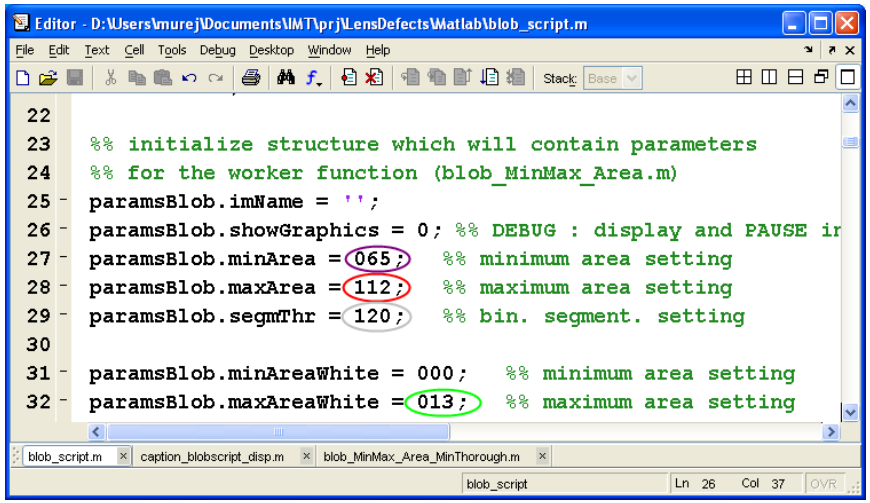


Blob area - Implementation

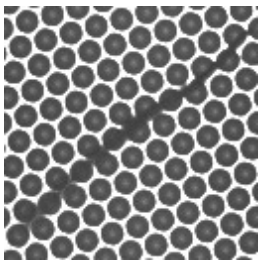
The defect detection module is implemented in Matlab and uses the Image Processing Toolbox.

Parameters considered:

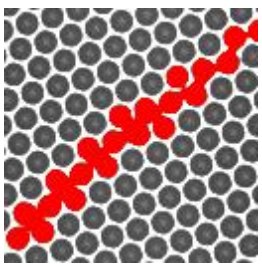
- segmentation intensity → `segmThr`
- lens area → `minArea, maxArea`
- maximum *hole* area → `maxWhiteArea`

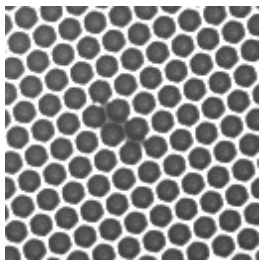


Blob area - Defect detection

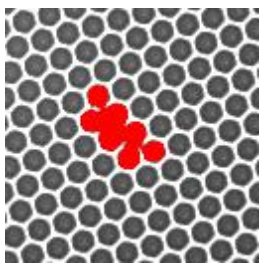


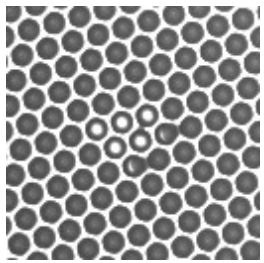
maxLensArea





maxLensArea

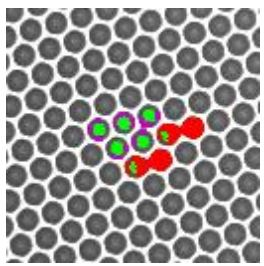


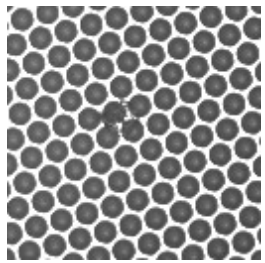


maxLensArea

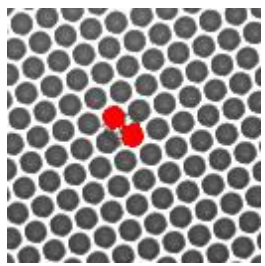
minLensArea

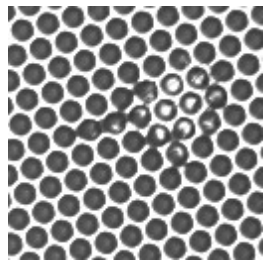
maxMetalArea





maxLensArea

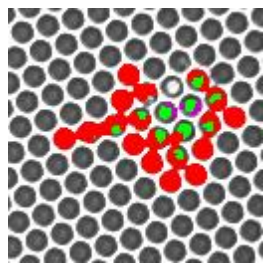




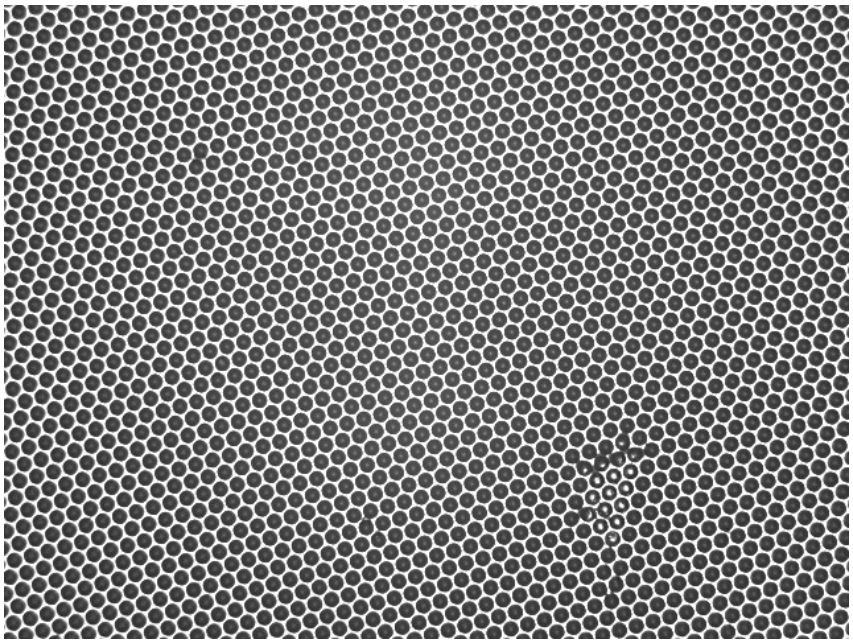
maxLensArea

minLensArea

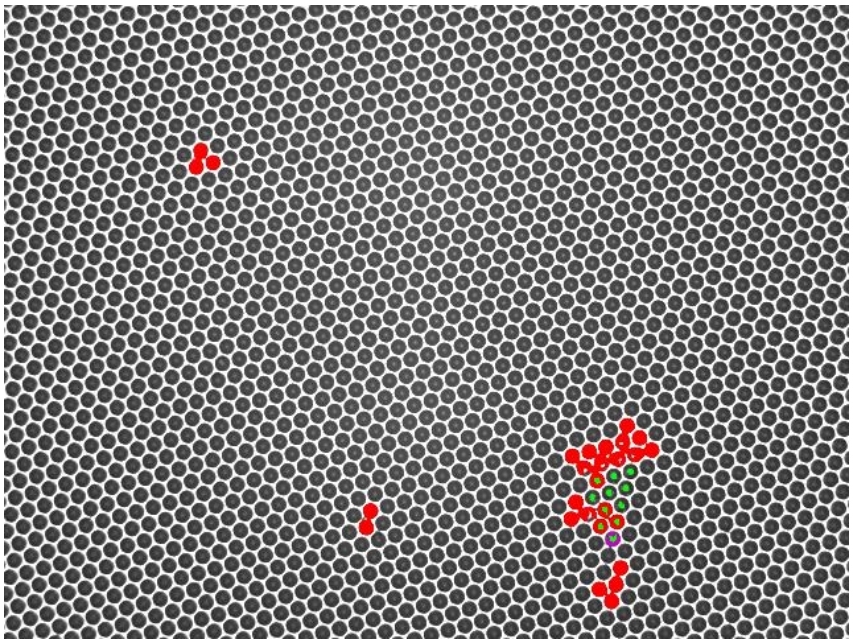
maxMetalArea



Blob area - Results

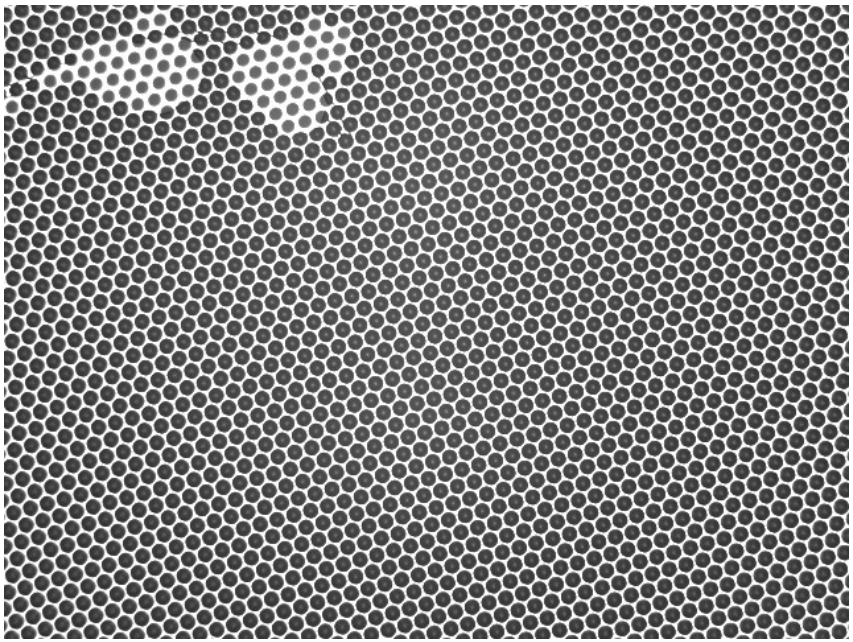


Test image

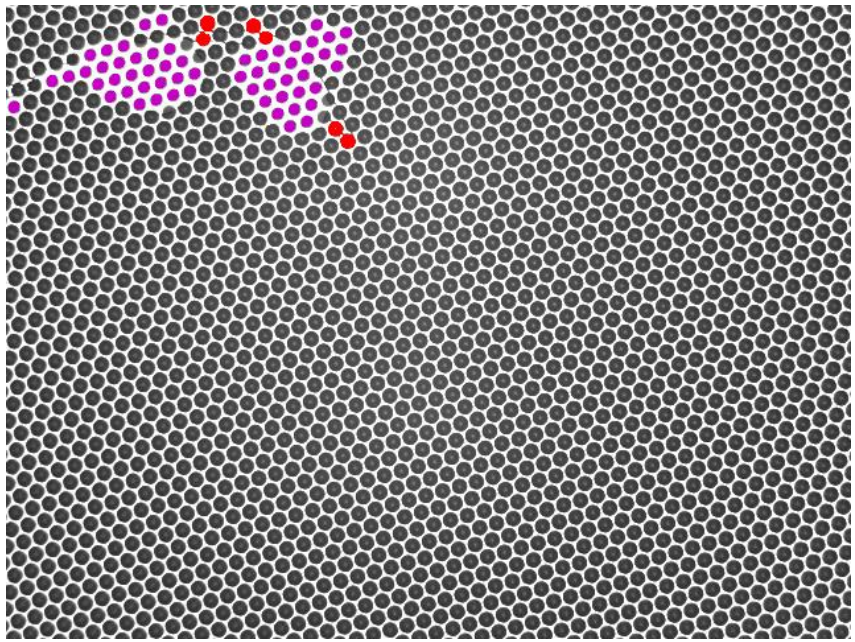


Composite output

Blob area - Results

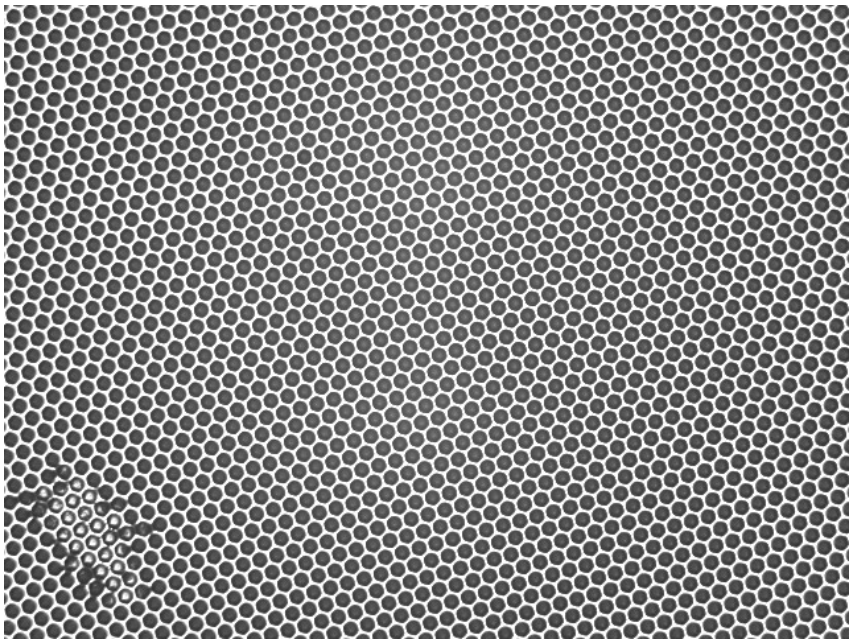


Test image



Composite output

Blob area - Results



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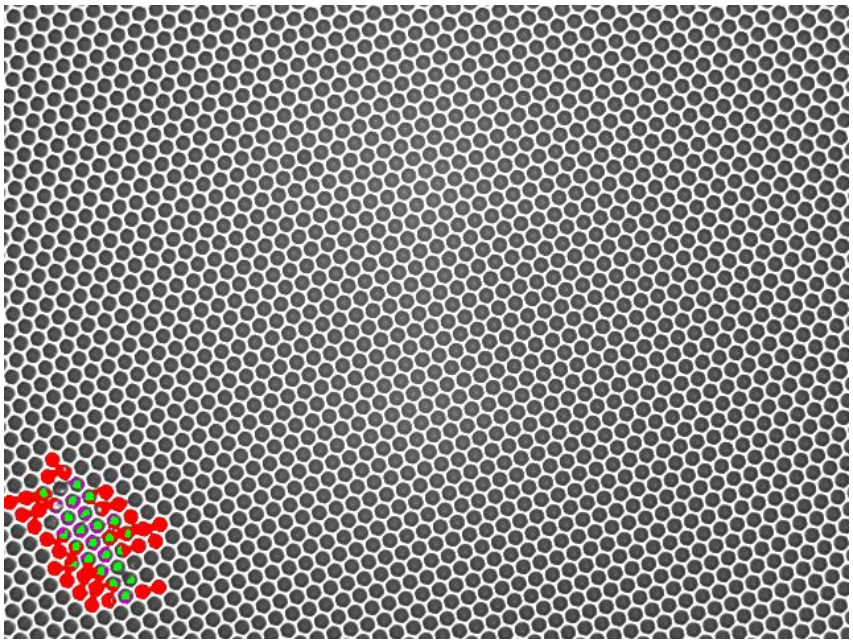
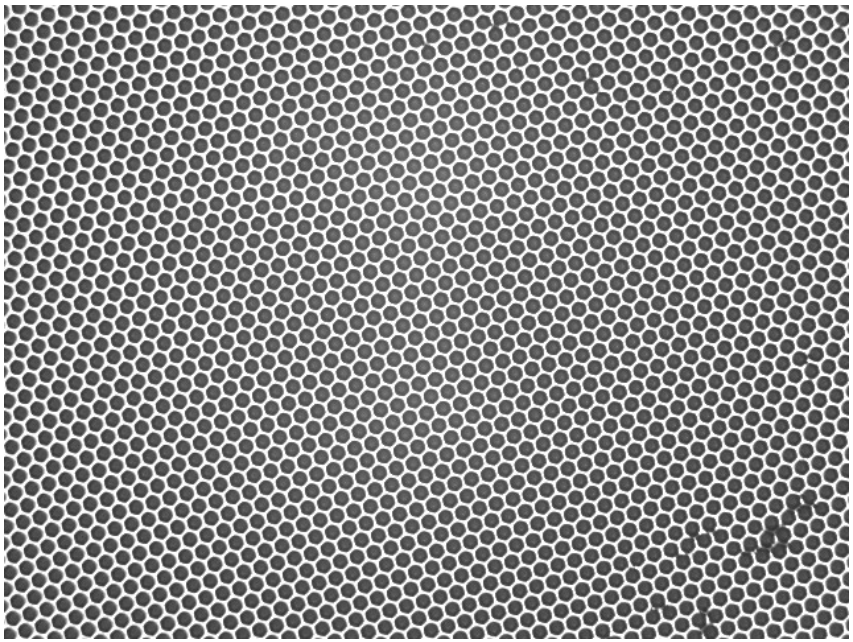
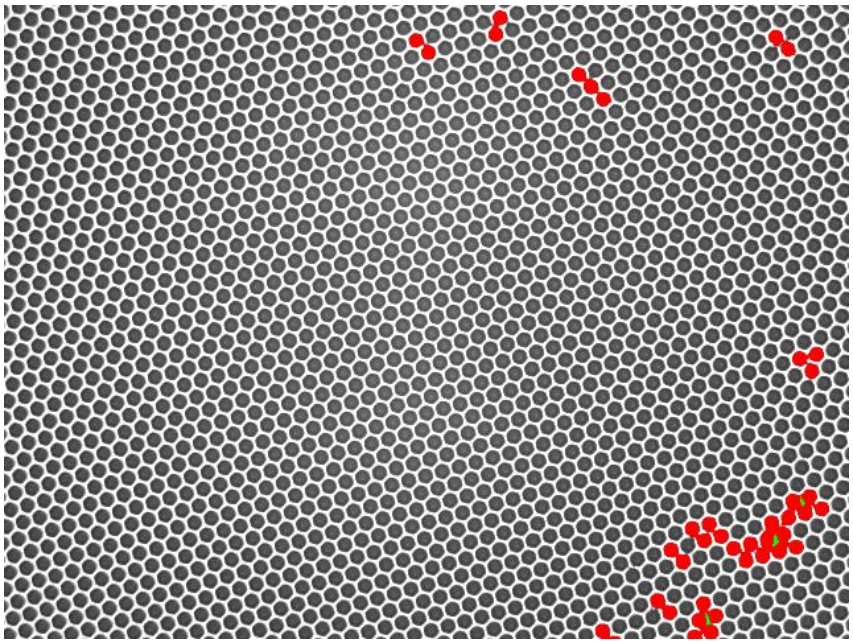


Composite output

Blob area - Results



Test image



Composite output

Blob area - Performance

Tests carried out on devices with a high number of defects.

Device	A	B
Images acquired	1804	1804
Defect detected automatically	446	242
Independent human annotation		
Defects found	133	58
False positive rate	**17.4%**	**10.2%**
False negative rate	**0%**	**0%**
Semi-automated human annotation		
Defects found	433	242
False positive rate	**0.72%**	**0%**
False negative rate	**0%**	**0%**

Outline

Conclusions

- Image processing methods enabling automation of microlens arrays inspection were studied
- An automated **defect detection** system was realized, based on a blob analysis method
- Tests confirm that no defect goes through the system.
- Tests show a low false positive rate: the human supervisor is freed from the burden of watching large series of defect free images.
- Possible improvements:
  - Automatic parameter generation from reference image**s**
  - Smarter segmentation methods (gradient based)

Acknowledgments

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Thank you for your attention !

Bibliography I


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Design, fabrication and testing of microlens arrays for sensors and microsystems.
Pure Appl. Opt., 6:617–636, 1997.