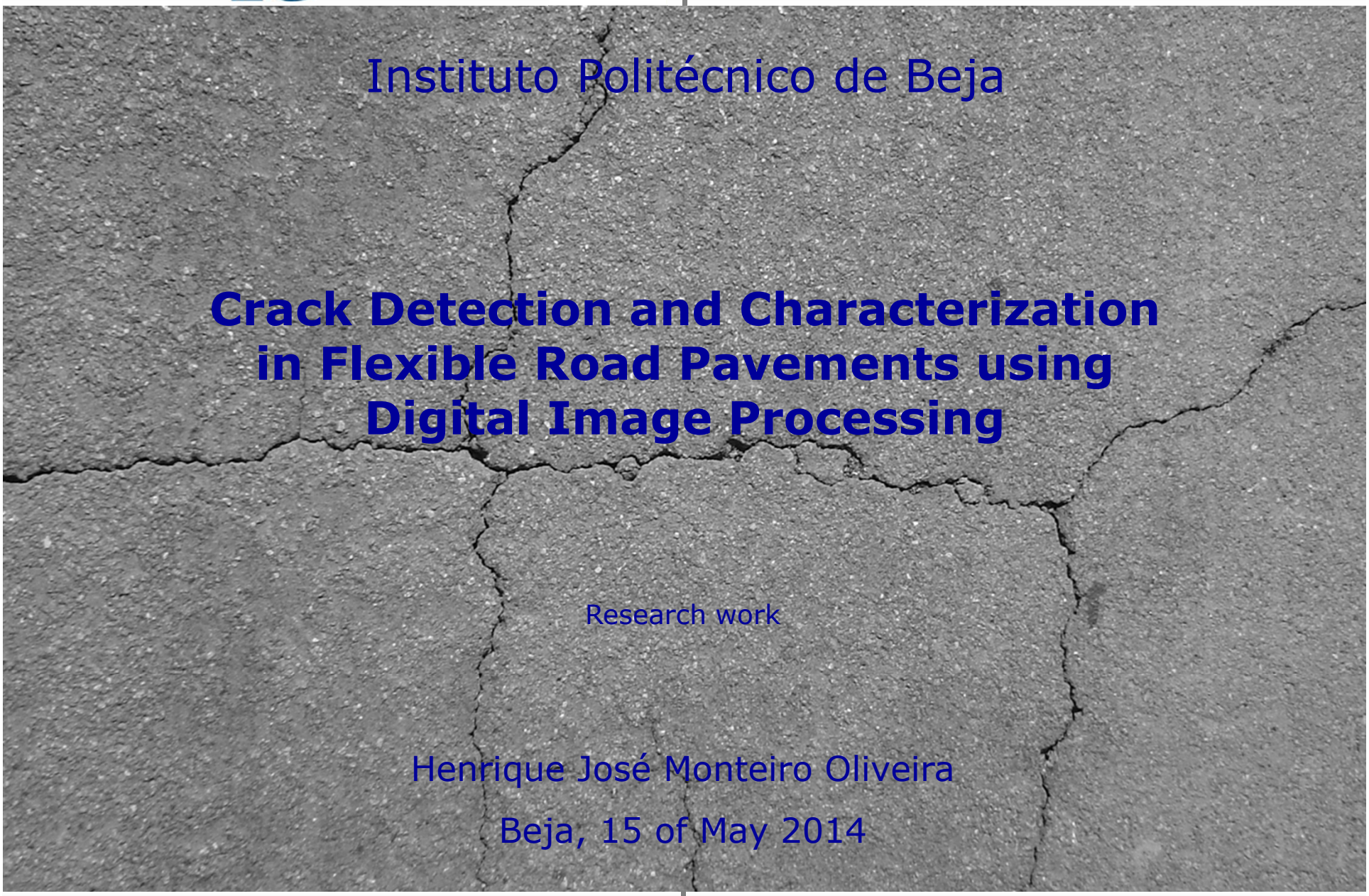


Instituto Politécnico de Beja

Crack Detection and Characterization in Flexible Road Pavements using Digital Image Processing

Research work

Henrique José Monteiro Oliveira

Beja, 15 of May 2014

OUTLINE:

1. Context and Motivation
2. Main Objectives
3. Proposed CrackIT System Architecture
4. Image Aquisition and Pre-processing
5. Crack Detection (block-based and pixel-based analysis)
6. Crack Type Characterization and Severity Level Assignment
7. Experimental Results
8. Conclusions and Future Work

1. Context and Motivation

- **Roads**
  (Important man-made infrastructures)

(Source -> http://www.map-of-portugal.co.uk/maps/road-map.gif)

- **Evaluate road pavement surface condition**
  (An important task)

(Source -> http://www.sendeasy.gr/blog/wp-content/uploads/2011/09/lorriesMotorway_1431412c_0.jpg)

(Source -> http://www.juremafm.com.br/web/webroot/uploads/img/JUREMA+FM/noticias/preview_97995_radios.jpg)

(Source -> http://www.flickr.com/photos/katebodger/4969307966/)

(Source -> http://www.halifax.ca/designcon/cons/images/SDI2.JPG)

1 – Context and Motivation

➢ Traditionally surveys

(Inspectors at road edges, as well as doing manual labeling while driving - dangerous?)

(Source -> http://www.arrb.com.au/ admin/file/ content2/ c3/Road%20inspection.JPG)

(Source -> http://img.ksl.com/slc/532/53276/5327681.jpg)

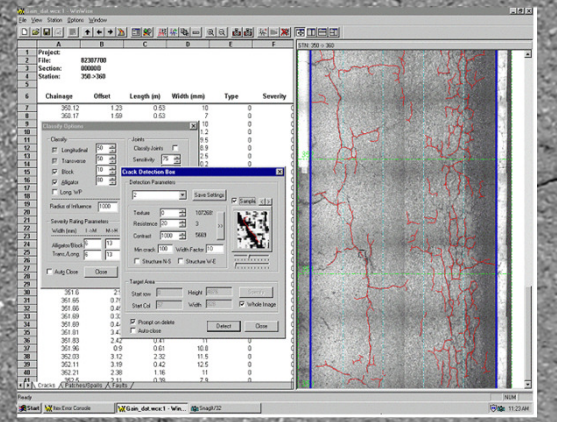
➢ Automatic surveys

(Acquiring images by special imaging devices carried by fast surveying vehicles for posterior analysis)

Automatic surveys

(Source -> http://www.roadware.com/images/ aran-9000-207601-09000600.jpg)

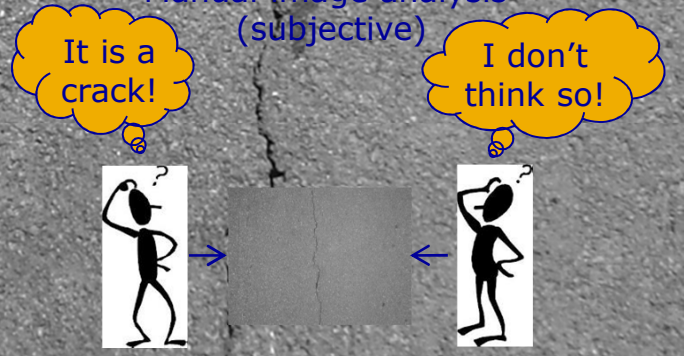
Automatic image analysis



(Source - http://www.roadware.com/ Software/ W<iseCrax_Software/)

Manual image analysis (labor-intensive)

Manual image analysis (subjective)



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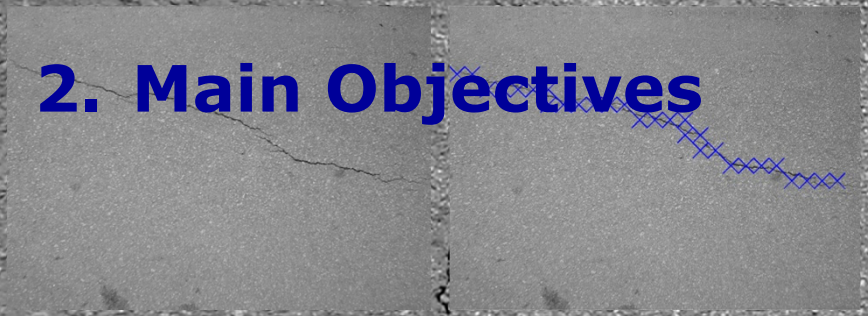
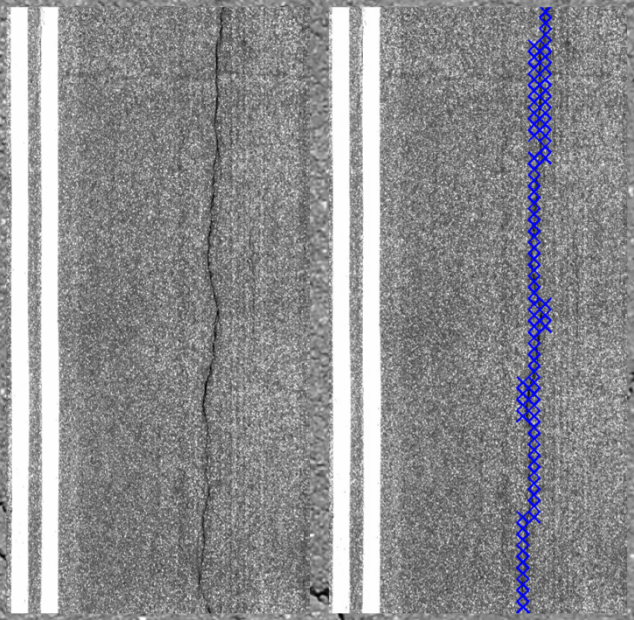
2. Main Objectives

➢ What is proposed by the CrackIT system?

✓Crack detection:



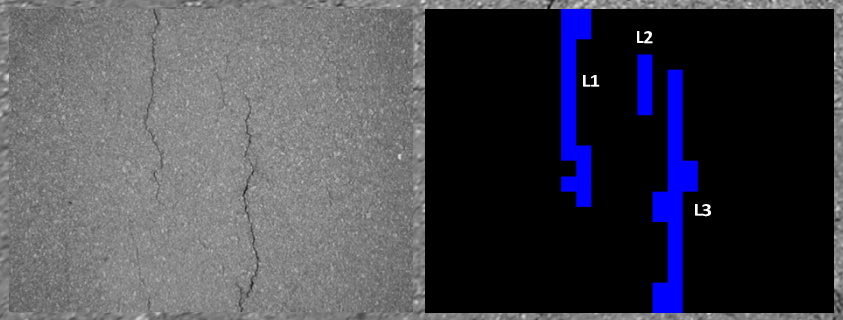
Original image — Processed image



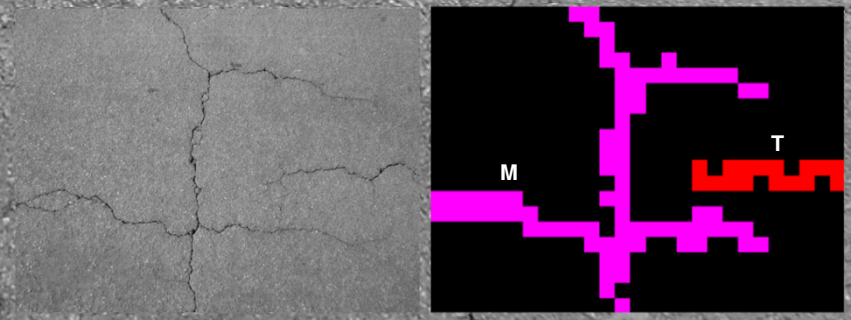
Original image — Processed image

✓Crack type characterization:

- Longitudinal (L), Transversal (T), Miscellaneous (M):
  (National Distress Catalogs: USA, French, Spanish, Portuguese)



Original image — Crack types

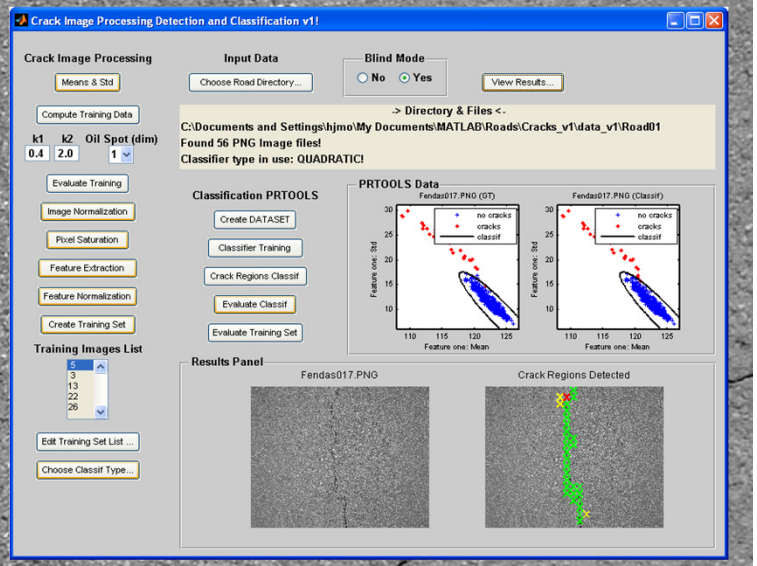


Original image — Crack types

2. Objectives and Original Contributions

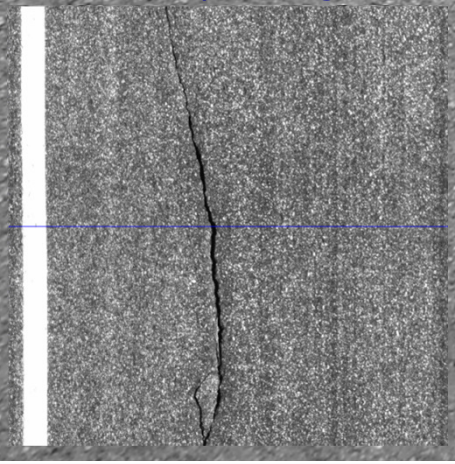
Major contributions:

- **Proposal of a novel fully automatic crack detection strategy**:
  - combining image analysis at two levels:
    - block-based, using pattern recognition techniques;
    - pixel-based, using digital image processing techniques.

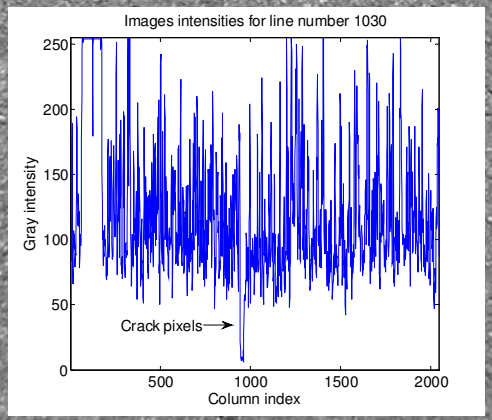


- **Proposal of a novel image smoothing technique**:
  - R-UINTA, based on the UINTA technique (Suyash and Whitaker, 2006), with improved entropy reduction and computationally more efficient;

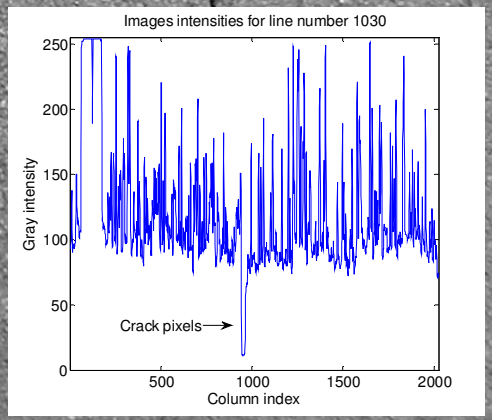
Sample image



Original intensities



Smoothed intensities

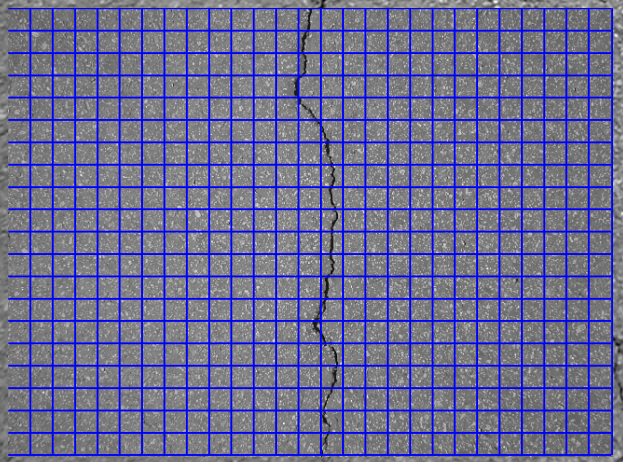


Major contributions:

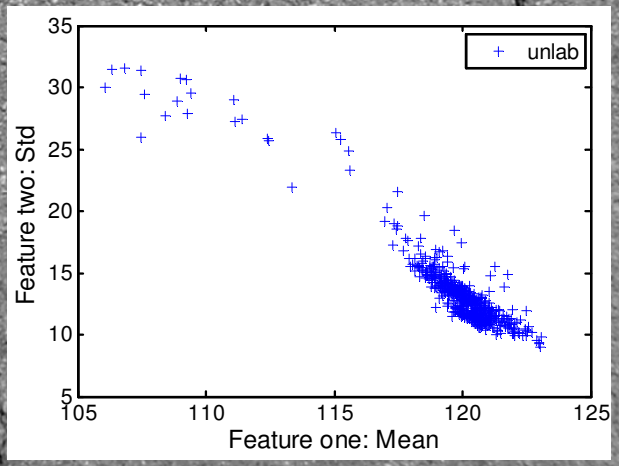
- **Proposal of a novel preliminary crack detection strategy**, whose results are used:
  - firstly, at pre-processing stage, allowing to simplify images and prepare them for a more efficient crack detection;
  - secondly, to automatically select images to train the novel crack detection pattern recognition system;

- **Proposal of a novel two-dimensional feature space:**
  - used by the pattern recognition system to detect cracks in images.

Sample image divided into blocks



Sample 2D feature space

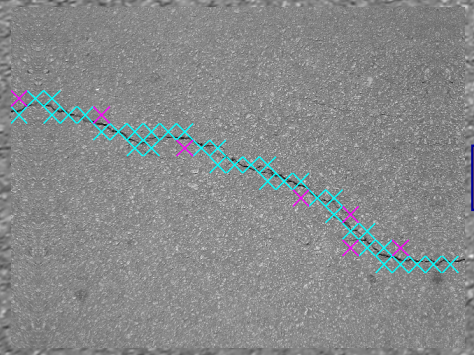


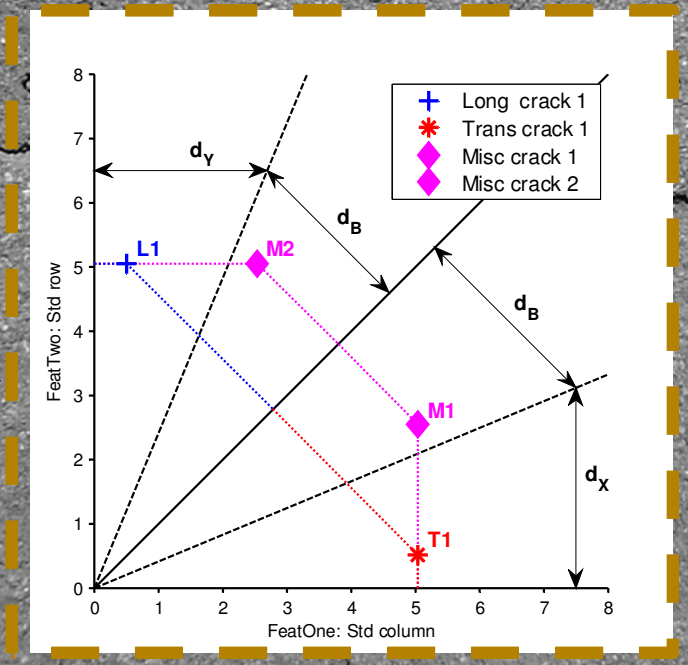
Major contributions:

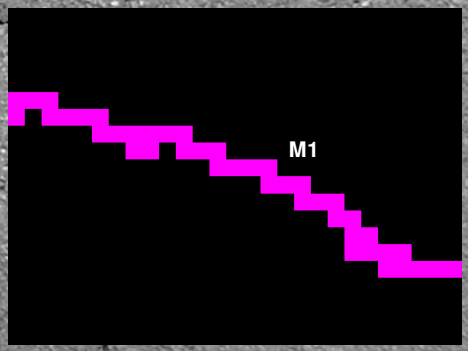
- **Proposal of a novel crack type classification algorithm**:
  - to automatically characterize the detected cracks as Longitudinal (L), Transversal (T) or Miscellaneous (M);

Novel feature space developed for cracks characterization

Crack detection results

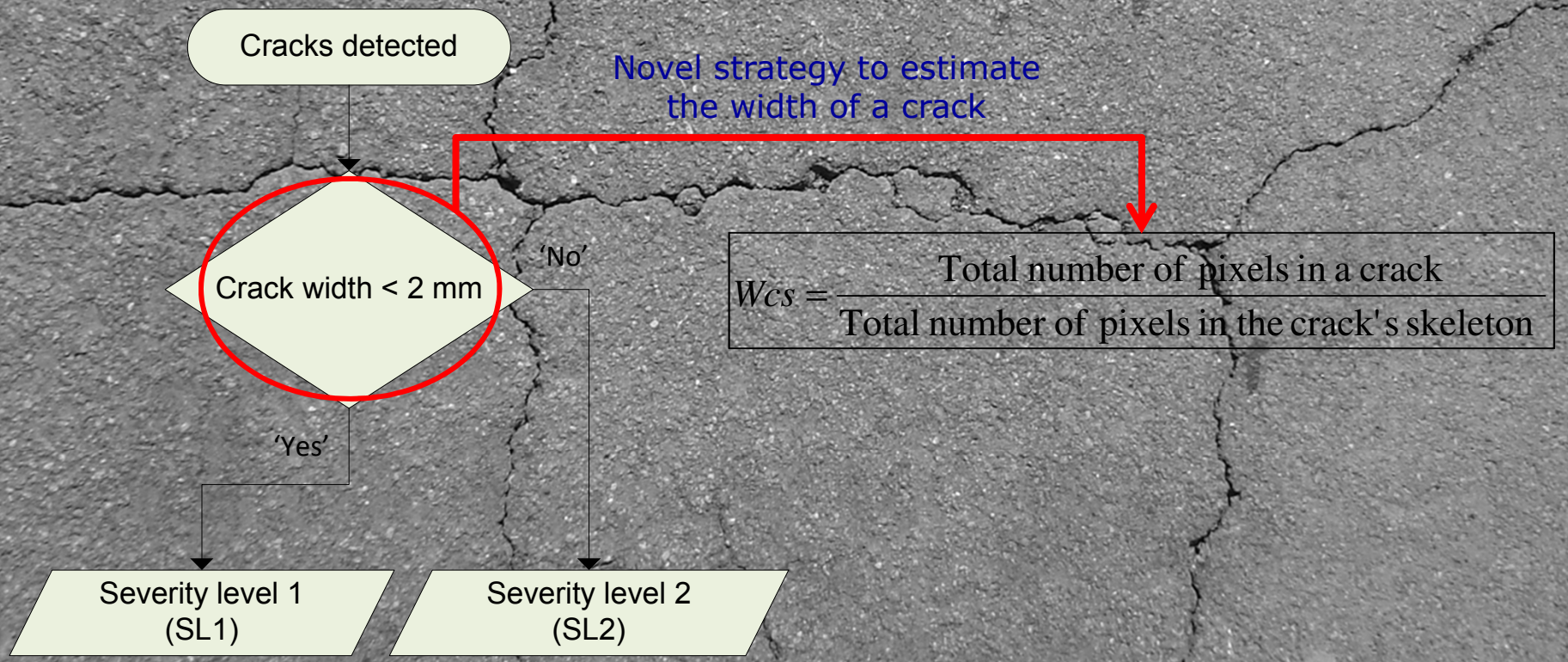






Major contributions:

- **Proposal of a novel crack severity labeling procedure:**
  - based on a novel strategy to estimate the width of a crack, to automatically assign one of the severity labels foreseen in the Portuguese Distress Catalog (JAE, 1997) to each of the detected cracks (SL1, SL2 & SL3);



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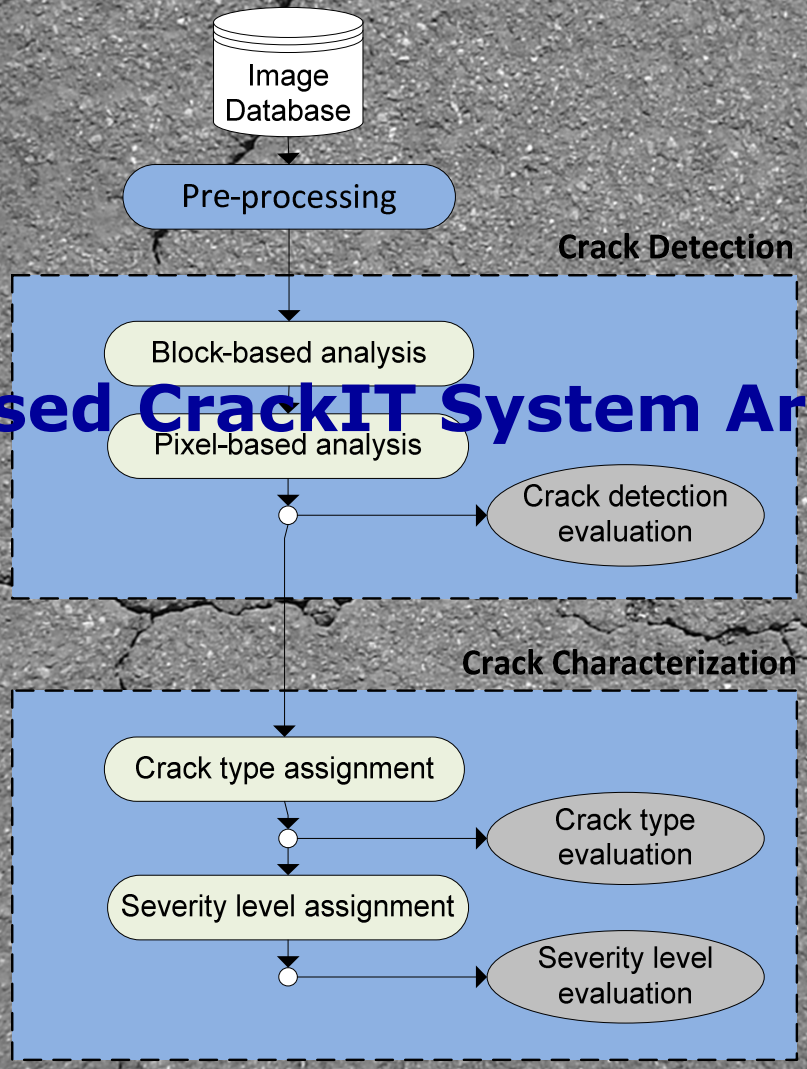
3. Proposed CrackIT System Architecture



Evaluation metrics: Recall *(re)*; Precision *(pr)*; F-Measure *(Fm)*

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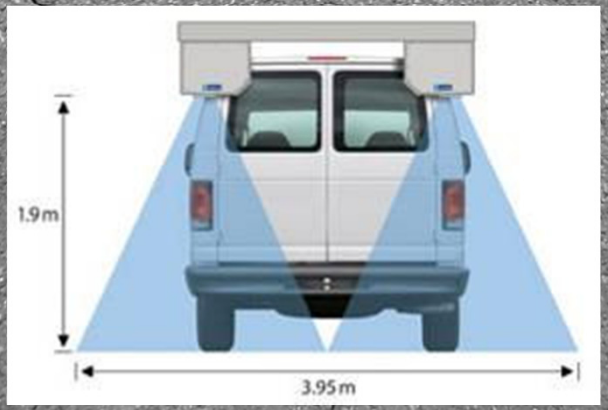
4. Image Aquisition and Pre-processing

- **Human survey (ImgSet1):**
  - Inspection made when traveling along the surveyed road;
  - 2048 x 1536 pixels, with ~1 pixel/mm^2.

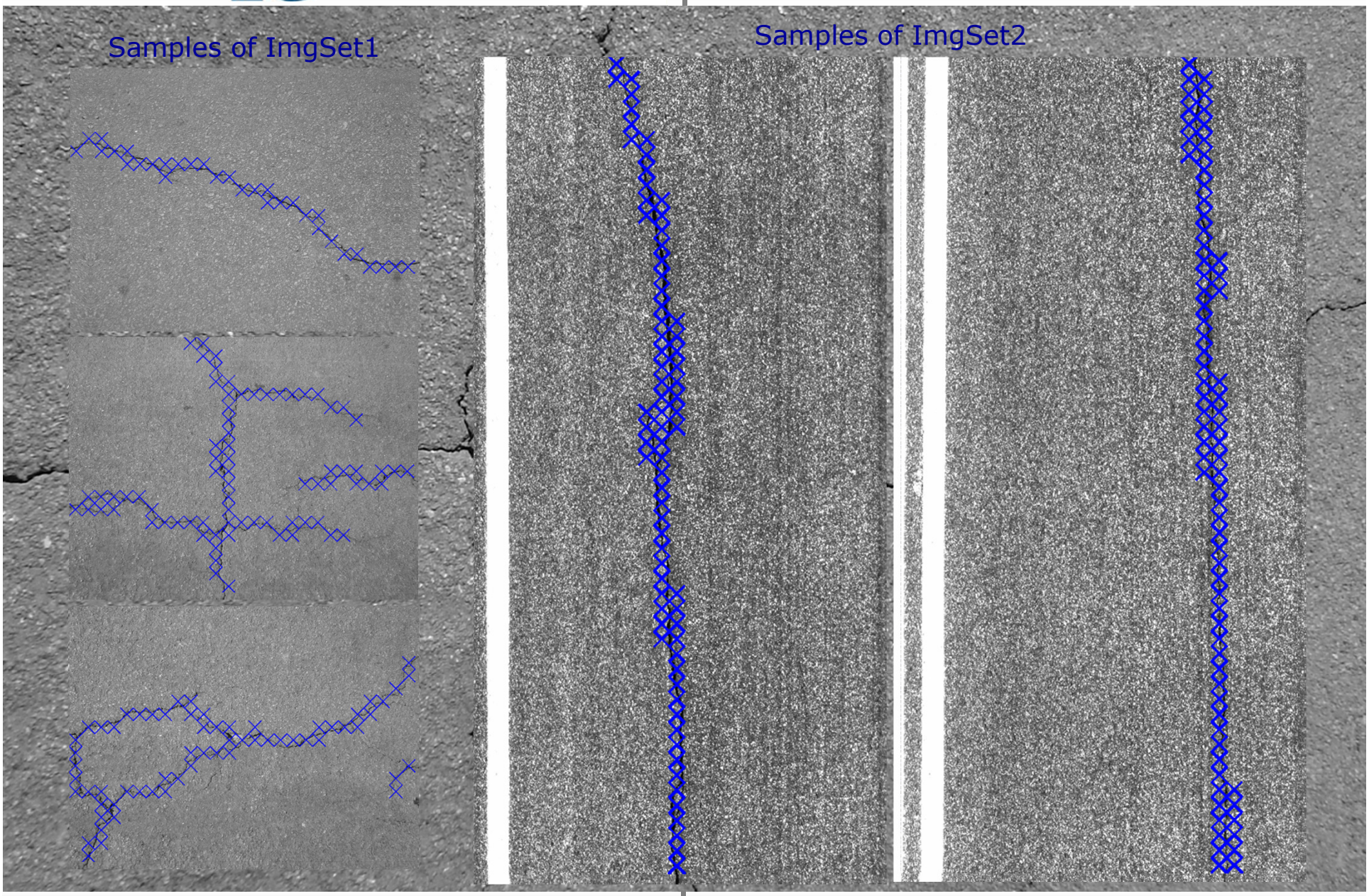
(Source -> http://www.sony.pt)

- **Automatic Surveys (ImgSet2):**
  - Using active illumination imaging systems, like the one developed by the INO LRIS 4K model;
  - 4096 x 2048 pixels, with ~1 pixel/mm^2.



(Source -> http://www.ino.ca/en-ca/achievements/description/project-p/laser-road-imaging.html)

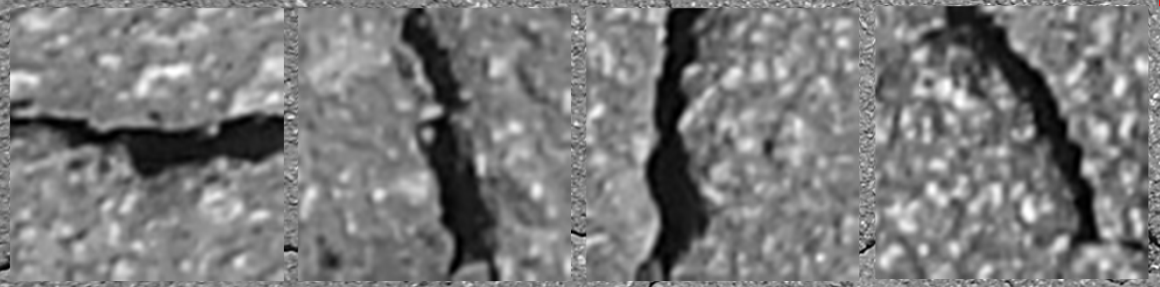
4. Image Aquisition and Pre-processing

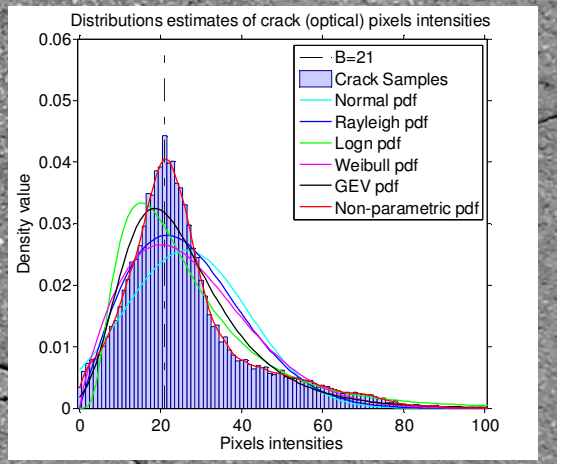


➢ Synthetic images

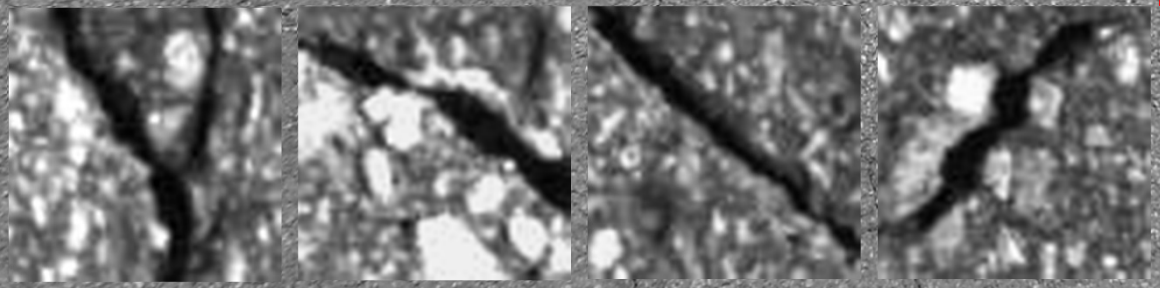
- Created to obtain a reference measurement of the performance of the smoothing algorithms developed.

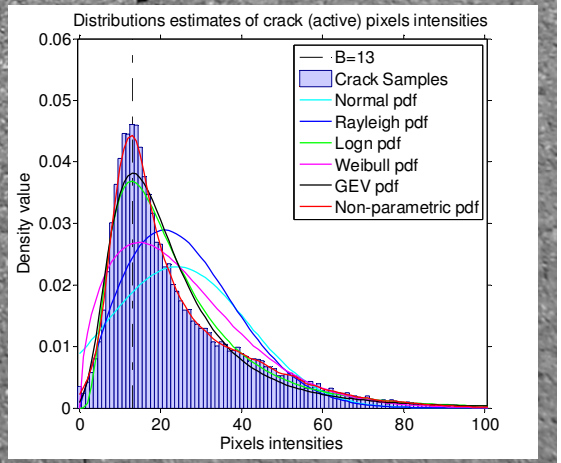
Samples of $S_{ImgSet1}(50)$





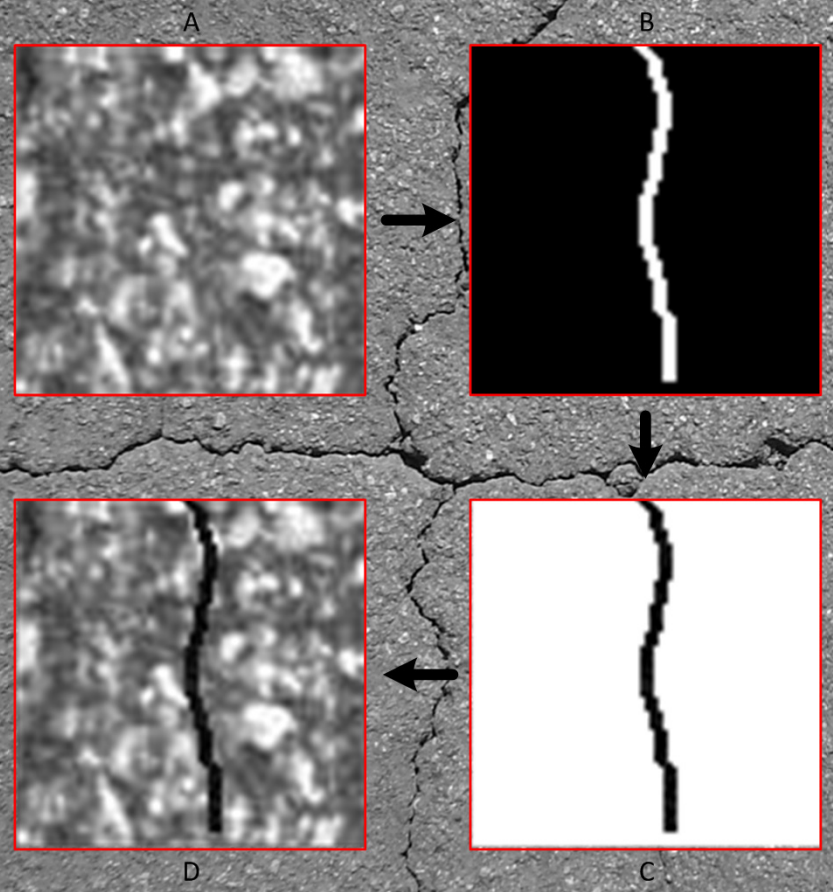
Samples of $S_{ImgSet2}(50)$





4. Image Aquisition and Pre-processing

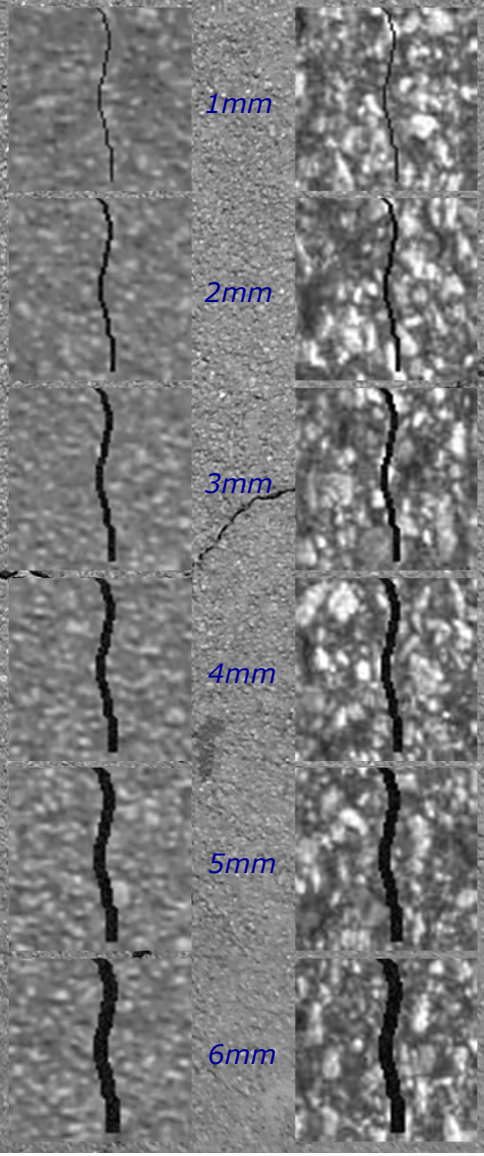
➢ Generation of synthetic imagery



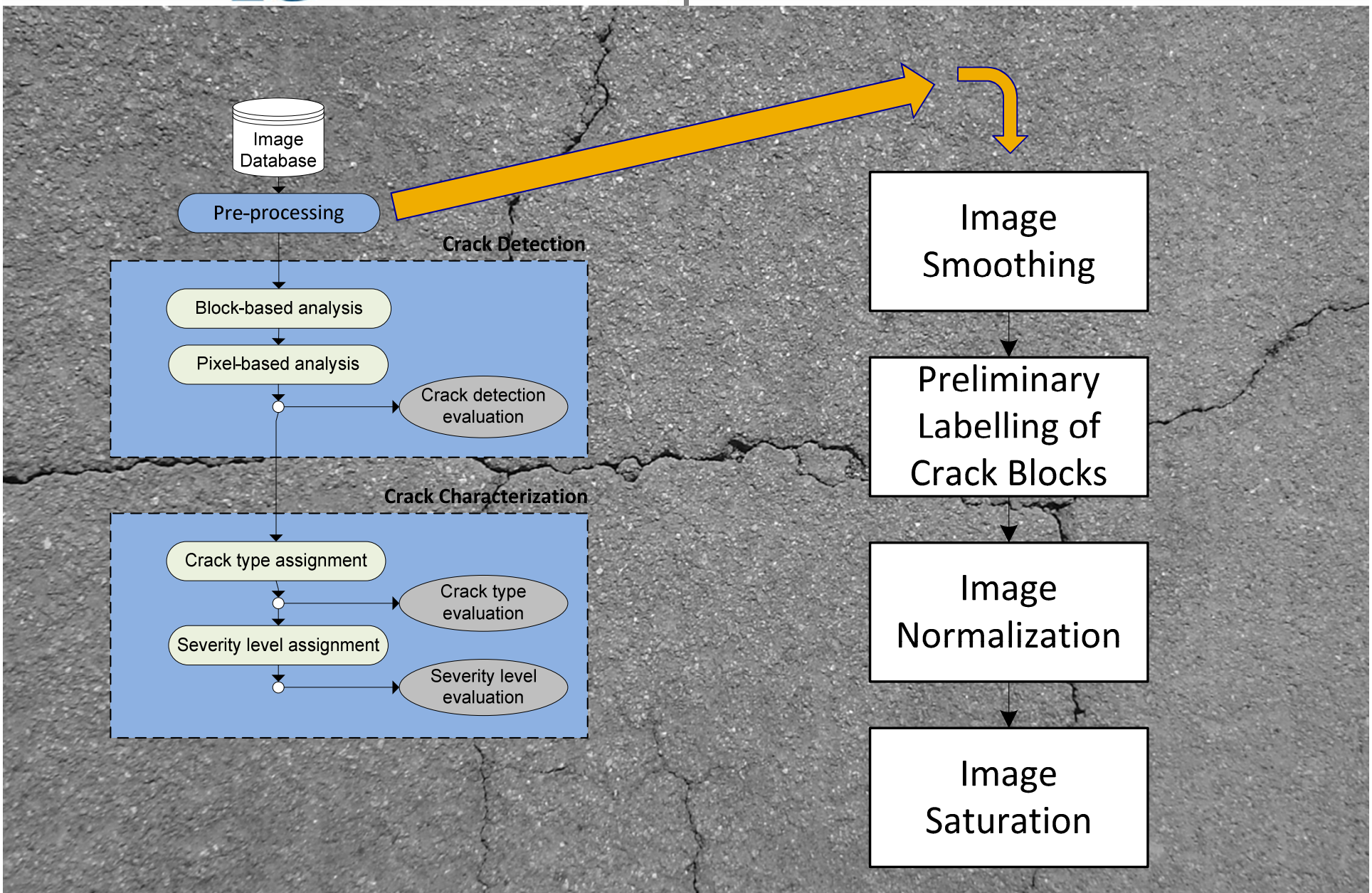
A- Original image
B- Binary mask
C- Crack pixels intensities generated using GEV distribution
D- Final synthetic image

Samples of ImgSet3

Samples of ImgSet4



4. Image Aquisition and Pre-processing

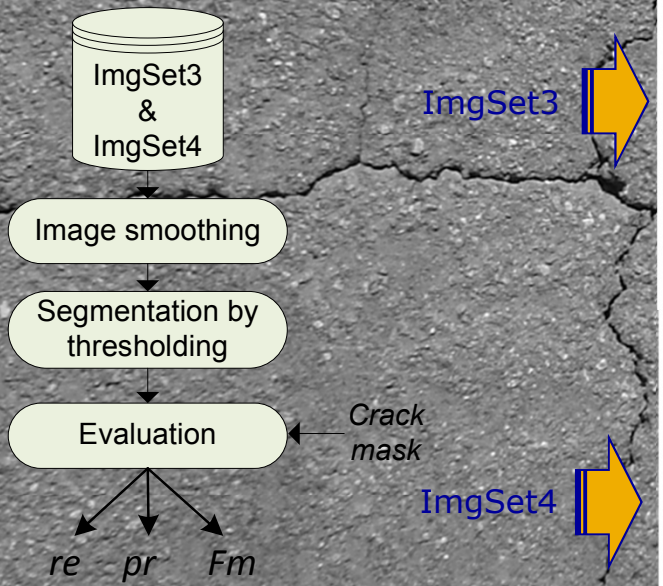


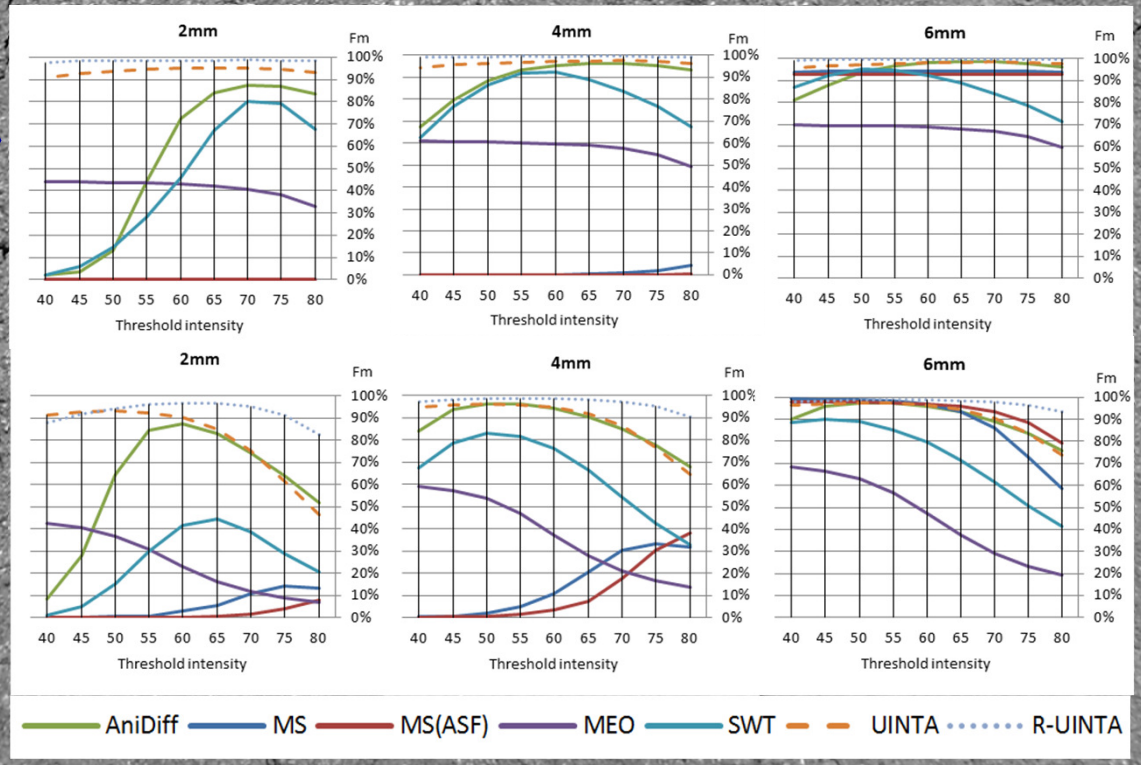
4. Image Aquisition and Pre-processing

➢ Image smoothing:

- **Unsupervised Information-theoretic Adaptive Image filtering with Reduced Dimensionality (R-UINTA)**
  - Unsupervised Information-theoretic Adaptive Image filtering (UINTA) – [Awate and Whitaker, 2006: IEEE T-PAMI]
  - Anisotropic diffusion – [Nguyen, Avila and Stephane, 2009: EUSIPCO]
  - Morphological smoothing (with and without ASF) – [Yu, 2011:]
  - Morphological erosion followed by opening – [Yu, 2011: MSc]
  - Wavelet denoising (SWT) – [Subirats et al., 2006: ICIP]

➢ Evaluation procedure of smoothing techniques:





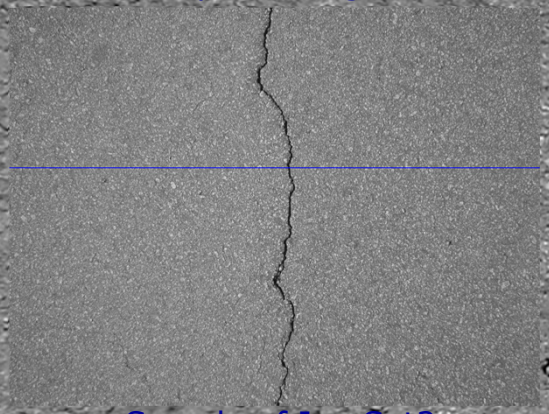
The number of operations in R-UINTA is 60 times less than with UINTA.

4. Image Aquisition and Pre-processing

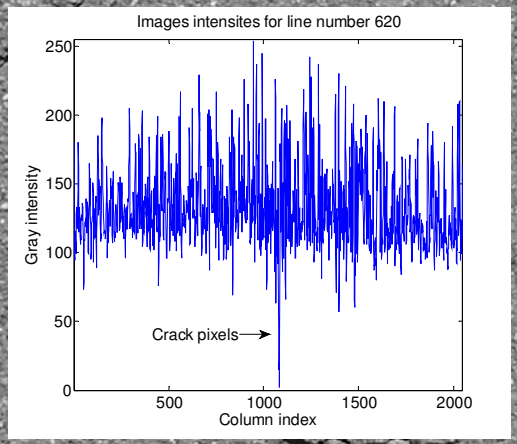
➢ Sample results of image smoothing:

R-UINTA

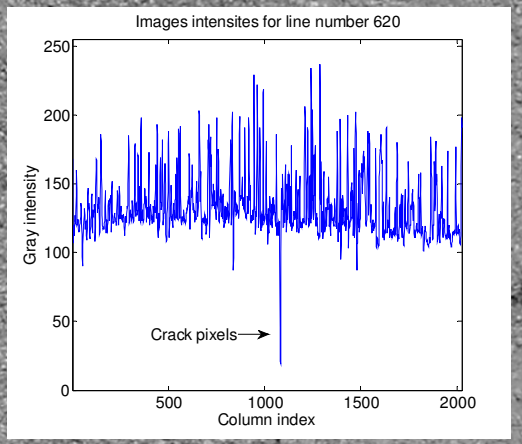
Sample of ImgSet1



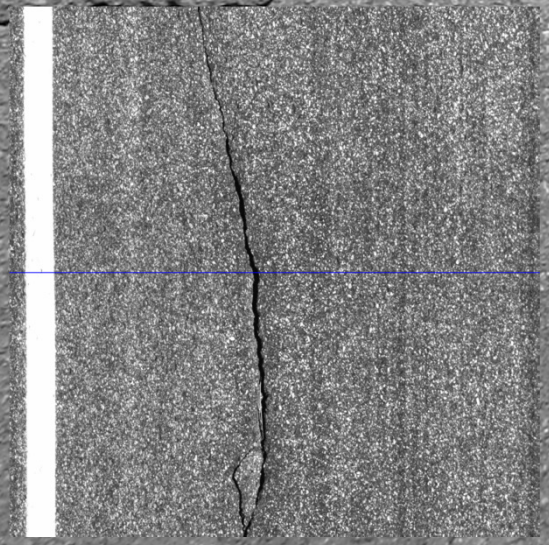
Original intensities



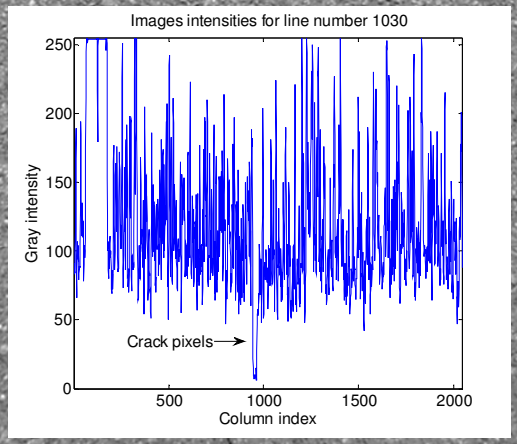
Smoothed intensities



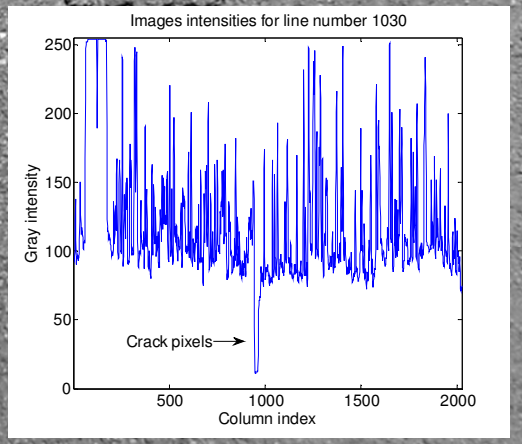
Sample of ImgSet2



Original intensities



Smoothed intensities

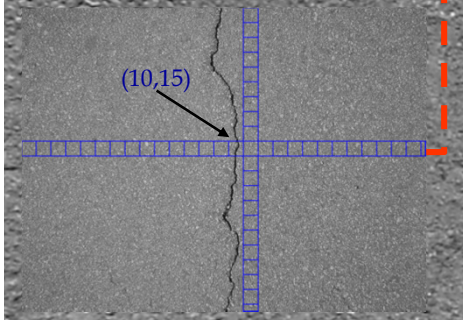


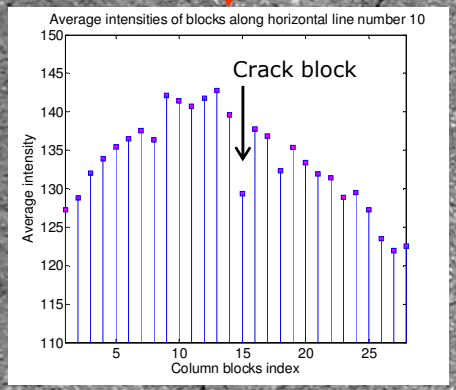
4. Image Aquisition and Pre-processing

➢ Preliminary labelling of 'crack' blocks:

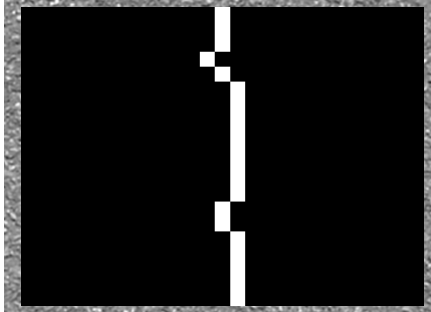
(Fm=91%->ImgSet1; Fm=68%->ImgSet2)

Original image (ImgSet1)



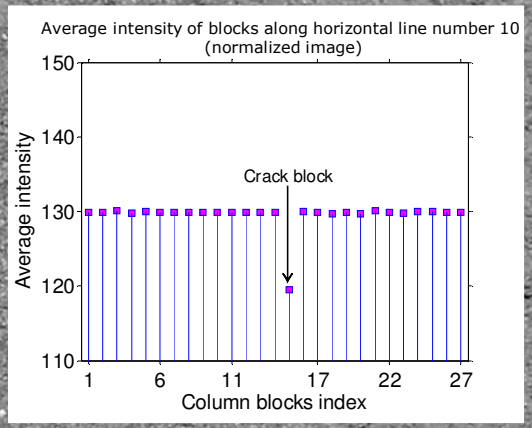


Output image (ImgSet1)



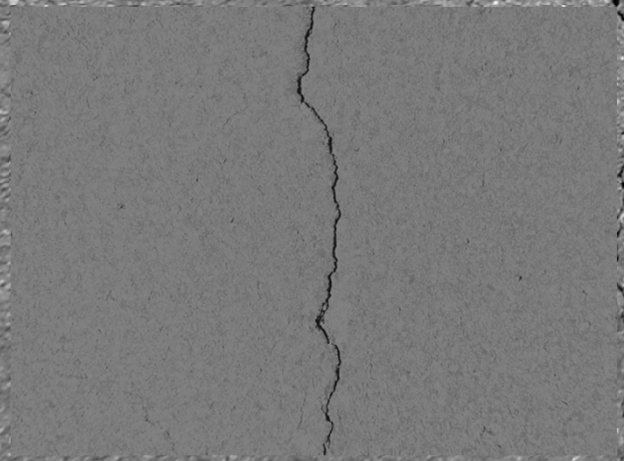
➢ Image normalization:

(only ImgSet1)

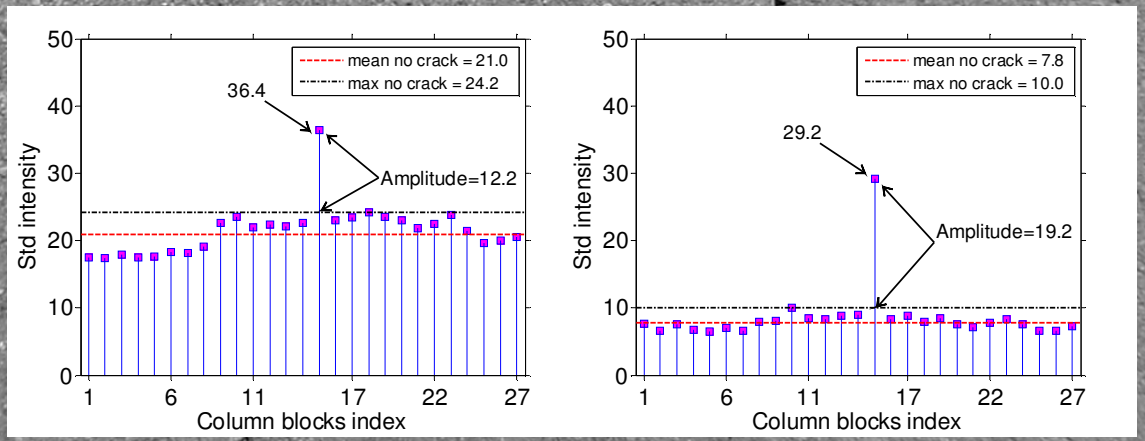


➢ Image saturation:

Saturated image (ImgSet1)



Block's average intensity values along the row selected for the image considered, before (left) and after applying the saturation algorithm (right)



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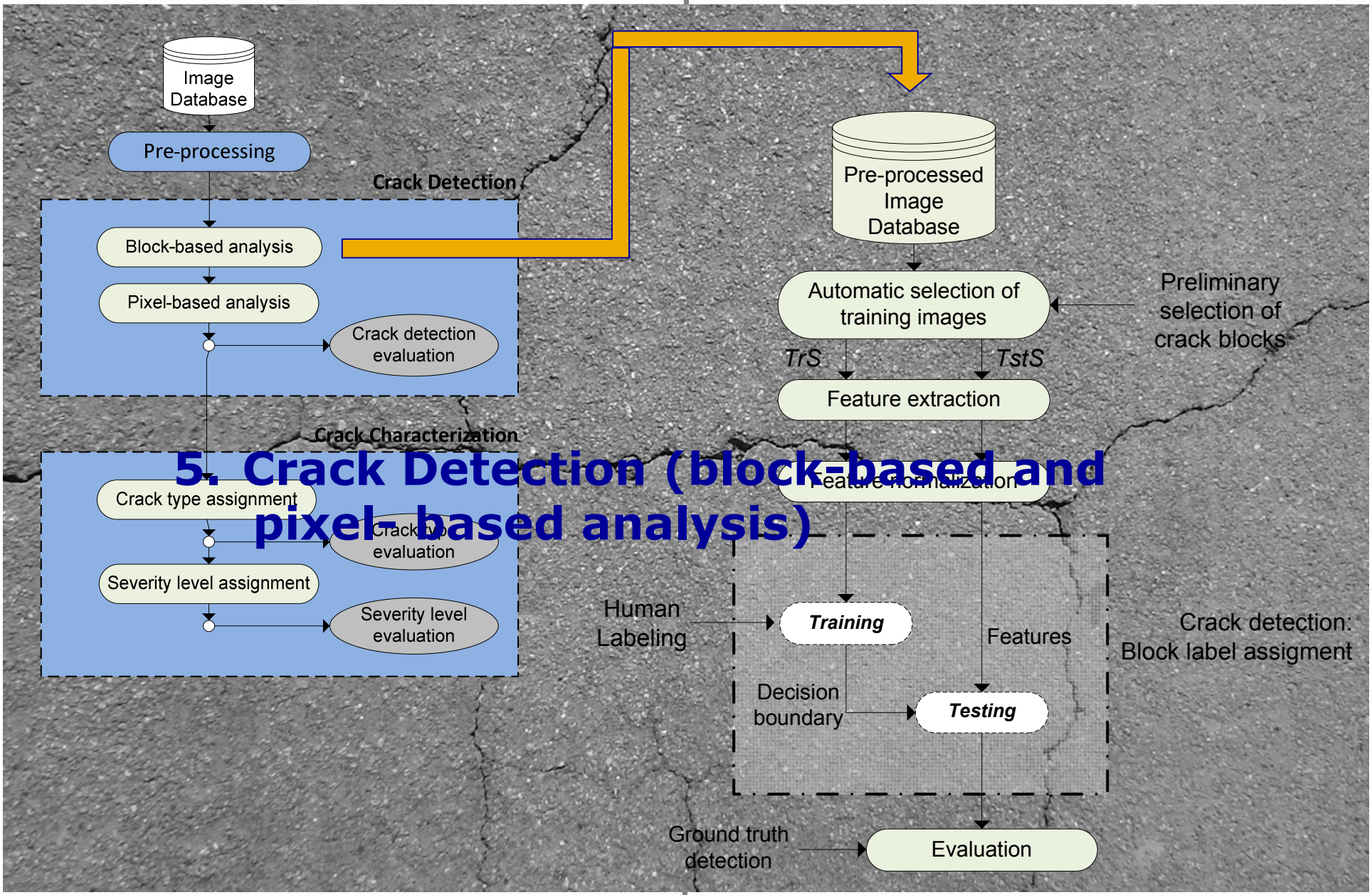
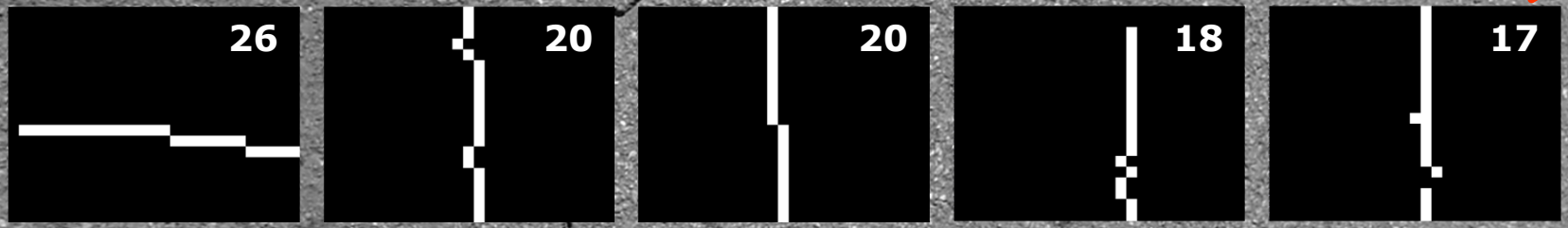
5. Crack Detection (block-based and pixel- based analysis)



5. Crack Detection (block-based and pixel-based analysis)

Automatic selection of training images:

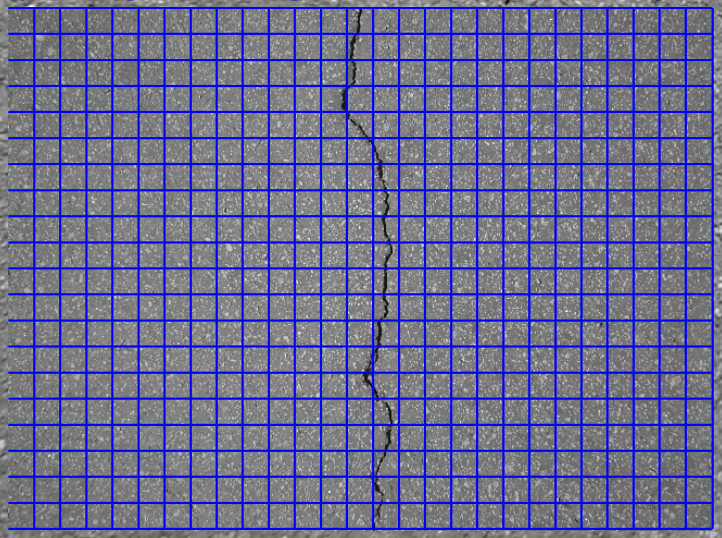
- Sorting all images in descending order of the value of the longest connected component found based on the preliminary selection of 'crack' blocks.



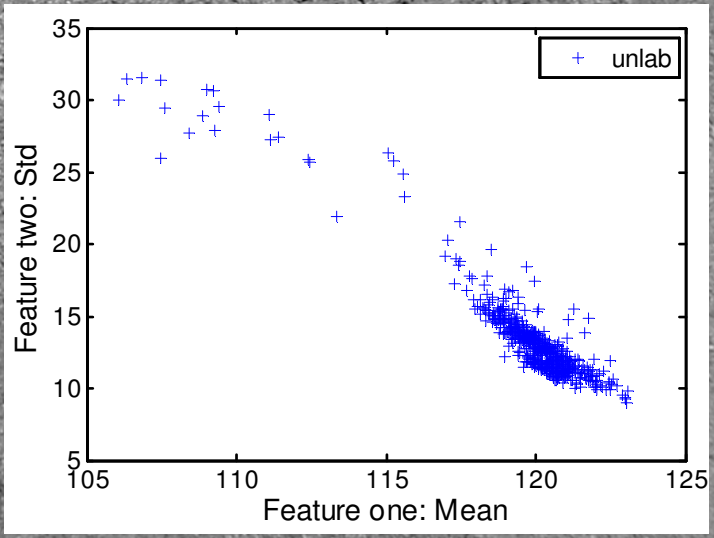
Feature extraction:

- Feature one: **mean** values of pixel normalized and saturated intensities;
- Feature two: **standard deviation** values of pixel normalized and saturated intensities.

Sample ImgSet1 image divided into blocks (75x75)

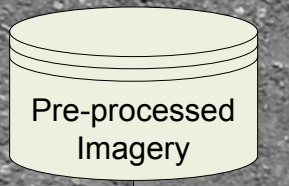


Sample 2D feature space



5. Crack Detection (block-based and pixel-based analysis)

➢ Feature normalization:
(to reduce the scattering among image features)

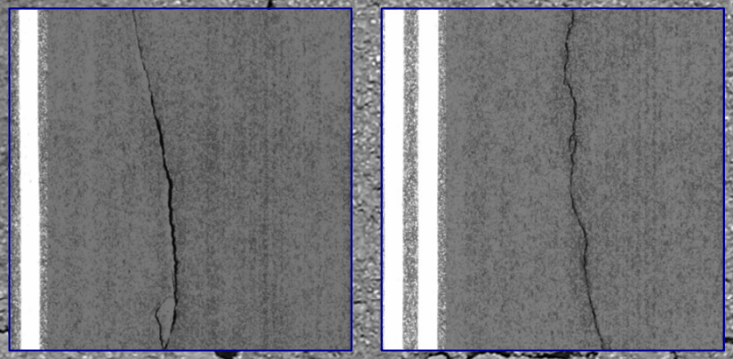


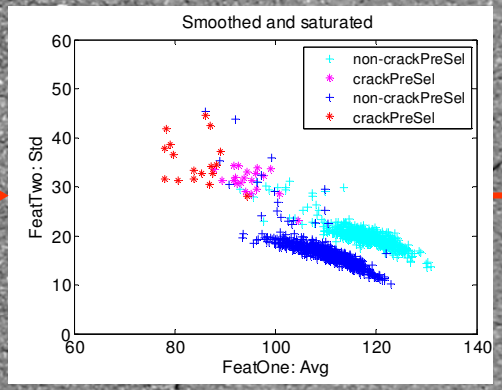
Target cluster analysis

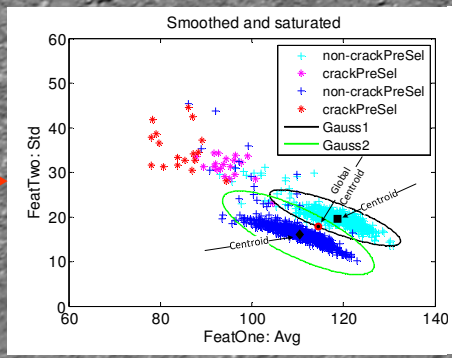
Translation (global centroid)

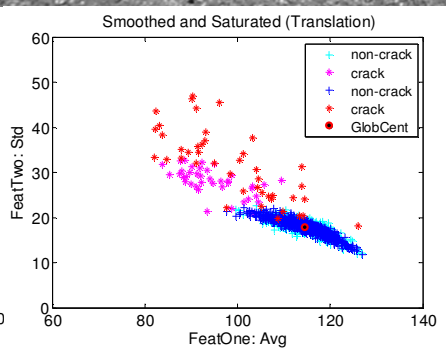
Alignment (global angle)

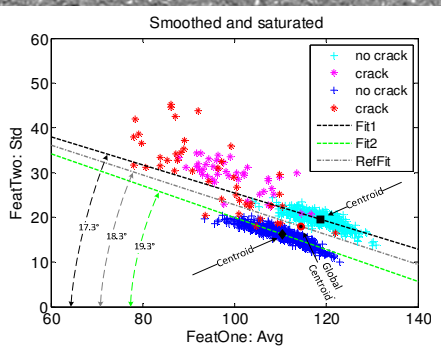
ImgSet2 samples

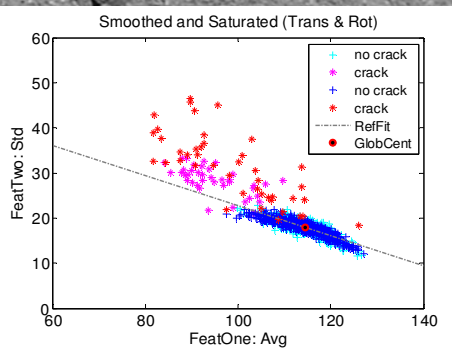






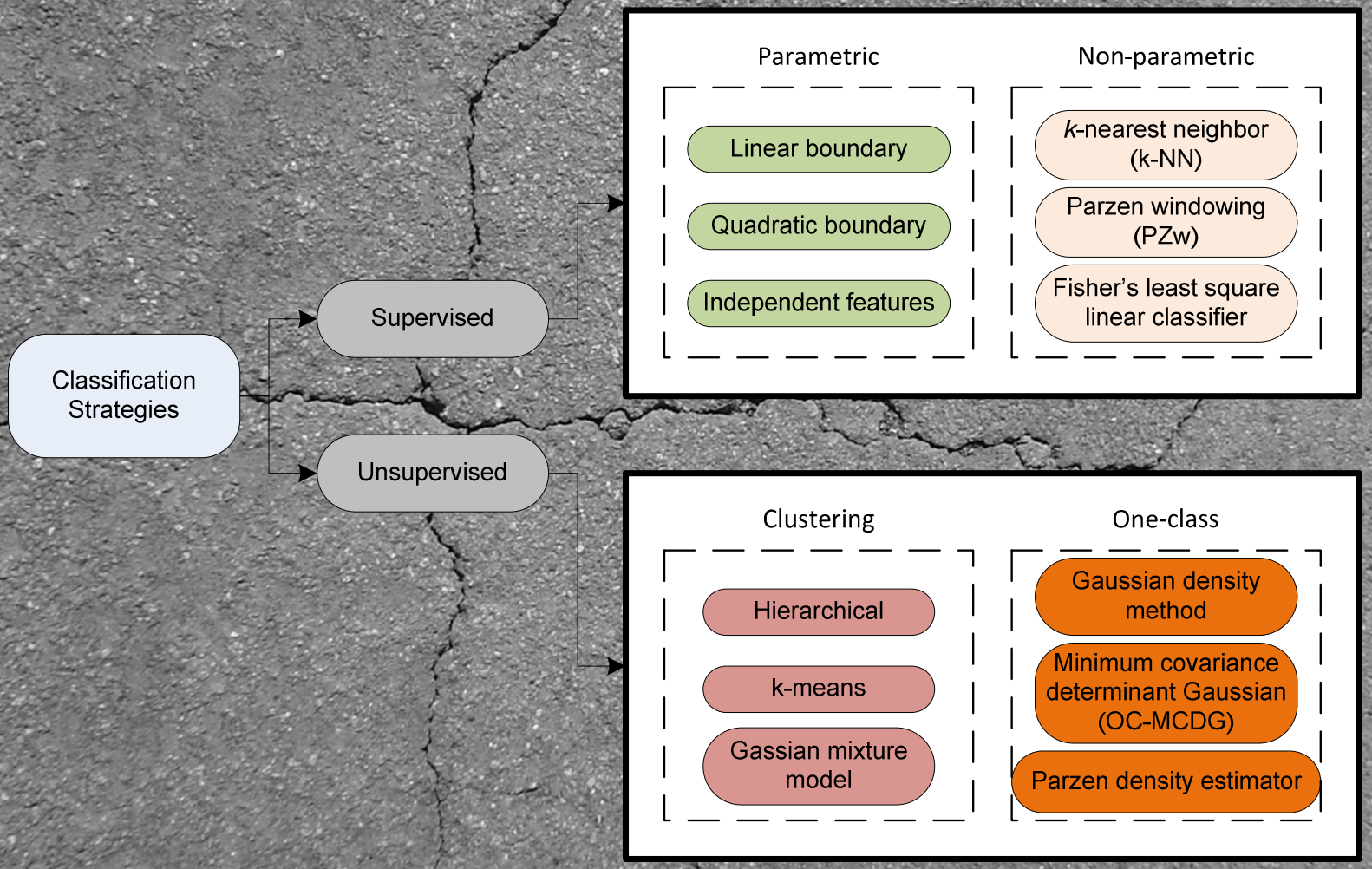






5. Crack Detection (block-based and pixel-based analysis)

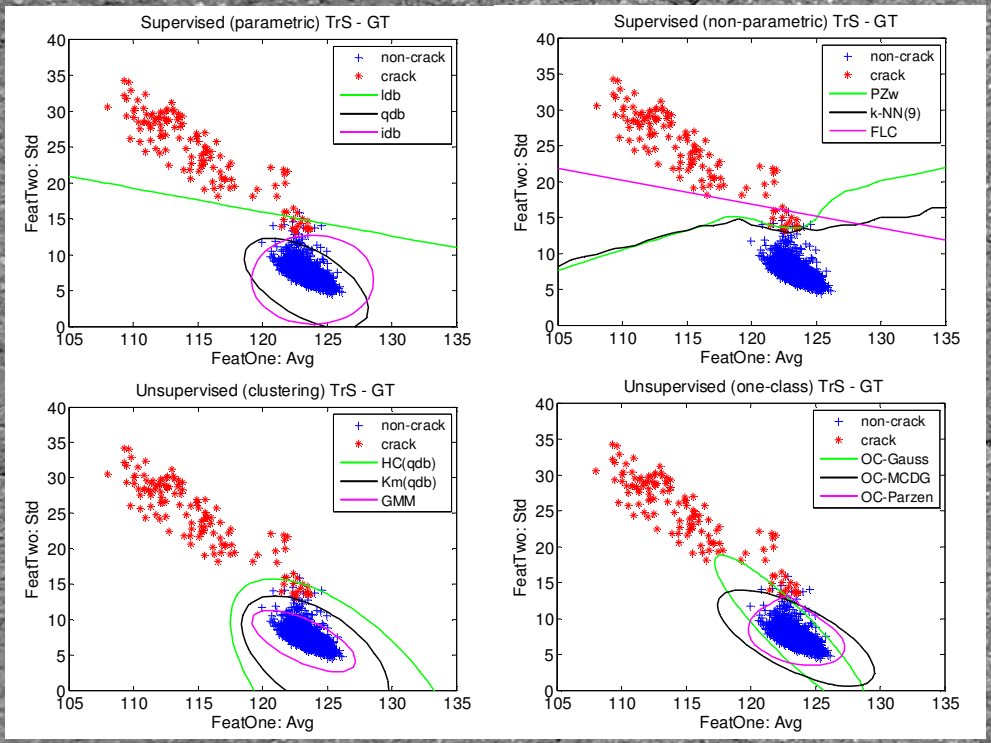
➢ Block label assignment ('Crack' or 'Non-Crack'):



5. Crack Detection (block-based and pixel-based analysis)

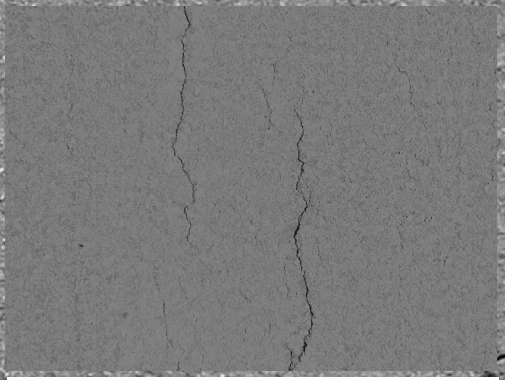
➢ Block label assignment ('Crack' or 'Non-Crack):

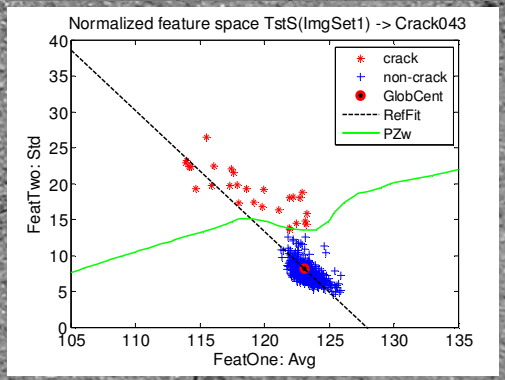
Classifiers training results (ImgSet1)

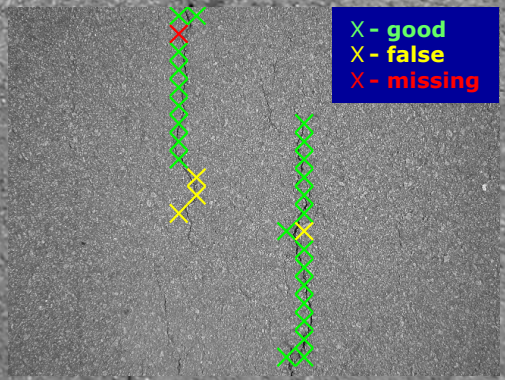


Classification Strategies	Recall	Precision	F-measure	
PZw	98.5%	95.5%	**97.0%**	0.3%
k-NN(9)	99.2%	94.8%	**97.0%**	0.3%
k-means	100%	92.8%	**96.3%**	0.4%
OC-MCDG	100%	92.1%	**96.0%**	0.4%

PZw results (ImgSet1)

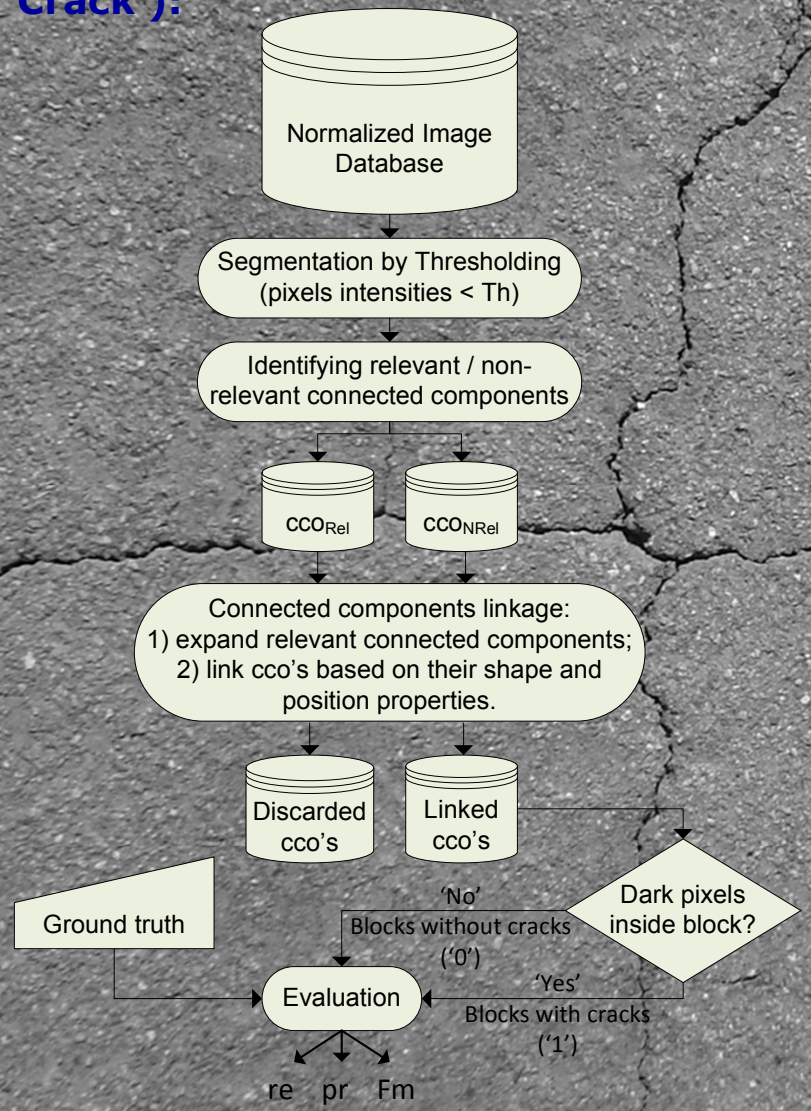






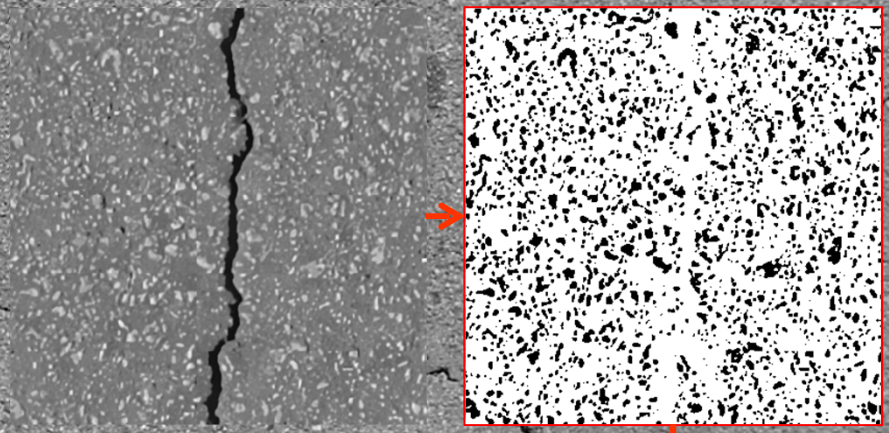
5. Crack Detection (block-based and pixel-based analysis)

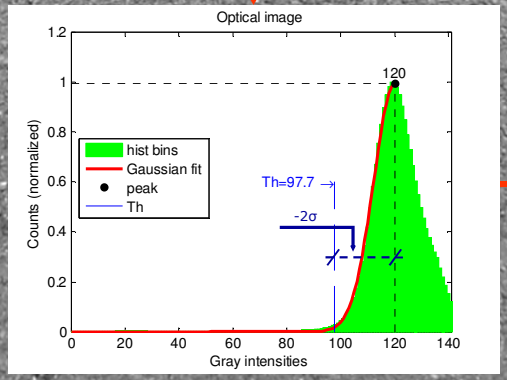
➢ Pixel label assignment ('Crack' or 'Non-Crack'):

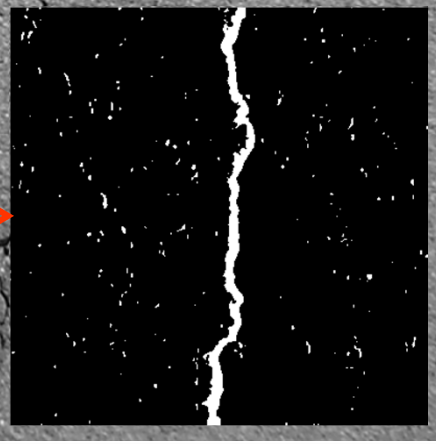


➢ Segmentation by thresholding:

- Calculate (i_{img}) using the Otsu algorithm and compute an histogram;
- Computed *Th*, so that P(*Th*) ≈ 95.5 % (*Th*=μ−2×σ).





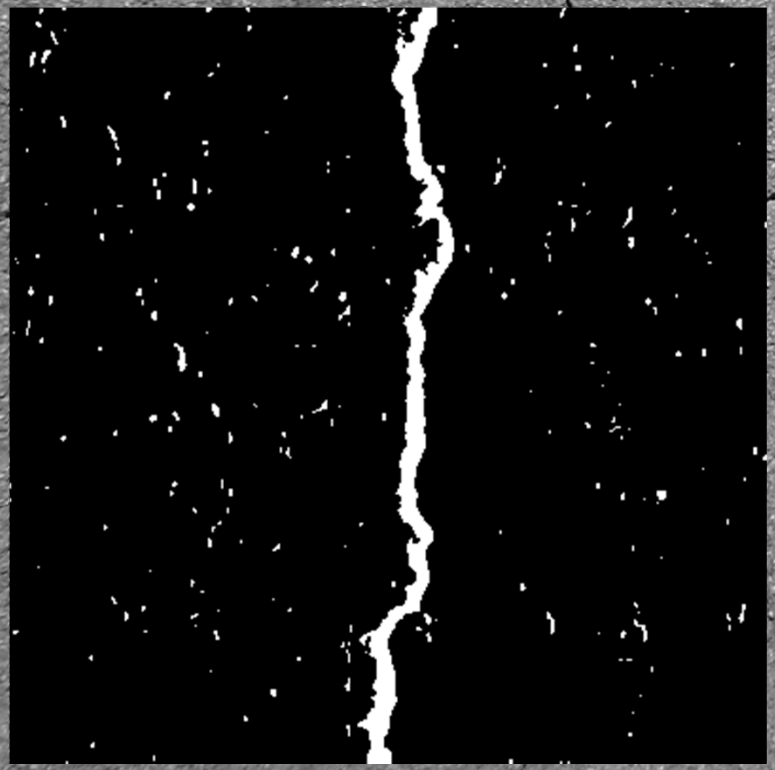


5. Crack Detection (block-based and pixel-based analysis)

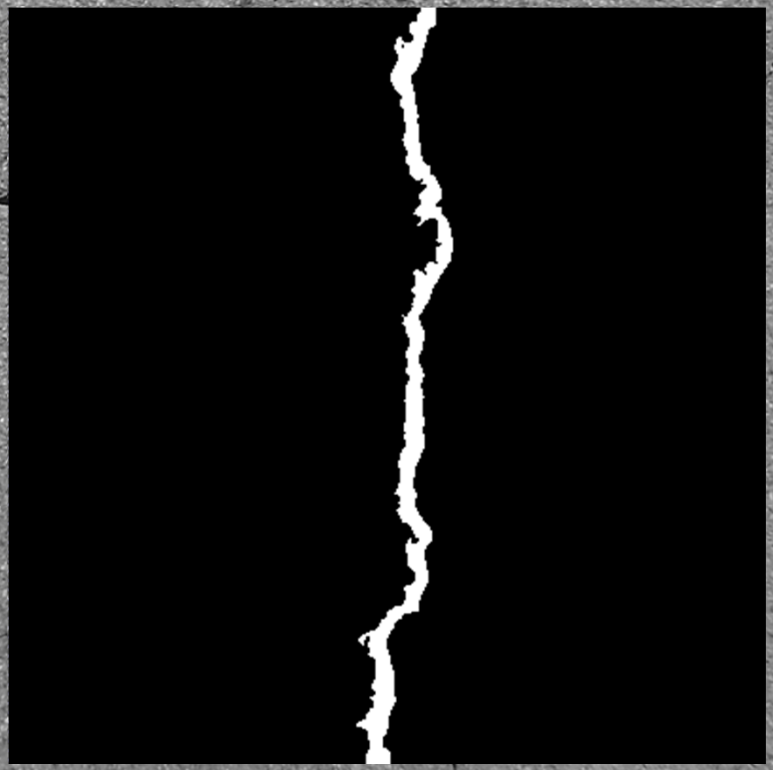
- **Identify relevant crack connected components (cco_{Rel}):**
  - (1) More than 70% of eccentricity for an ellipse fitted to it;
  - (2) Major axis of a fitted ellipse longer than 25 pixels;
  - (3) Width higher than or equal to 2 mm (computed dividing the number of pixels in the *cco* by the numbers of pixels in its skeleton).

ImgSet1 sample results

Original binary regions (*cco*)

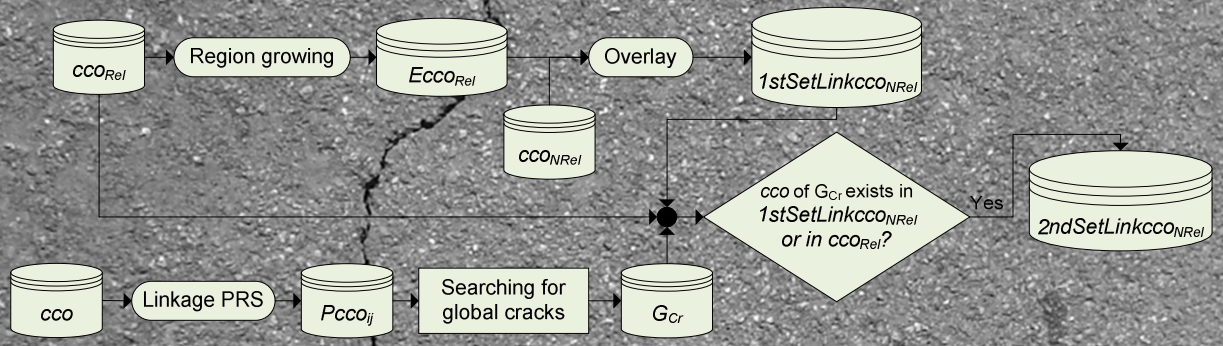


cco_{Rel} identified



5. Crack Detection (block-based and pixel-based analysis)

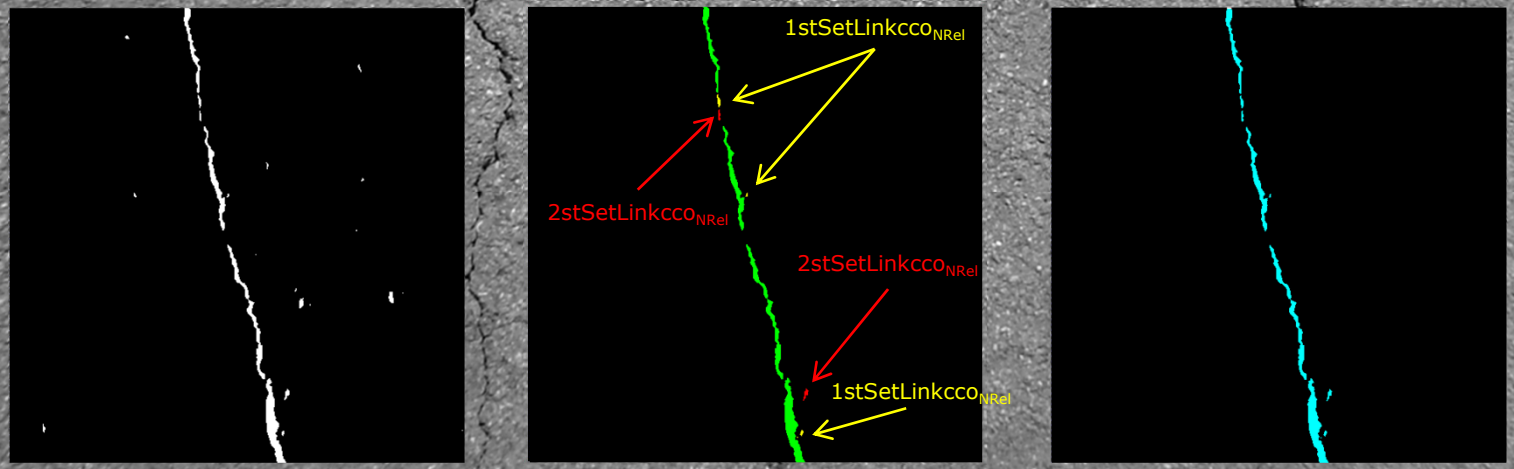
➢Connected components linkage:



MAP classifier: (features)

(1) $x1_{ij}$, the shortest distance between all the crack candidates (*cco*) obtained after segmentation by thresholding;

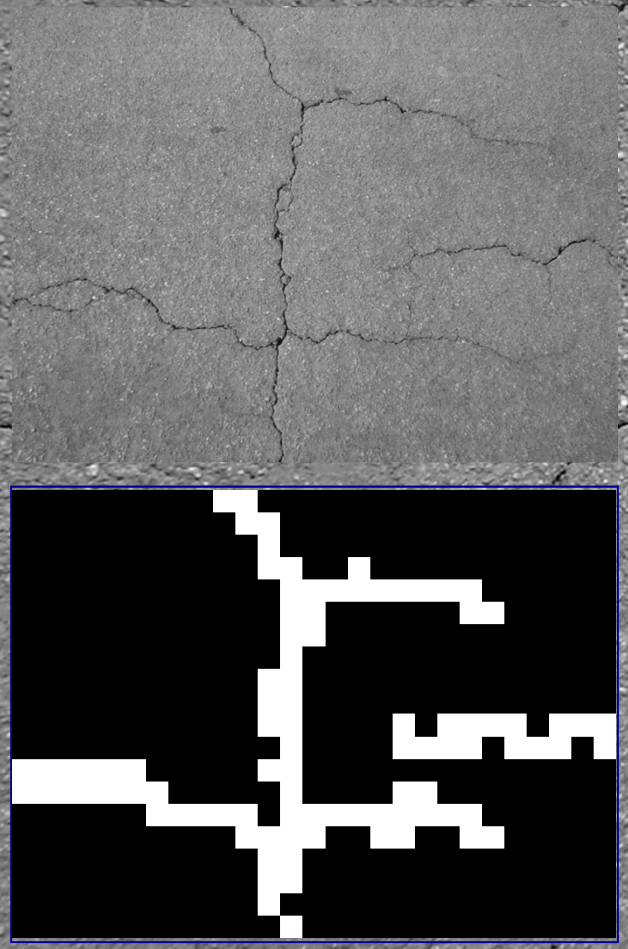
(2) $x2_{ij}$, the sum of absolute values of two inner products calculated between the vector defined by the pair of connected component centroids under analysis and the vectors representing each major axis of the ellipses that has the same second-moments as the *cco*.



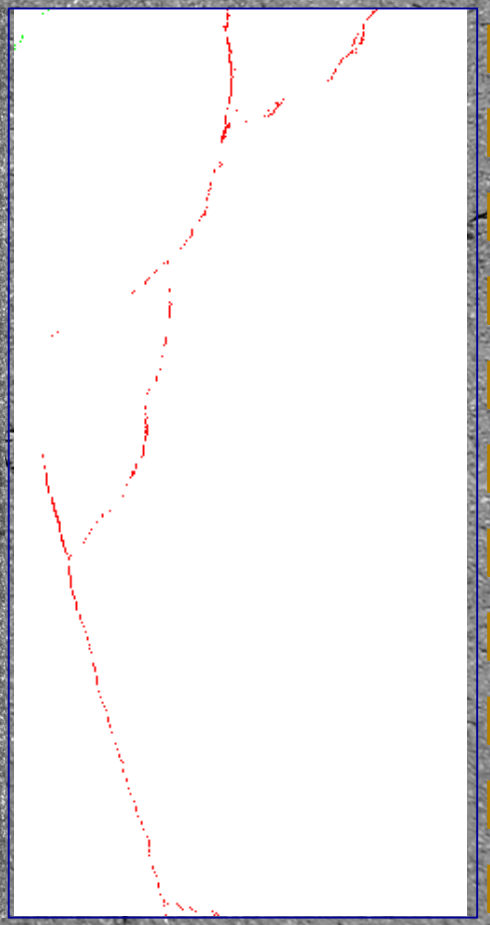
5. Crack Detection (block-based and pixel-based analysis)

➢ Connected components linkage:

ImgSet1 sample results

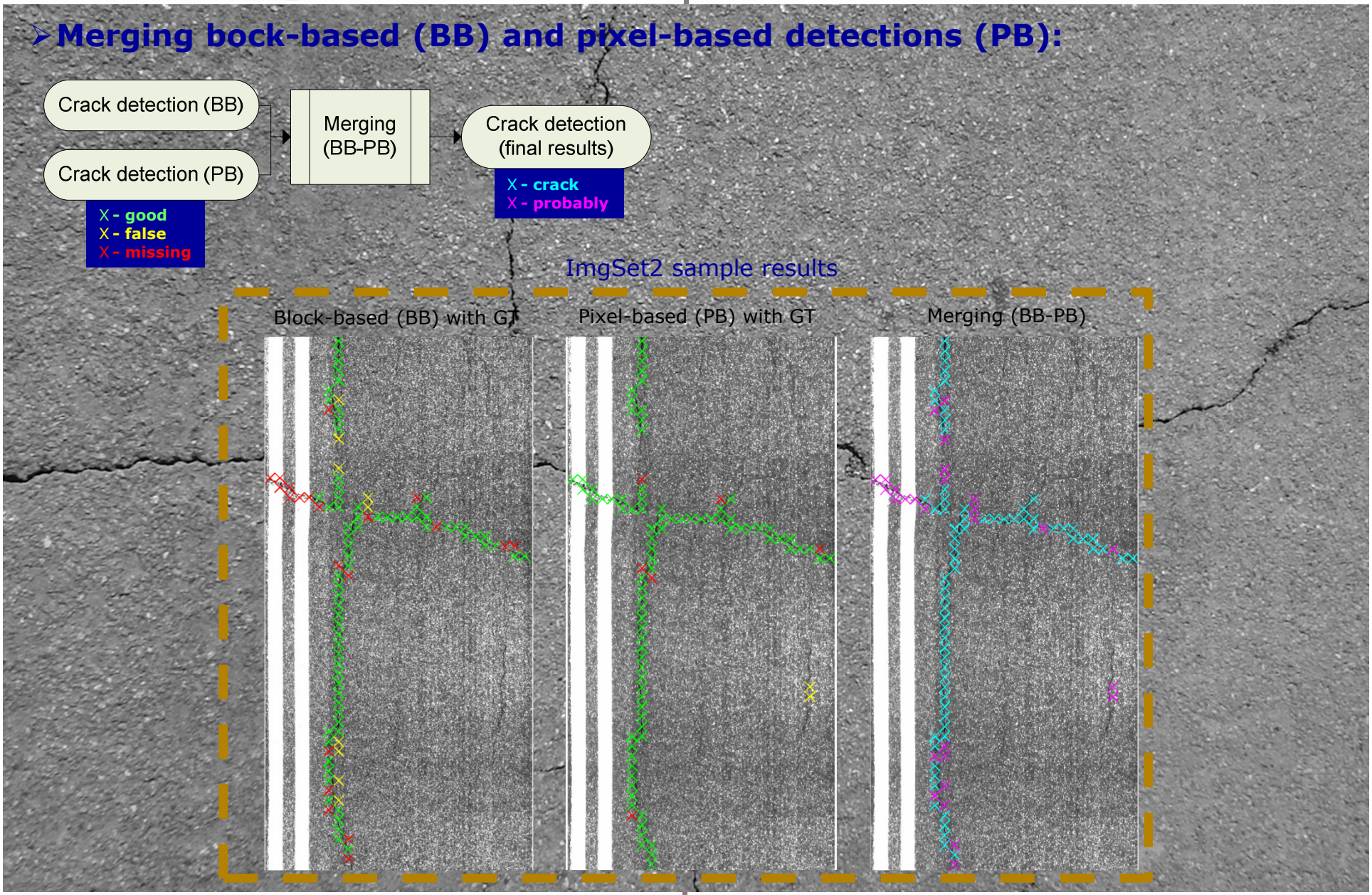


ImgSet2 sample results



5. Crack Detection (block-based and pixel-based analysis)

➢Merging bock-based (BB) and pixel-based detections (PB):



OUTLINE:

1. Context and Motivation
2. Main Objectives
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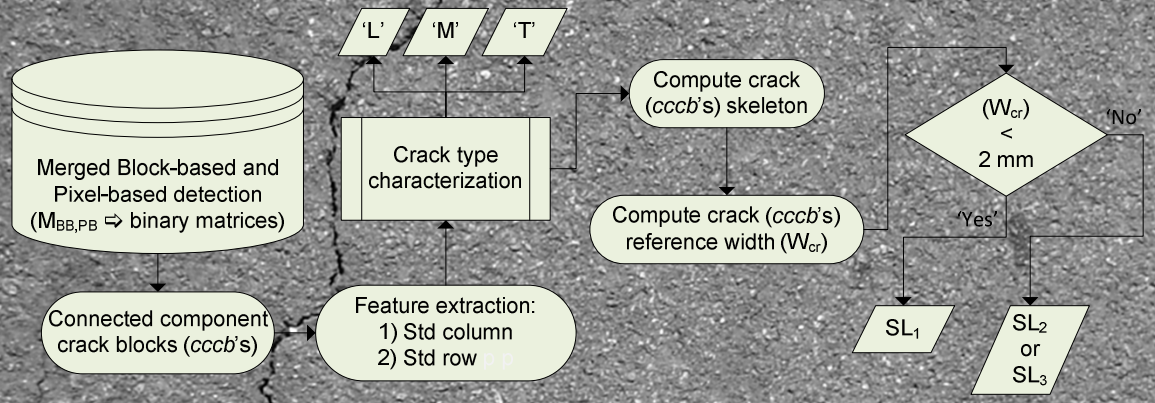
6. Crack Type Characterization and Severity Level Assignment

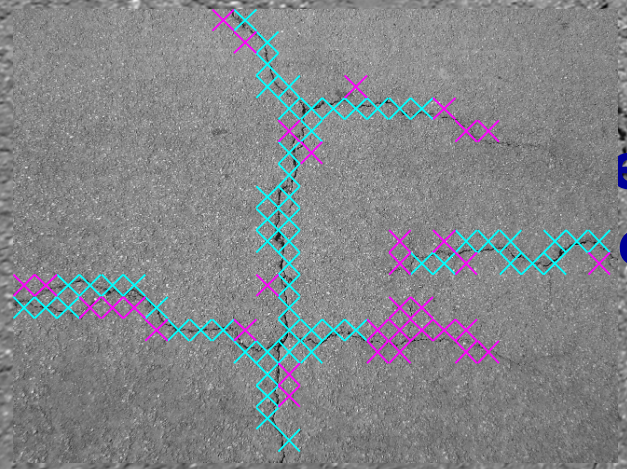
7. Experimental Results
8. Conclusions and Future Work

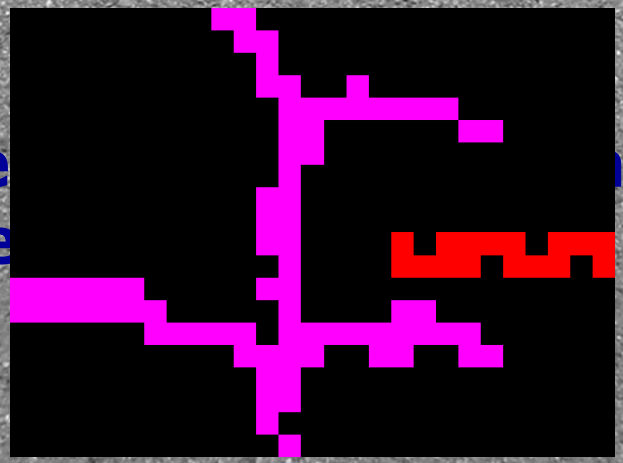
➢ Crack type characterization:

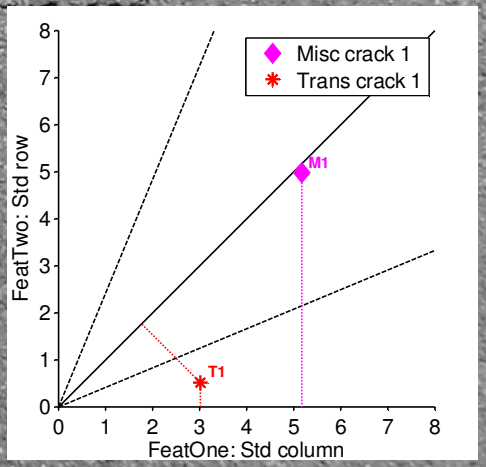
- Longitudinal (L); Transversal (T); Miscellaneous (M).



ImgSet2 sample results

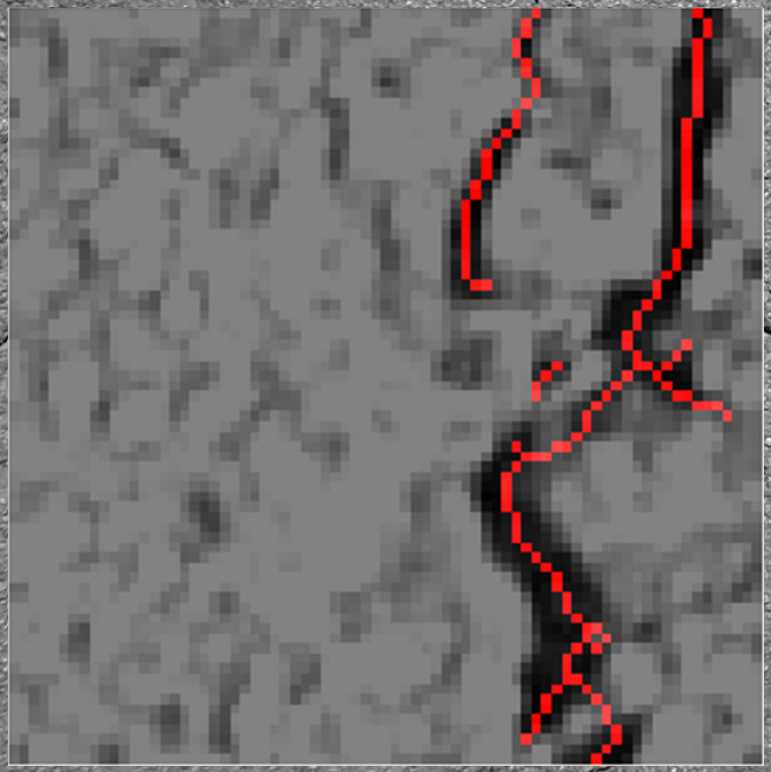


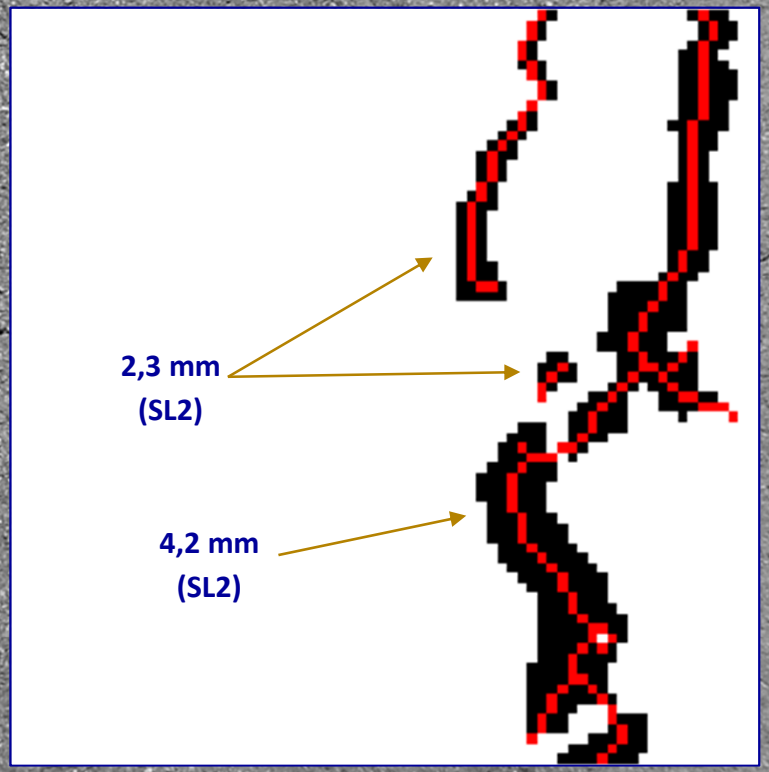




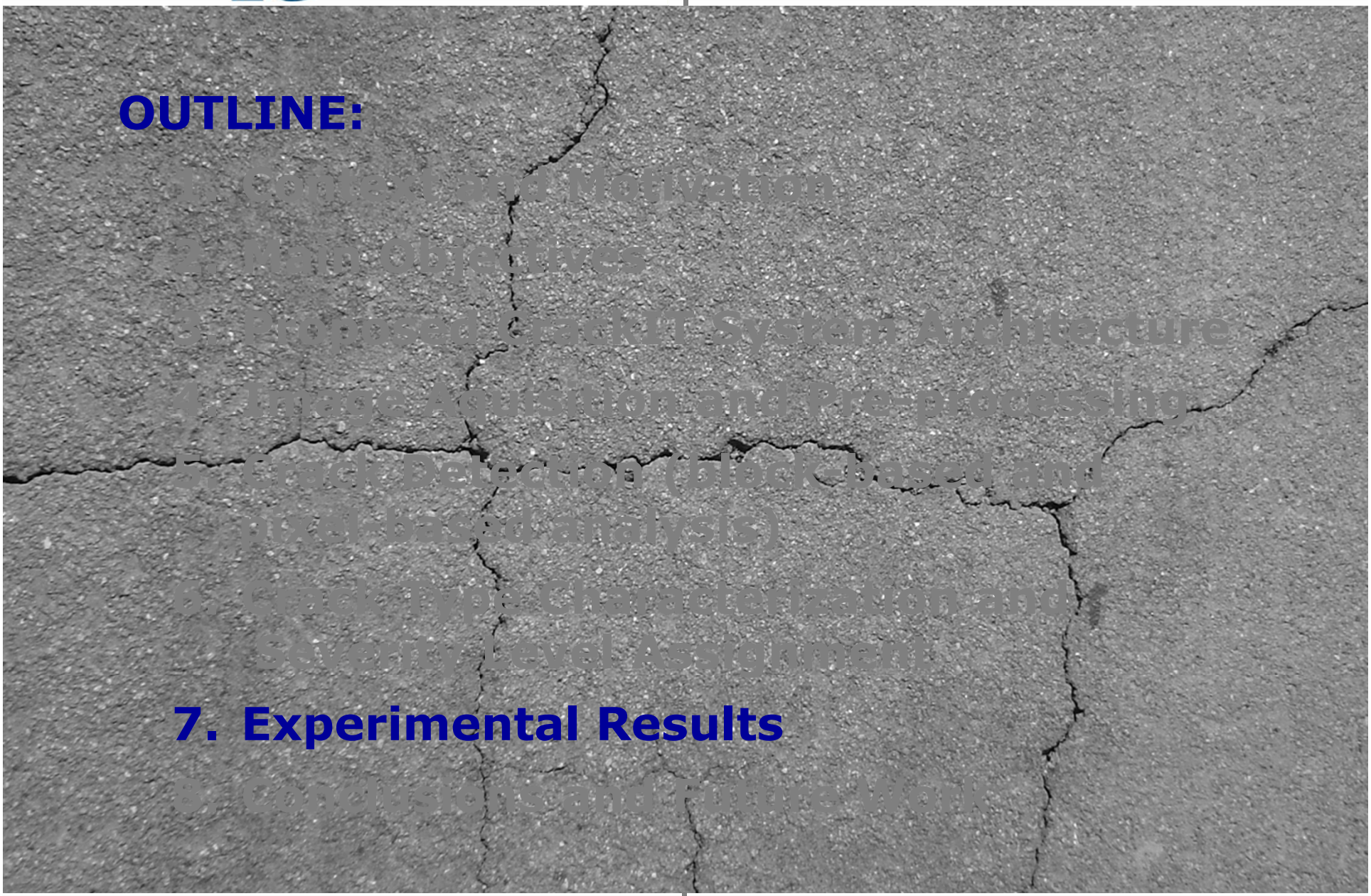
6. Crack Type Characterization and Severity Level Assignment

- **Severity level assignment:**
  (based only on the width of a detected crack)
  - Severity Level 1 (SL1) assigned to cracks with less or equal than 2 mm width;
  - Severity Level 2 (SL2) assigned to cracks of more than 2 mm width.





$$Wcs = \frac{\text{Total number of pixels in a crack}}{\text{Total number of pixels in the crack's skeleton}}$$



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7. Experimental Results

➢**ImgSet2:** (sample results)

Original image

Crack detection

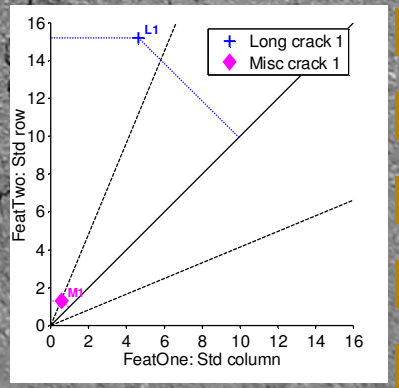
X - crack
X - probably

Comparison with ground truth (GT)

X - good
X - false
X - missing

Cracks at pixel level

Crack type characterization



$$Wcs(\mathrm{L1}) = \frac{\text{Total number of pixels in a crack}}{\text{Total number of pixels in the crack's skeleton}} = 5.7\text{mm}$$ ⇒ **SL2**

$$Wcs(\mathrm{M1}) = \frac{\text{Total number of pixels in a crack}}{\text{Total number of pixels in the crack's skeleton}} = 4.7\text{mm}$$ ⇒ **SL2**

- **Constrains regarding the comparison of the experimental results obtained with other strategies developed:**
  - Three major reasons justify the constrains:

1) usually this type of systems have a commercial nature, thus leading to a limited amount of information about the systems' limitations and performance being available (Gavilán et al., 2011: pp. 9631);

2) there is no publicly available image database shared among researchers for crack detection and characterization evaluation purposes (Moussa and Hussain, 2011);

3) there are no available protocols or standardized methods for evaluating the performance of the developed systems and to compare the published approaches, leading the authors to consider different protocols, despite some harmonization efforts undertaken by researchers (Chambon and Moliard, 2011) and (Moussa and Hussain, 2011) (Gavilán et al., 2011: pp. 9631).

7. Experimental Results

➢ **Quantitative evaluation:**

Crack detection results (ImgSet1):

Classification Strategies	Recall	Precision	F-measure		
Parzen windowing (PZW)	98.4%	95.5%	**97.0%**	0.3%	1.6%
k-NN(9)	99.0%	94.5%	**96.9%**	0.3%	1.0%

Crack detection results (ImgSet2):

Classification Strategies	Recall	Precision	F-measure		
Parzen windowing (PZW)	88.4%	97.8%	**93.7%**	0.7%	11.6%
k-NN(9)	89.0%	98.0%	**93.4%**	0.8%	11.0%

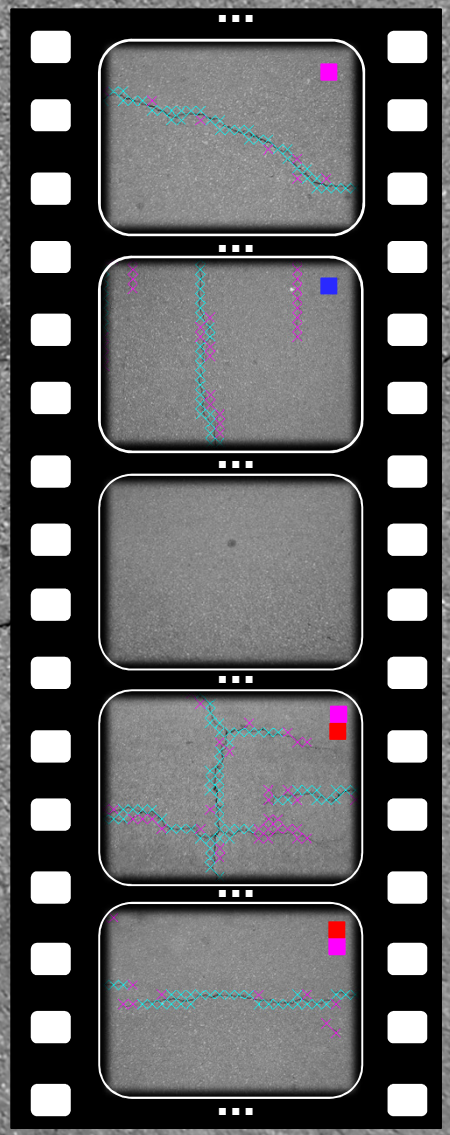
➢ Quantitative evaluation:

Crack type characterization results (ImgSet1):

Crack Types	Longitudinal		Transversal		Miscellaneous	
	PZW	K-NN(9)	PZW	K-NN(9)	PZW	K-NN(9)
Ground truth	50	50	5	5	17	17
Manually labeled and detected by the system	50	50	5	5	17	17
Not manually labeled but detected by the system	3	2	1	1	2	3

Crack type characterization results (ImgSet2):

Crack Types	Longitudinal		Transversal		Miscellaneous	
	PZW	K-NN(9)	PZW	K-NN(9)	PZW	K-NN(9)
Ground truth	125	125	12	12	43	43
Manually labeled and detected by the system	125	125	12	12	43	43
Not manually labeled but detected by the system	3	2	1	1	2	3



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8.Conclusions and Future Work

➢ **Conclusions:**

- The proposed R-UINTA allows for a faster and more effective smoothing than the original UINTA and other pre-processing strategies. Crack information is correctly maintained. Pixel intensity variance is significantly reduced;
- Parzen windowing and *k* nearest neighbours classification strategies allow for interesting generalization capabilities, since both lead to better performance regarding crack detection, either for ImgSet1 and ImgSet2;
- Crack detection *Fm* values obtained are considered good, notably when the expected variation of road expert accuracy levels is between 1% and 2.5%, due to human pattern recognition limitations (Sanz, 2008);
- The CrackIT system is able to detect multiple cracks in a given image;
- Better characterization for cracks with at least 2 mm width.

8. Conclusions and Future Work

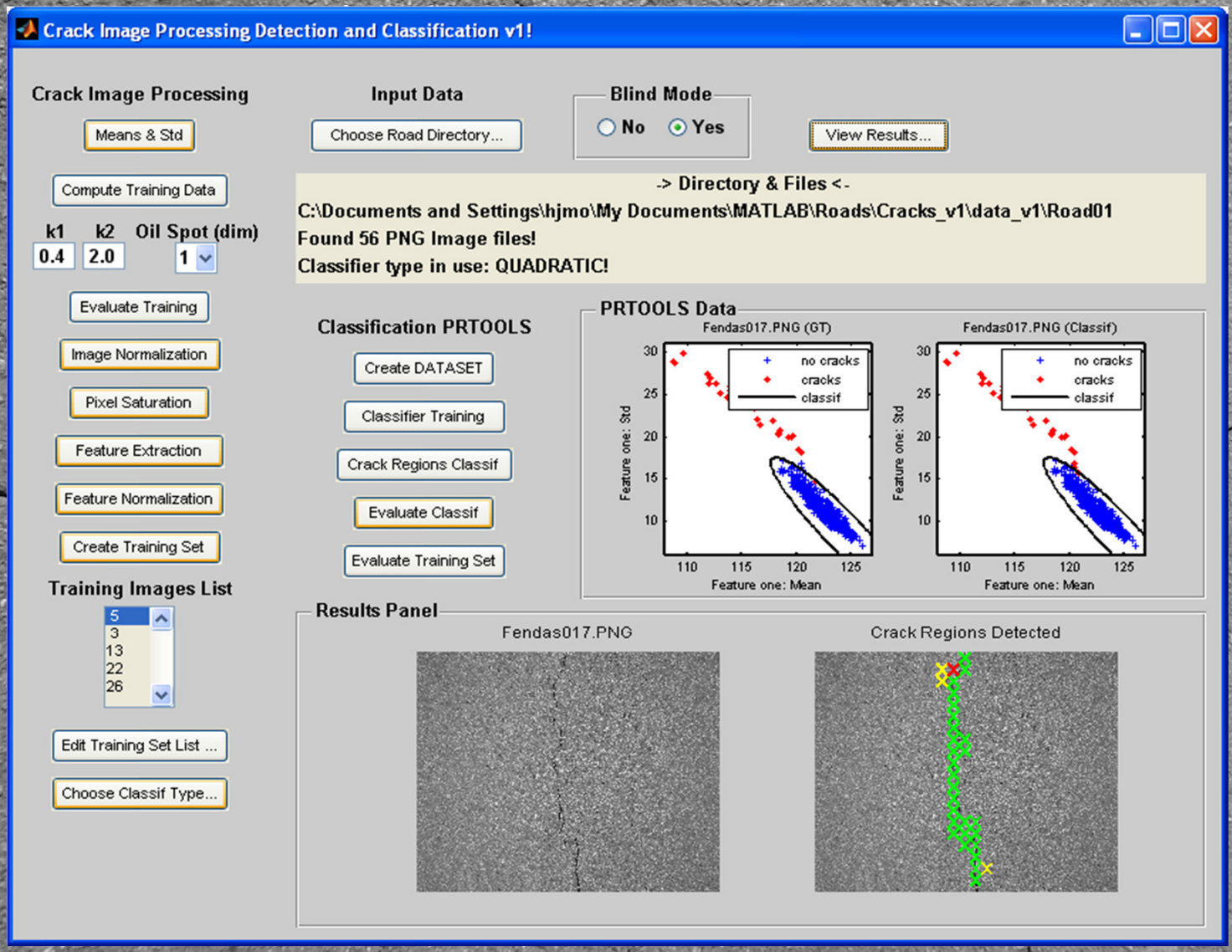
➢Future Work:

- Improve smoothing, to reduce further pixel intensity variance in non-crack blocks, and to increase robustness to image brightness variations, as well as to variations in pavement texture along the same road being surveyed;

- Investigate the suitability of alternative/additional features, aiming to increase the separability between the classes considered, and a better crack detection performance of CrackIT;

- For crack linking purposes (connected components linkage), the merging of crack segments, using e.g. crack width information, will be investigated, since this crack characteristic can be extremely helpful here;

- To introduce more pavement surface distress types, as well as the implementation of SL3 severity level assignment.


Crack Image Processing Detection and Classification v1!
Crack Image Processing
Means & Std
Compute Training Data
k1
0.4
k2
2.0
Oil Spot (dim)
1
Evaluate Training
Image Normalization
Pixel Saturation
Feature Extraction
Feature Normalization
Create Training Set
Training Images List
5
3
13
22
26
Edit Training Set List ...
Choose Classif Type...
Input Data
Choose Road Directory...
Blind Mode
No
Yes
View Results...
-> Directory & Files <-
C:\Documents and Settings\hjmo\My Documents\MATLAB\Roads\Cracks_v1\data_v1\Road01
Found 56 PNG Image files!
Classifier type in use: QUADRATIC!
Classification PRTOOLS
Create DATASET
Classifier Training
Crack Regions Classif
Evaluate Classif
Evaluate Training Set
PRTOOLS Data
Fendas017.PNG (GT)
Fendas017.PNG (Classif)
no cracks
cracks
classif
Feature one: Std
Feature one: Mean
Results Panel
Fendas017.PNG
Crack Regions Detected

List of publications

Papers in Journals [1]

- Oliveira, H.; Correia, P.L.; "Automatic Road Crack Detection and Characterization", IEEE Trans. on Intelligent Transportation Systems, Vol. 14, No. 1, pp. 155 - 168, March, 2013.

Book Chapters [1]

- Oliveira, H.; Correia, P.L.; "Supervised Crack Detection and Classification in Images of Road Pavement Flexible Surfaces" - Chapter in Recent Advances in Signal Processing, In-Tech, In-Tech, Austria, 2009.

Papers in Conference Proceedings [13]

- Oliveira, H.; JJC Caeiro; Correia, P.L.; "Improved Road Crack Detection Based on One-class Parzen Density Estimation and Entropy Reduction", Proc IEEE International Conf. on Image Processing - ICIP, Hong Kong, Hong Kong, September, 2010.
- Oliveira, H.; Correia, P.L.; "Automatic Crack Detection on Road Imagery Using Anisotropic Diffusion and Region Linkage", Proc European Signal Processing Conf. - EUSIPCO, Aalborg, Denmark, August, 2010.
- Oliveira, H.; Correia, P.L.; "Automatic Road Crack Segmentation Using Entropy and Image Dynamic Thresholding", Proc European Signal Processing Conf. - EUSIPCO, Glasgow, United Kingdom, August, 2009.
- Oliveira, H.; Correia, P.L.; "Identifying And Retrieving Distress Images from Road Pavement Surveys", Proc ICIP Workshop on Multimedia Information Retrieval: New Trends and Challenges, San Diego, United States, October, 2008.
- Oliveira, H.; Correia, P.L.; "Supervised Strategies for Cracks Detection in Images of Road Pavement Flexible Surfaces", Proc European Signal Processing Conf. - EUSIPCO, Lausanne, Switzerland, August, 2008.

References to the research work developed [≥50];