Cloud Chamber Image processing

From raw data to particle tracks

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Summary

1 Data acquisition
- Raw Data optimization
- Lighting analysis
- Collected data

2 Cleaning raw images and extracting tracks
- Outlook of the algorithm
- Trigger
- Denoising
- Tracks Extraction

3 Results and outlook
- Results
- Outlook

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Section 1

Data acquisition

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Raw Data manipulation

Data were acquired by means of a Raspberry Pi Camera (Module v2).

Raw video optimization

- Focal distance tuning
- CAMERA CONTROL OPTIONS from RASPBERRY PI CAMERA MODULE : sharpness, brightness, ISO, contrast, saturation, exposure.

More information about setting parameters can be found at
`https://www.raspberrypi.org/documentation/raspbian/applications/camera.md`

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Raw Data manipulation

Data were acquired by means of a Raspberry Pi Camera (Module v2).

Data Format

- Raw videos are saved in H264 format.
- A script converts video from H264 to MP4 format.
- Frames are extracted (5 frames per second) in PNG format.

The code `ExtractFrames.py` is based on `ffmpeg` libraries. For more information see `https://ffmpeg.org`

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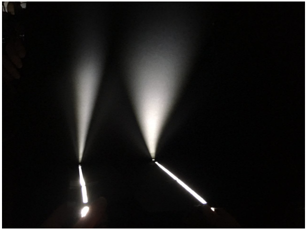
Lighting analysis

Efficient volume for tracks detection.

↓

Enlightening a thin section of the chamber.



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Lighting analysis

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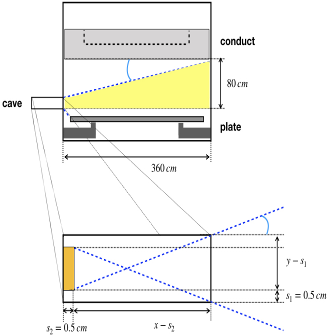
↓

Light collimation studies :

$$\frac{y - s_1}{x - s_2} \leq \frac{80\ mm}{360\ mm}$$

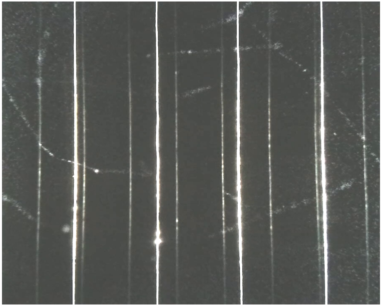
Final choice :
$x = 7\ cm\,, \quad y = 1\ cm$



Collected data

Data were collected when the chamber was still under construction to look for benefits coming from the enhancements of the set up.
Different kind of noises were observed and a solution for each of them was figured out.

- **29-03-2018 :** wires reflect on the plate
- **06-04-2018 :** gas condensed on the wires
- **12-04-2018 :** fog in the left side of the chamber
- **24-04-2018 :** sparks



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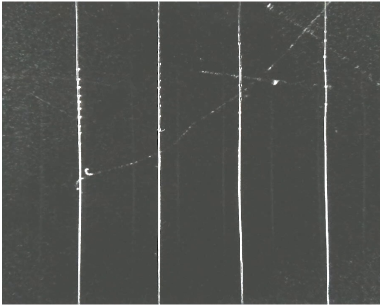

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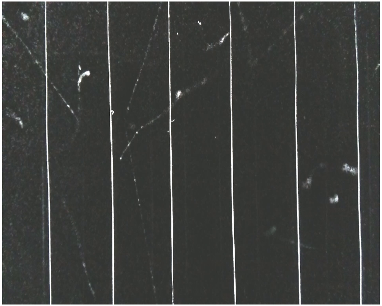

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Section 2

Cleaning raw images and extracting tracks

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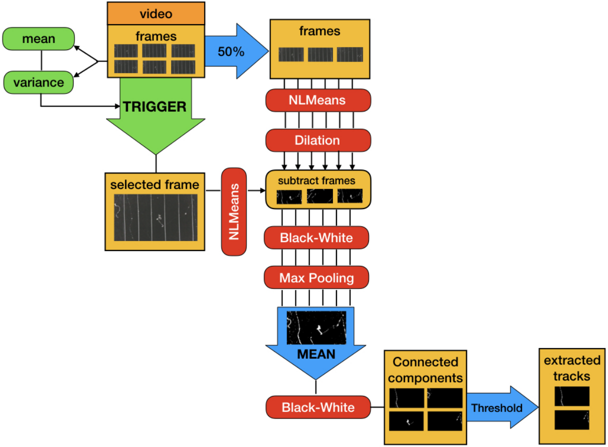
Outlook of the algorithm



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Subsection 2

Trigger

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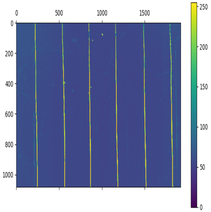
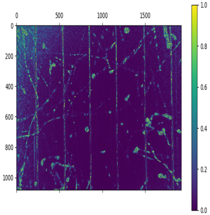
Trigger

The purpose was catching frames deviating from the average.

- Frame Matrix :
  $f_{ij}^{\alpha} \in F = \{f_{ij}^{\alpha}, \alpha = 0, 1, ...\}$
- Mean Matrix :
  $M_{ij} = \frac{1}{|F|} \sum_{\alpha} f_{ij}^{\alpha}$
- Variance Matrix :
  $V_{ij} = \left(\frac{1}{|F|} \sum_{\alpha} (f_{ij}^{\alpha})^2 \right) - (M_{ij})^2$
- Deviance Matrix :
  $v_{ij}^{\alpha} = (f_{ij}^{\alpha} - M_{ij}^{\alpha})^2$
- Ratio :
  $R^{\alpha} = \frac{\sum_{i,j} v_{ij}^{\alpha}}{\sum_{i,j} V_{ij}} > thr$



(c) Mean Matrix



(d) Variance Matrix

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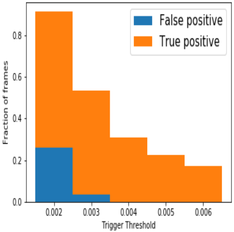

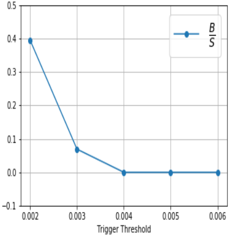

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Subsection 3

Denoising

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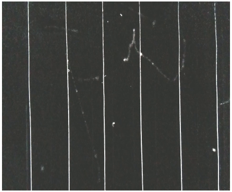
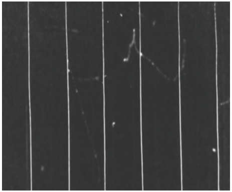
Denoising

Different kind of filters were tested.

- FastNlMeansDenoising (OpenCV) :
  based on *Non Local Means method*, it aims to replace the color of a pixel with an average of the colors of similar pixels.
- Dilation (OpenCV) :
- Black-White cut :
- MaxPooling (Keras Convolutional Neural Network) :



(g) Before



(h) After

See http://www.ipol.im/pub/art/2011/bcm_nlm/

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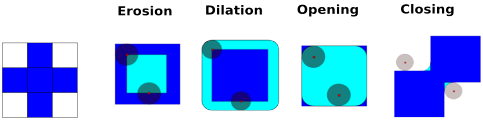
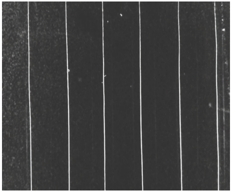
Denoising

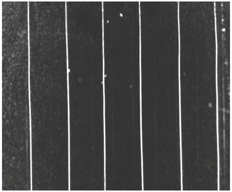
Different kind of filters were tested.

- FastNlMeansDenoising (OpenCV) :
- Dilation (OpenCV) : replace the value of a pixel by the maximal value covered by the structuring element.
- Black-White cut :
- MaxPooling (Keras Convolutional Neural Network) :





(i) Before



(j) After

See https://docs.opencv.org/2.4/modules/imgproc/doc/filtering.html?highlight=dilate#dilate

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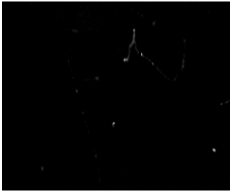
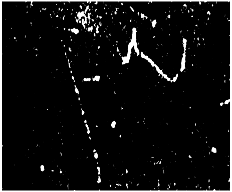
Denoising

Different kind of filters were tested.

- FastNlMeansDenoising (OpenCV) :
- Dilation (OpenCV) :
- Black-White cut :
  set a threshold to binarize the greyscale.
- MaxPooling (Keras Convolutional Neural Network) :



(k) Before



(l) After

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Denoising

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- FastNlMeansDenoising (OpenCV) :
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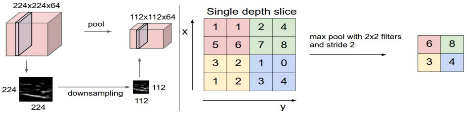
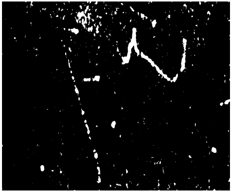
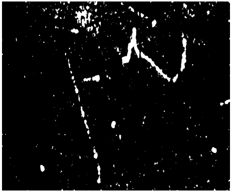
- MaxPooling (Keras Convolutional Neural Network) :
  a pooling filter reduces the size of the input image, making an assumption on how to synthesize the information ; max pooling saves the maximum value for each bunch of pixel.





(m) Before



(n) After

See https://keras.io/layers/pooling/#maxpooling2d

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Denoising

Two kind of noises have to be faced :

- Systematic noise :
  static objects in the picture (wires, reflex, ...)
  $\rightarrow$ removed simply by **subtraction** of a background frame
- Random noise :
  dynamic objects in the picture (gas in chaotic motion, drops, sparks, ...)
  $\rightarrow$ a **statistical** approach is needed...

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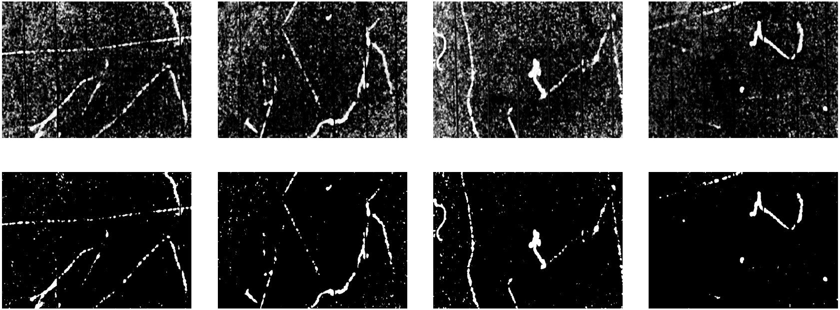
Denoising

A unique solution was found by subtracting to each processed frame all the other frames in the video and then picking the average image.



→ Both systematic and casual errors were reduced.

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Subsection 4

Tracks Extraction

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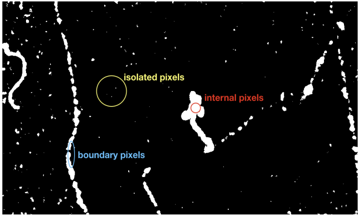
Finding Connected Components

The first attempt has been writing an algorithm for clustering from scratch.
The main concept come from basics of graph theory.

The code was built on the definition of a **topology** on a set of pixels :

- **signals** : all the white pixels
  - pixel contained in a track
  - boundary of the track
  - isolated pixel
- **backgrounds** : all the black pixels



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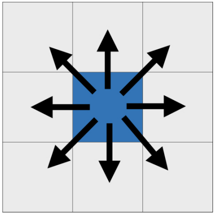
Finding Connected Components

The first attempt has been writing an algorithm for clustering from scratch. The main concept come from basics of graph theory.

And on the definition of **link** between pixels :

- **link** : two pixels are linked when their distance is 1.
- **distance between two white pixels** : number of moves in the grid. (admitted moves : up, down, left, right, up-left, up-right, down-left, down-right)
- **neighbors of p** : group of white pixels linked to p.



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Finding Connected Components

A **Search Algorithm** was implemented. The algorithm scans all the pixels and associate to each point of the matrix one of the following categories :

- **undiscovered** : not yet analyzed pixel
- **discovered** : analyzed pixel
- **candidate** : white neighbors of white discovered pixels
- **selected** : white discovered pixel with at least one white neighbor

Great performance but unfeasible from a computational point of view : execution time for one frame was order of 10 minutes !

$\rightarrow$ look for image manipulation tools already available online...

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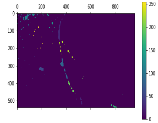
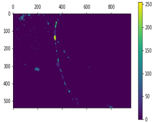
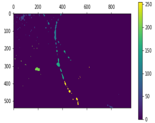
Finding connected components



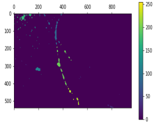
(w) Ward



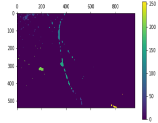
(x) Spectral Clustering



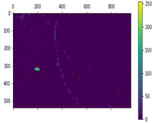
(y) Affinity Propagation



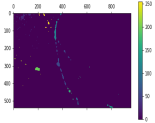
(z) Agglomerative Clustering



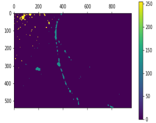
() Birch



() DBSCAN



() Gaussian Mixture



() Mean Shift

FIGURE – Tests done one clustering algorithms provided by SCIPY packages for image manipulation.

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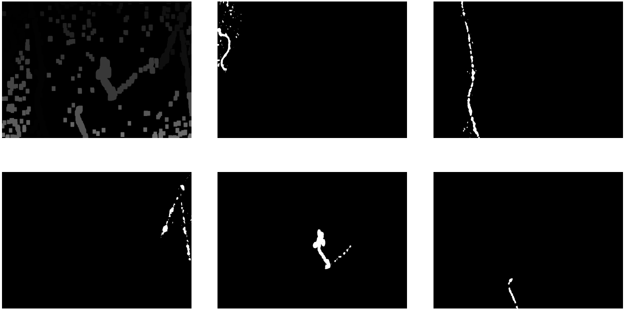
Finding Connected components

Chosen algorithm : `scipy.ndimage.label`



http://lagrange.univ-lyon1.fr/docs/scipy/0.17.1/generated/scipy.ndimage.label.html

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Section 3

Results and outlook

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Subsection 1

Results

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Results

Video (date, time)	Duration (s)	Execution time per second of video (s/s)	Triggered frames per second of video (frames/s)	Trigger Efficiency	selected conn. comp. per second of video (1/s)	selected tracks per second of video (1/s)	Efficiency
29-03-2018 12 :19 :07	12	37	1.42	0.31	3.5	3.4	0.97
06-04-2018 14 :47 :00	12	65	1	0.23	1.8	1.7	0.94
12-04-2018 17 :41 :45	12	49	0.92	0.22	3.9	2.7	0.69
24-04-2018 18 :25 :12	18	63	1.17	0.29	4.1	2.54	0.62
Average		50	1.11	0.26			0.81

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Results

Sparks effects are the worst cause of noise.
The algorithm is not able to discriminate between sparks and tracks.
Hopefully, sparks can be easily turned off by properly setting the electric field voltage.

Video (date, time)	Duration (s)	Execution time per second of video (s/s)	Triggered frames per second of video (frames/s)	Trigger Efficiency	selected conn. comp. per second of video (1/s)	selected tracks per second of video (1/s)	Efficiency
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12-04-2018 17 :41 :45	12	49	0.92	0.22	3.9	2.7	0.69
Average		50	1.11	0.25			0.87

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Subsection 2

Outlook

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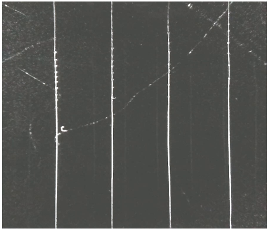
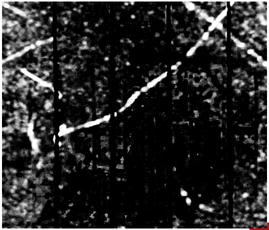
Outlook

Next enhancements :

More improvements in the chamber **set up** can be done to reduce the sources of noise and raise the quality of the image :

- reducing the number of wires for the electric field
- optimizing the lighting (more powerful leds, focalizing the light beam...)





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Outlook

Next enhancements :

Further optimization of the **algorithm** can be done :

- setting the trigger threshold depending on computation resources (increasing the rate of analysis).
- tune the filter to adapt the algorithm to specific noises.

Moreover, **machine learning** tools can be used to implement tracks clustering.

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