METEORIX

A new processing chain for detection and tracking of meteors from space

M. Millet[1,2], N. Rambaux[3], A. Petreto[1,2], F. Lemaitre[1], L. Lacassagne[1]

[1]LIP6, Sorbonne Université, CNRS

[2]LERITY - Alcen

[3]IMCCE, Observatoire de Paris, PSL Université, Sorbonne Université, CNRS

International Meteor Conference

September 26th, 2021

The project :

- Universitary CubeSat mission of Sorbonne University[1]
- Several purposes :
  - **Educational** Enroll students in a space mission
  - **Astronomical** Estimate the flux of meteoroids and space debris entering the atmosphere
  - **Technological** Show the feasibility of a *real-time* processing chain embedded in a nanosatellite.
- Step A : proof of concept validated
- Step B : definition and prototyping of the payload (in progress)

The CubeSat :

- CubeSat 3U : 3 cubes of $10cm^3$.
- Payload :
  - Camera
  - Processing chain
- **Strong energy constraint** : -10W available

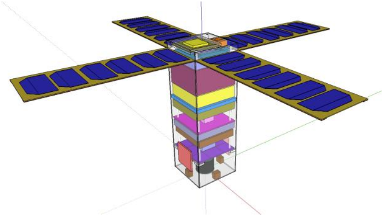


Figure 1 – View of Meteorix's CubeSat[2]

State of art

- MeteorScan (1995) [3], MetRec (1999) [4], UFOCapture (2004) [5]
  - Old but still used and popular
  - Probability of detection in real-time greater than 80%.
- Ground camera networks
  - FRIPON[6] (by IMCCE) with 250 cameras
  - Wide sky coverage
- RPi Meteor Station [7]
  - Croatian Meteor Network
  - Designed for low power computer (Raspberry Pi)
- Processing chains with neural networks
  - Probability of detection between 96%[8] and 99.9%[9].
  - Require hardware[10][8] that can't be embedded in a nanosatellite.
  - Too few images of meteors from space.

State of art

Image processing techniques used for meteor detection are not suited for space detection.

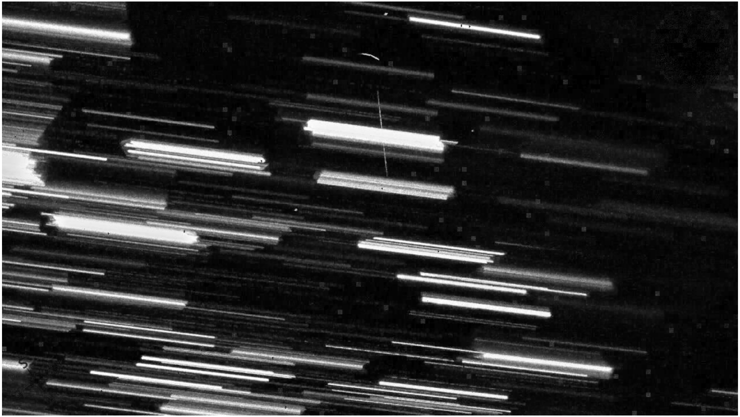


Figure 2 – Example from RMS : Which lines are meteors ? Which lines are cities ?

⇒ **No processing chain for space detection**

Processing chain

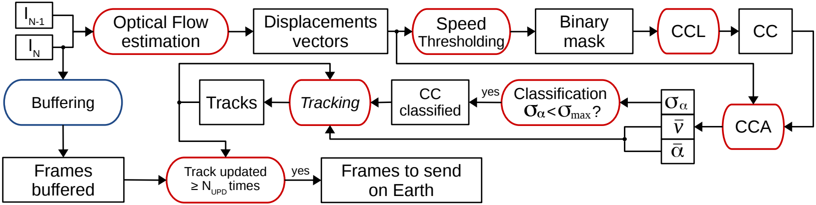


Figure 3 – CC = Connected Components, CCL = Connected Components Labelling, CCA = Connected Components Analysis, $\bar{v}$ = average speed, $\bar{\alpha}$ = mean angle, σ_α = angular standard deviation, $\sigma_{max} = 30\,\text{deg}$, $N_{MAJ} = 3$

Step 1 : Optical flow

- Optical flow estimation = apparent movement estimation
- Horn & Schunck [11]
  - Iterative algorithm
  - Pyramidal algorithm [12]
- Field of displacement vectors
- Speed in px/frame

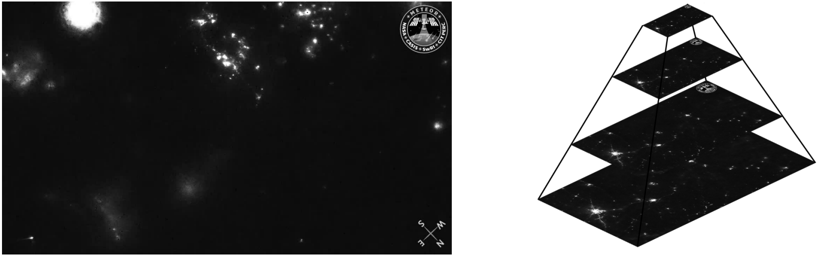


Figure 4 – Frame 119 from sequence v86

Step 1 : Optical flow

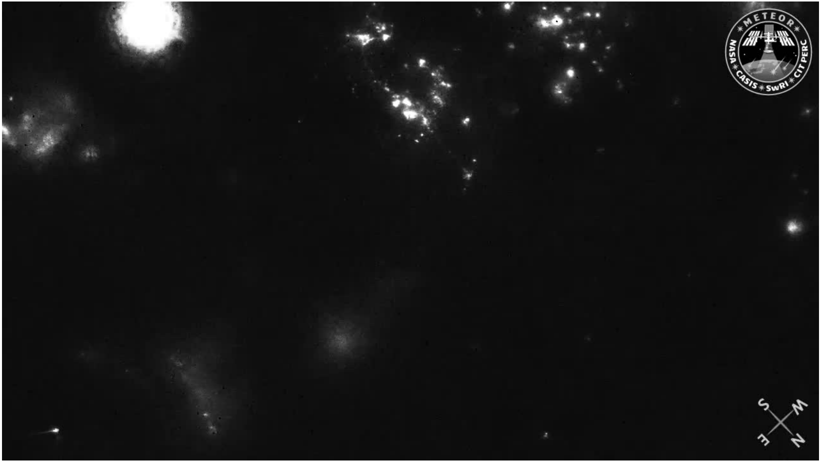


Figure 5 – Example : Frame 119 of sequence v86

Step 1 : Optical flow

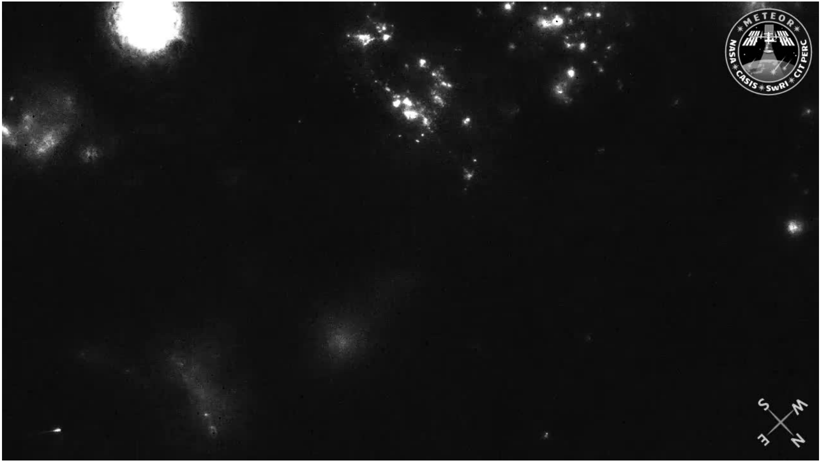


Figure 6 – Example : Frame 120 of sequence v86

Step 1 : Optical flow

Figure 7 – Example : optical flow between frame 119 and 120

Step 2 : Speed thresholding

- Meteors, space debris and lightnings are faster than Earth.
- Threshold set at 2.5px/frame.

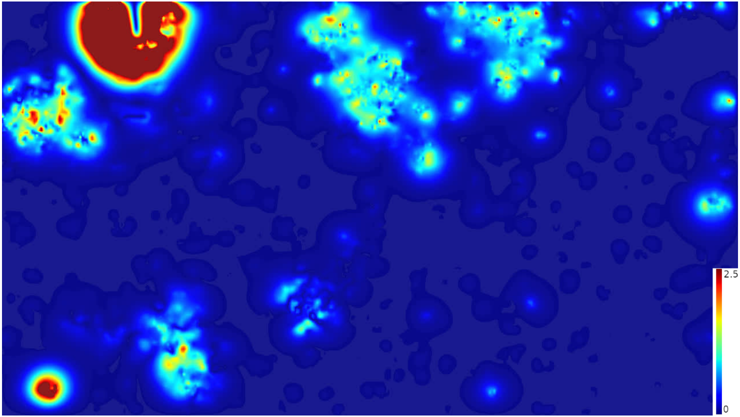


Figure 8 – Example : norm of displacements vectors

Step 2 : Speed thresholding

- Mathematical morphology : opening and closing.
  - To remove pixels without neighbors.
  - To regroup nearby cluster of pixels.

Figure 9 – Example : Binary mask of the fastest pixels.

Steps 3 and 4 : Connected Components Labelling and Analysis

- Pixels representation → objects representation.
- Compute statistical features on each object.
  - Average speed $\bar{v}$.
  - Average angle $\bar{\alpha}$ and its standard deviation σ_α.

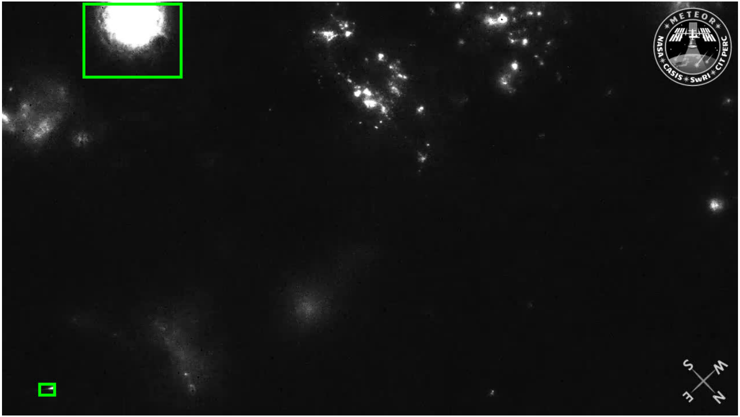


Figure 10 – Example : connected components with their bounding box.

Step 5 : Classification by σ_α

- How to differentiate the connected components ? (= fastest objects)
  - The trajectory of the meteor is rectilinear.
  - Low angular standard deviation ⇒ displacement vectors have a similar direction.
- A lightning spreads in all directions inducing a high angular standard deviation.

Figure 11 – Example : Angles

Step 6 : Tracking

- Simple algorithm based on a state machine
- The position of a meteor can be extrapolated in case of temporary loss.
- 2 purposes :
  - To confirm that it is a meteor (3 detections in less than a second).
  - To group frames into a sequence.

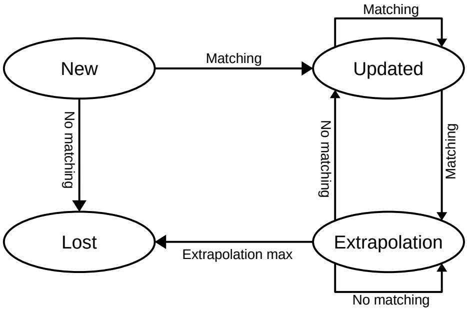


Figure 12 – State machine

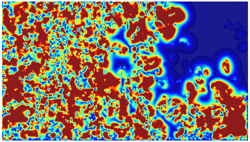
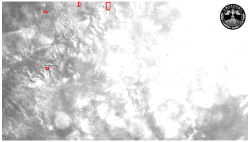
Validation bench

⇒ Qualify the processing chain

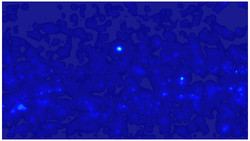
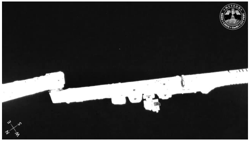
- ISS Meteor mission of Chiba University (Japan) [13].
  - High resolution camera filming Earth from the ISS [14].
  - 150 video sequences containing 50 meteors.
- Manual analysis to build a ground truth for each meteor.
- What is a valid detection ?
  - The supposed meteor is on the ground truth's trajectory.
  - The supposed meteor progresses on this trajectory in the right direction.
- Three scores :
  - Meteor detected or not.
  - Ratio between number of frames containing a meteor and number expected from the ground truth.
  - Number of false positives

Results

- 48 out of 50 meteors detected.
  - Probability of detection : 96%.
  - 70% of frames containing meteors are labelled as such.
  - Not really comparable to state of art results.
- Some issues
  - Cloudy and brightly sequences $\Rightarrow$ false positives

  - Fixed speed threshold $\Rightarrow$ false negatives

- Bonus : detection seems work on Earth (with stationary camera).

Conclusion

- Proposition of a new processing chain for meteors detection from space.
- Validation bench to qualify the chain.

Next steps :

- Adaptive threshold on speed.
- Algorithm optimizations.
  - Quality [15]/consumption [16]/speed [17] trade-off.
  - Simple and/or efficient algorithms [18, 19].
- Consider other hardware architectures (FPGA ?) [20].

Thanks

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Example

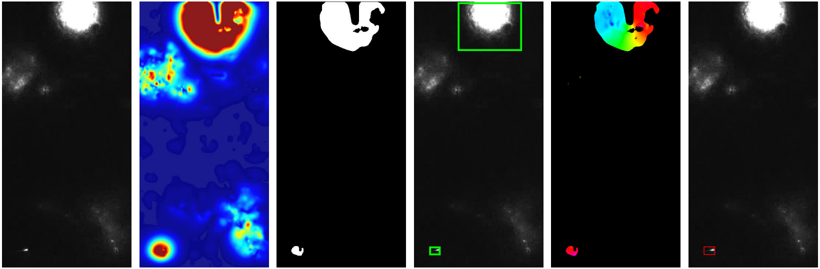

Figure 13 – Complete example for frame 119

How to speed up detection ?

Our goal is to reach real-time rate (25 frame/s).

- High Level Transforms
  - reducing time and energy consumption [21, 22, 23].
- Code parallelization
  - Multi-threading
  - SIMD (data parallelism) [24]
- Quality trade off

Connected Component Labeling

- Performed with Light Speed Labeling algorithm [25].
  - Available in a parallel version [26].
  - Very fast and energy efficient [27].