VISION - M2 IMA

Practical work report
Implementation of optical flow methods

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Contents

1 – Objective

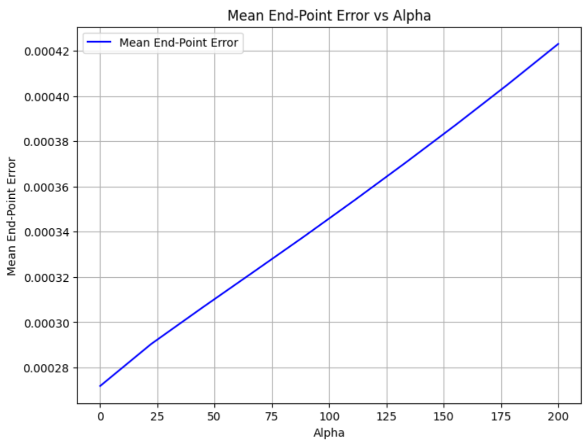
The objective of this practical work is to implement and compare various optical flow estimation methods, specifically the Horn-Schunck, Lucas-Kanade, and Nagel methods. These techniques are fundamental in computer vision for estimating motion between consecutive image frames.

The tasks involve:

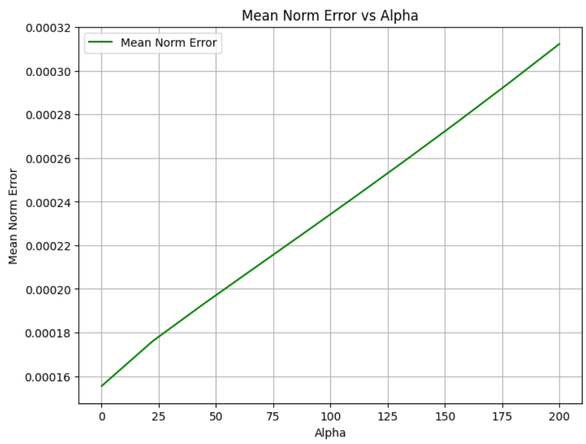
- Implementing the Horn-Schunck and Lucas-Kanade methods to compute optical flow.
- Computing spatial and temporal image gradients necessary for the estimation process.
- Testing the implementations on provided datasets and analyzing the accuracy using metrics such as endpoint error and angular error.
- Comparing the different methods in terms of accuracy and computational performance.

The results will be evaluated through visual representations of the estimated velocity fields and statistical comparisons when ground truth data is available. The report will focus on discussing the outcomes and hyper-parameter choices rather than detailing the implementation specifics.

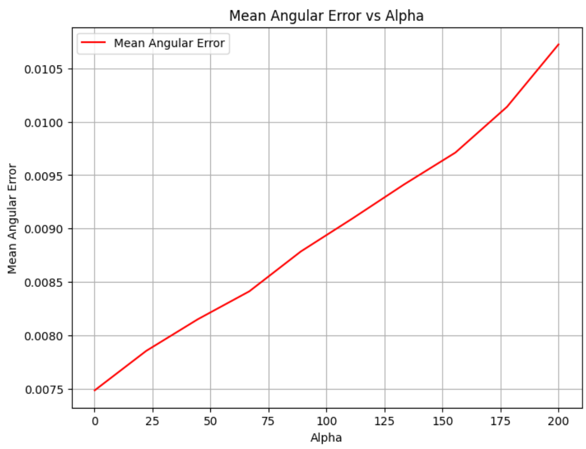
2 – Horn-Schunck method



(A) Mean of EPE as a function of α.



(B) Mean of Norm Error as a function of α.



(C) Mean of Angular as a function of α.

Figure 1 : Looking for the optimal α.

By computing the three types of errors we find that the optimal α is 1.

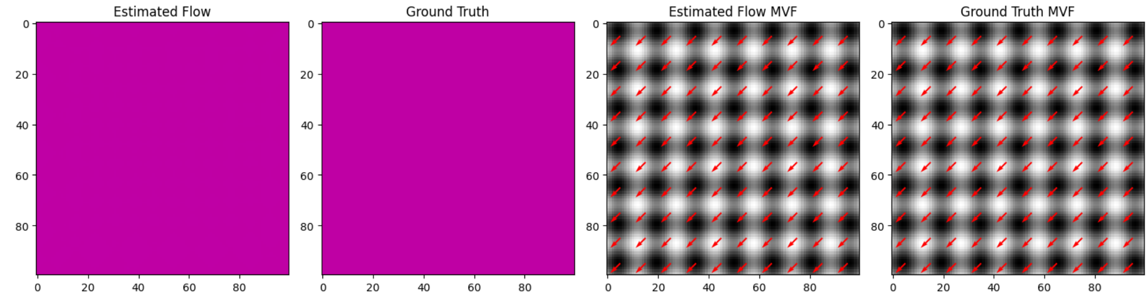
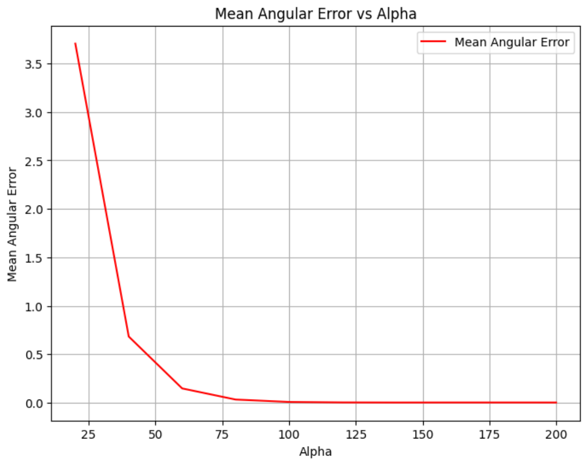
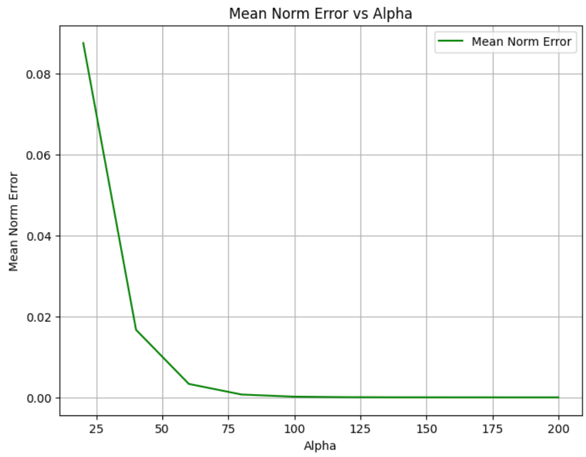


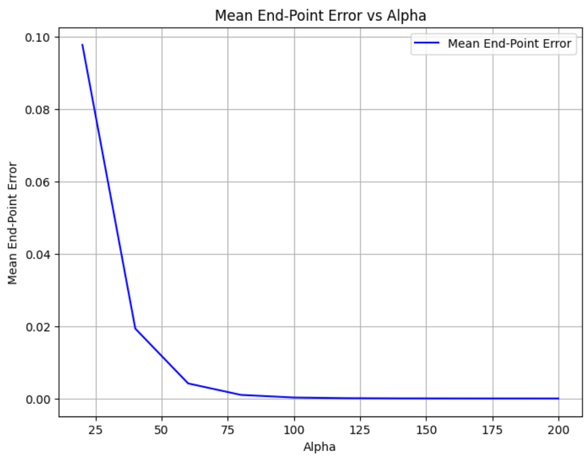
FIGURE 2 : Comparaison of the velocity map obtained with the Horn algorithm and the ground-truth



(A) Mean of EPE as a function of N.



(B) Mean of Norm Error as a function of N.



(C) Mean of Angular as a function of N.

FIGURE 3 : Looking for the optimal N.

From the figures above, we can confirm that the algorithm converges starting from $N = 100$.

3 – Lucas-Kanade method

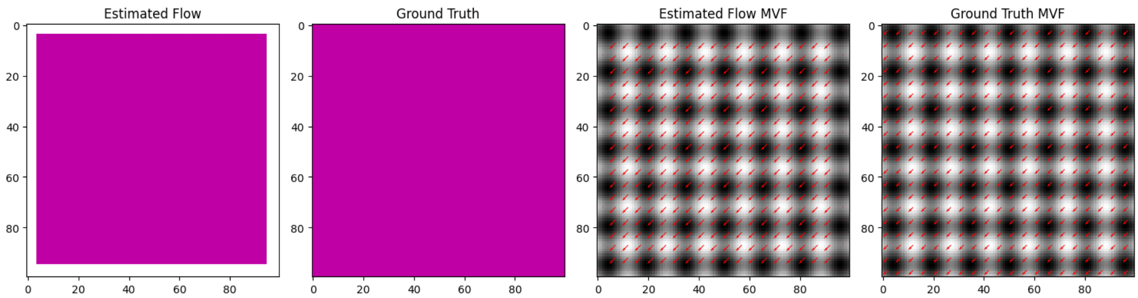
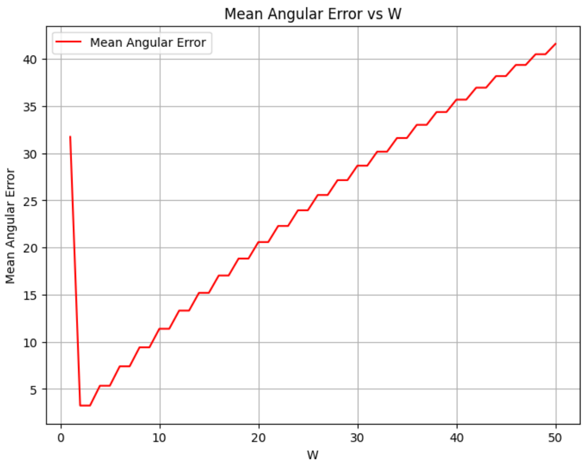
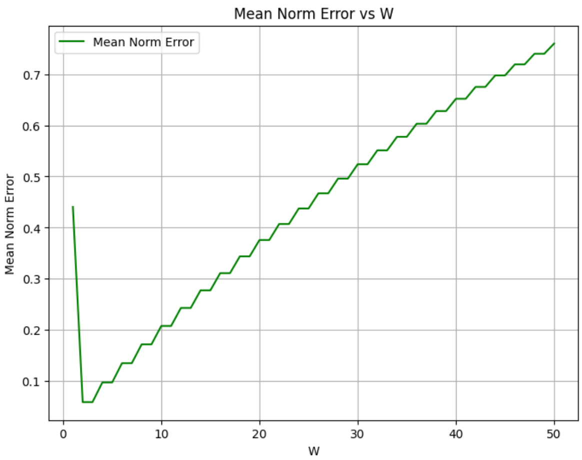


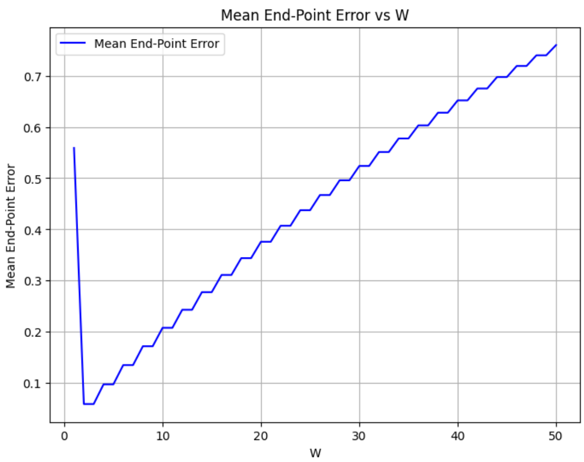
Figure 4 : Comparaison of the velocity map obtained with the Lucas-Kanade algorithm and the ground-truth



(A) Mean of EPE as a function of W.



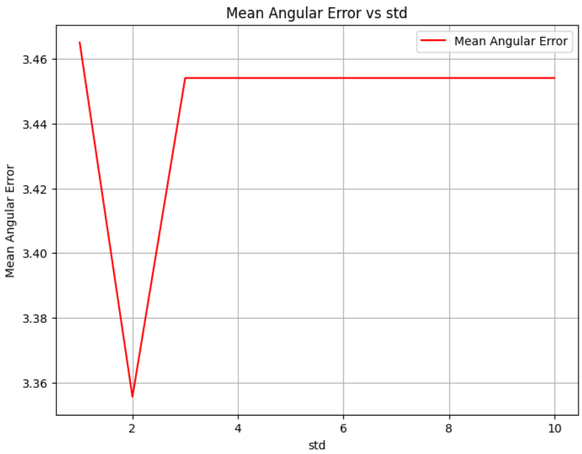
(B) Mean of Norm Error as a function of W.



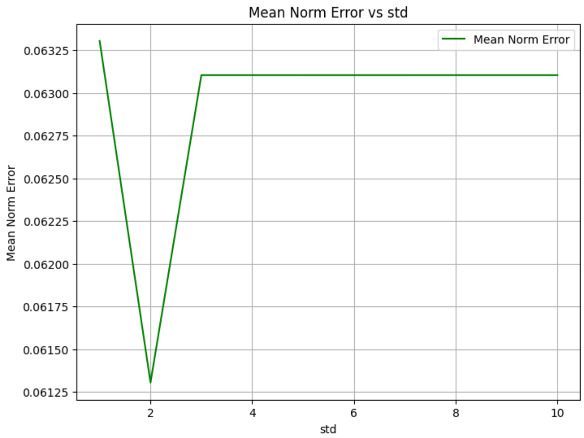
(C) Mean of Angular as a function of W.

Figure 5 : Looking for the optimal W size of the window.

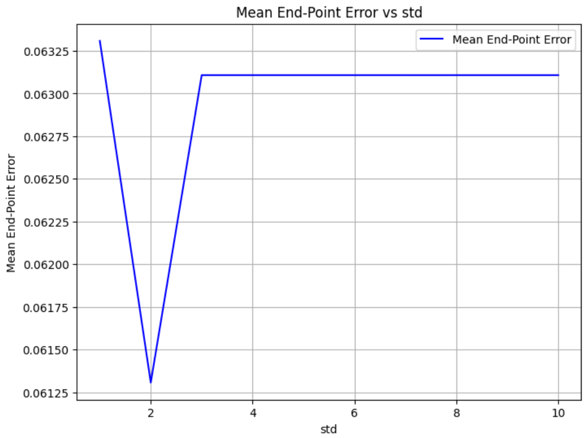
The best window size for the standard Lucas method is 3.



(A) Mean of EPE as a function of *std*.



(B) Mean of Norm Error as a function of *std*.



(C) Mean of Angular as a function of *std*.

FIGURE 6 : Looking for the optimal *std* standard deviation of the gaussian window.

The optimal std (standard deviation) for the Lucas method with the gaussian window is 2.

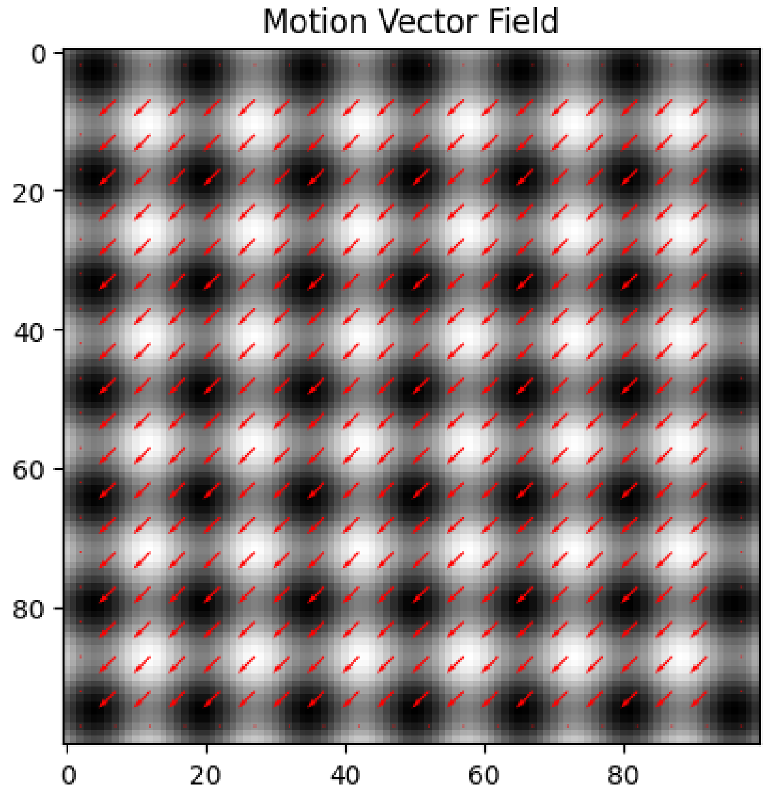


Figure 7 : Result of the Lucas method with a gaussian window.

Method	Angular Error	Norm Error	End-Point Error
L-K	1.54×10^{-4} (6.96×10^{-3})	2.49×10^{-6} (2.16×10^{-4})	4.81×10^{-6} (2.16×10^{-4})
L-K Gaussian	1.40×10^{-1} (2.73×10^{0})	2.49×10^{-3} (4.98×10^{-2})	2.49×10^{-3} (4.98×10^{-2})
H-S	4.10×10^{-3} (1.08×10^{-2})	1.05×10^{-4} (3.03×10^{-4})	1.81×10^{-4} (2.64×10^{-4})

Table 1 : Experiment results. Each value is reported as Mean (Std), rounded to two decimal places.

The results show that the standard Lucas-Kanade method achieves the lowest errors across all metrics, with an angular error of 1.542×10^{-4} and norm and end-point errors on the order of 10^{-6}, making it the most accurate method in this experiment. In contrast, the Lucas-Kanade method with a Gaussian window (even with the best size window and sigma) performs significantly worse, with errors increasing by several orders of magnitude, suggesting that the Gaussian weighting introduces excessive smoothing, leading to inaccurate motion estimation. The Horn-Schunck method, while not as precise as the standard Lucas-Kanade method, provides a reasonable trade-off between accuracy and robustness, with errors in the range of 10^{-4}, making it a viable choice in scenarios with high noise.

4 – Nagel method

Finally, we implemented the Nagel method, whose objective is to preserve velocity map discontinuities avoid smoothing along edge contours. The code and experiments can be found in the attached Notebook. In Figure 8 we can observe a first experiment with the NASA sequence, and in Figure 9 we can see the comparison with the available ground truth optical flows. The computed error statistics can be found in Table 2.

These experiments were performed with $\alpha = 0.9$ and $\delta = 0.1$ as hyper-parameter values. Increasing the value of α too much lead to solutions that are zero-everywhere while decreasing it too much leads to instability and convergence problems.

In general, we observe that this method leads to more sparse solutions thanks to the regularization performed. In the case of the "Square" sequence, we observe something interesting: Since most of the image is of constant color and there's a low amount of edges, the image gradient doesn't provide much information on most the image. Thus, the flow estimation is inaccurate in most the image, except near the contours, where we have some information on the gradient.

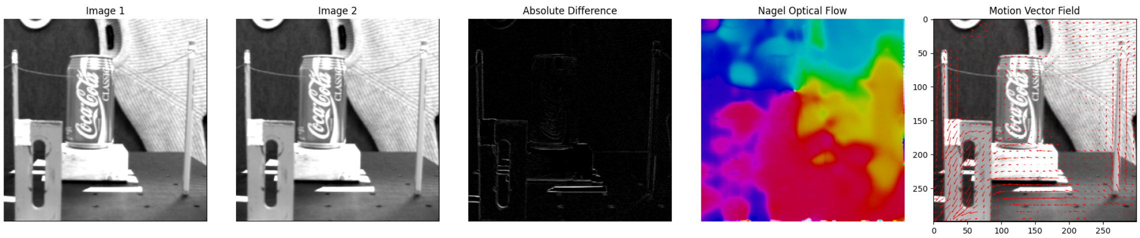


FIGURE 8 : Nagel method on the NASA image

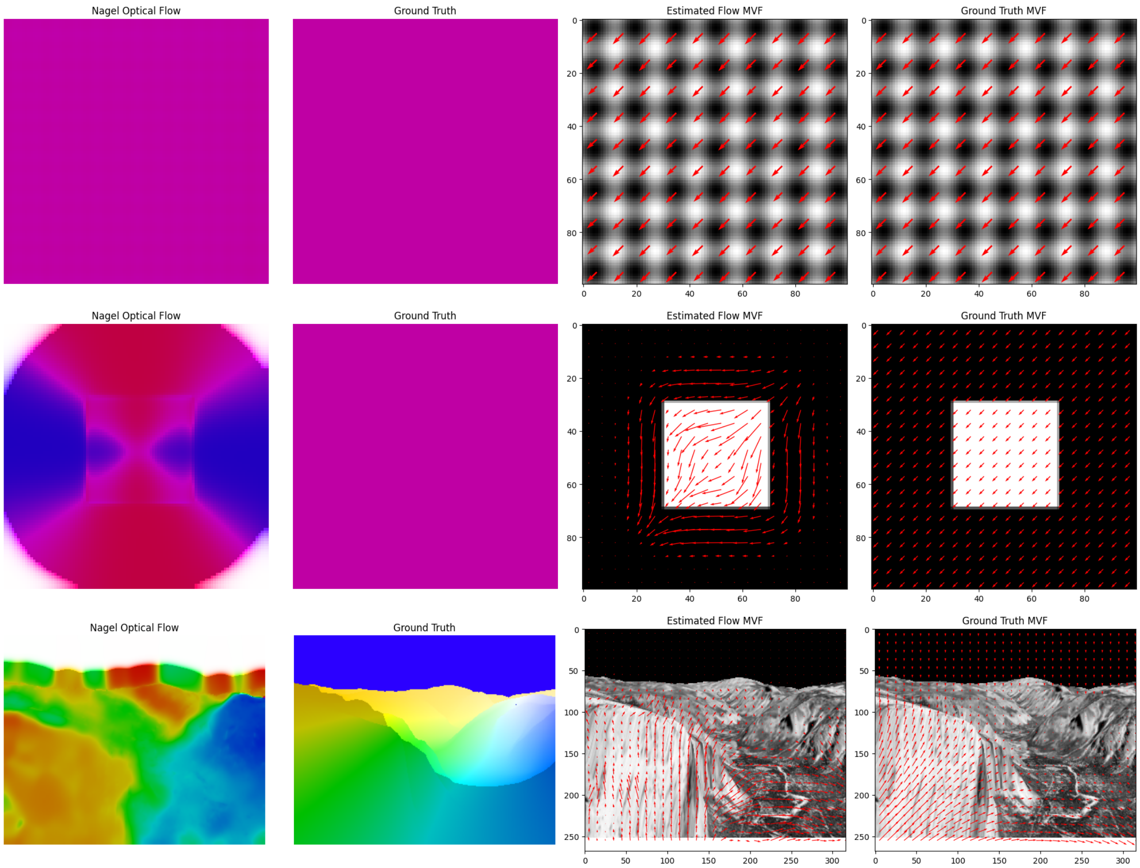


FIGURE 9 : Comparison with ground truth for the Nagel method.

Experiment	**Angular Error**	**Norm Error**	**End-Point Error**
Sine	35.18 (0.013)	-438.41 (26.54)	438.41 (26.54)
Square	40.18 (10.33)	-116.09 (162.83)	116.51 (162.53)
Yosemite	56.49 (24.31)	-138.29 (165.72)	138.94 (165.27)

TABLE 2 : Experiment results. Each value is reported as Mean (Std).