Plenoptic Cameras for Localization in Challenging Weather Conditions

Mathieu Labussière[1], Céline Teulière[1], Frédéric Bernardin[2] and Thierry Chateau[1]

[1]Université Clermont Auvergne, CNRS, SIGMA Clermont, Institut Pascal, F-63000 Clermont-Ferrand, France,
[2]Cerema Direction Centre-Est, F-63017 Clermont-Ferrand, France.

Micro-Lenses Array (MLA) based Plenoptic Cameras

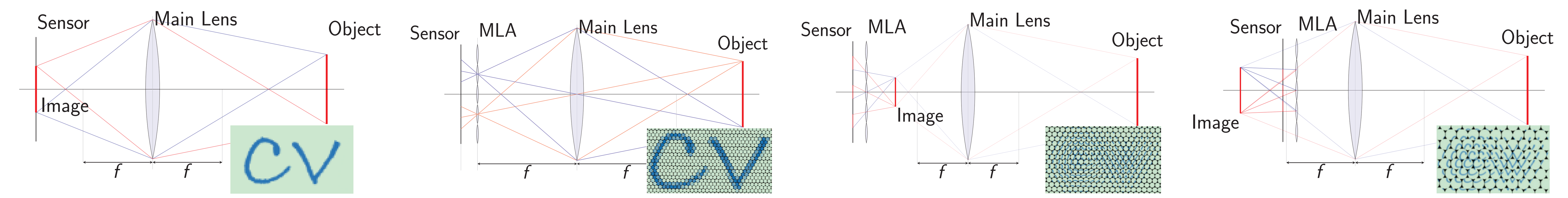

Figure 1: Comparison of optical design of a classic camera and plenoptic cameras. From *left* to *right*: classic camera, unfocused design (1.0), Keplerian design (2.0), and Galilean design (2.0).

Objectives

1. Improve the robustness and simplicity of computer vision in field robotics applications (*autonomous vehicles, drones, industrial manipulations, etc.*).
2. Investigate the use of a new type of passive vision sensor called a *plenoptic camera* in these applications.
3. Develop a localization algorithm (*Structure-from-Motion* (SfM), *Visual Odometry* (VO), *SLAM*, etc.) using a plenoptic camera to work in challenging weather conditions.

Context & Motivation

- In context of field robotics applications, challenging weather conditions (especially, *dust*, *rain*, *fog*, *snow*, *murky water* and *insufficient light*) can cause even the most sophisticated vision systems to fail.
- The robustness is usually addressed by the use of other sensors (*Lidar*, *radar*, *GPS*, *IMU*, etc.). But such sensors, usually active, suffer from interference. Contrarily, camera, which is a passive sensor, does not suffer from inter-sensor interference.

Imaging System

- The purpose of an imaging system is to map incoming light rays $\boldsymbol{r}$ from the scene onto pixels $\boldsymbol{p}_i$ of the photo-sensible detector. Each pixel collects radiance $\mathcal{L}$ from a bundle of closely packed rays in a non-zero aperture size system.
- The radiance is given by the *plenoptic function* $\mathcal{L}(\boldsymbol{x}, \boldsymbol{\theta}, \lambda, \tau)$ [1] where:
  - $\boldsymbol{x}$ is the *spatial* position of observation in space,
  - $\boldsymbol{\theta}$ is the *angular* direction of observation in space,
  - λ is the frequency of the light and τ is the time.
- Imaging systems allow to capture only a part of this function:

Sensors	**Spatial** (x)	**Angular** (θ)	**Temporal** (τ)
classic camera	✓	-	-
video camera	✓	-	✓
plenoptic cameras	✓	✓	-
plenoptic video cameras	✓	✓	✓

How to acquire the plenoptic function?

- From *Lumigraph* [2] to commercial *plenoptic cameras* [3, 4], several designs have been proposed to capture the plenoptic function.

Multi-sensors	**Sequential**	**Multiplexing**
camera array	gantry, coded aperture	micro-lenses array (MLA)

Figure 2: `Lytro Illum` camera [3]

Figure 3: `Raytrix R12` camera [4]

Plenoptic cameras capabilities

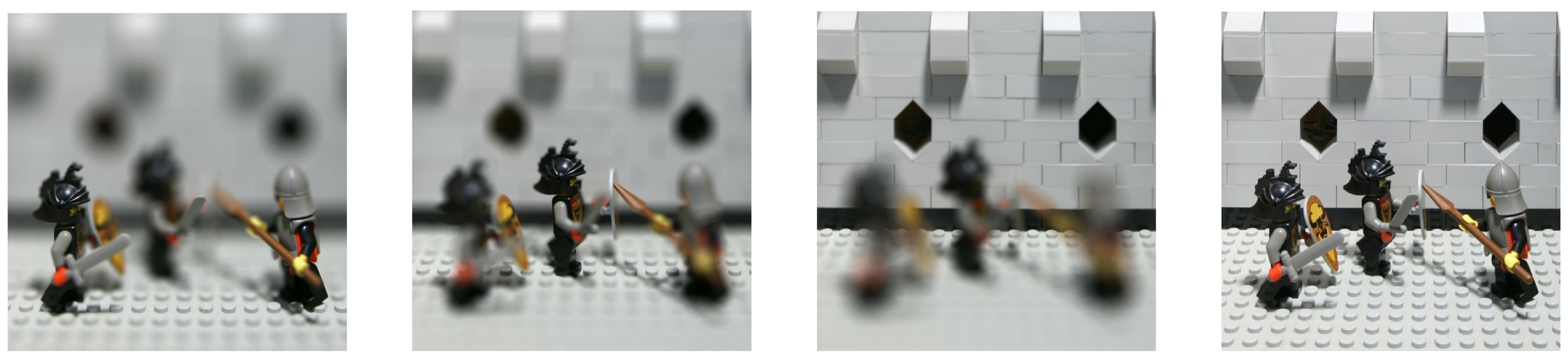

Figure 4: Post-capture refocusing and total focus reconstruction

Figure 5: Depth map

Figure 6: Occlusion management

Plenoptic cameras in field robotics applications

- Taking inspiration from bio-compound-eyes, Neumann et al. established the formalism for the plenoptic-based motion estimation.
- During his thesis, Dansereau used the plenoptic function to achieve real-time navigation, introducing three distinct closed-form solutions to extract the motions parameters from the plenoptic function.
- At the same period, Dong et al. gave a complete scheme to design usable real-time plenoptic cameras for mobile robotics applications.
- Zeller et al. adapted a *SLAM* formulation to deal with plenoptic information. Derived from their calibration model, they proposed a *visual odometry* framework, later improved with scale information.
- More recently, Hasirlioglu and al. investigated the potential of plenoptic cameras in the field of automotive safety.

Roadmap

- By taking into account blur information and the multi focal lengths:
  - Propose a new model and calibration procedure (*in progress*).
  - Develop a new approach to generate more precise depth map.
- Propose a probabilistic plenoptic-based *Structure-from-Motion (SfM)* approach.
- Create a *dataset* of plenoptic images captured from a vehicle under different weather conditions.

Conclusion

- Plenoptic cameras capture rich information about a scene (*spatial* and *angular* information). Given a single snapshot, a 3D representation of a scene can be passively created. With more information the robustness of localization algorithm is improved, especially during challenging weather conditions.

Acknowledgments

- This work has been sponsored by the AURA Region and the European Union (FEDER) through the MMII project of CPER 2015-2020 MMaSyF challenge.

Main References

[1] E. H. Adelson and J. R. Bergen. "The plenoptic function and the elements of early vision". In: *Computational Models of Visual Processing* (1991), pp. 3–20.
[2] Gabriel Lippmann. "Integral Photography". In: *Academy of the Sciences* (1911).
[3] Ren Ng et al. *Light Field Photography with a Hand-held Plenoptic Camera*. Tech. rep. Stanford University, 2005, pp. 1–11.
[4] Christian Perwaß, Lennart Wietzke, and Raytrix Gmbh. "Single Lens 3D-Camera with Extended Depth-of-Field". In: 49.431 (2010).

mathieu.labussiere@uca.fr