Plenoptic Cameras for Localization in Challenging Weather Conditions

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

<table>
<thead>
<tr>
<th>Sensors</th>
<th>Spatial ( x )</th>
<th>Angular ( \theta )</th>
<th>Temporal ( \tau )</th>
</tr>
</thead>
<tbody>
<tr>
<td>classic camera</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>video camera</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td>plenoptic cameras</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td>plenoptic video cameras</td>
<td>✓</td>
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</table>

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.

<table>
<thead>
<tr>
<th>Multi-sensors</th>
<th>Sequential</th>
<th>Multiplexing</th>
</tr>
</thead>
<tbody>
<tr>
<td>camera array</td>
<td>gantry, coded aperture</td>
<td>micro-lenses array (MLA)</td>
</tr>
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</table>

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 motion 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.

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Main References