From Alternate Exposure Imaging to 3D Reconstruction of Astronomical Phenomena

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Abstract

Microoptics in the form of a lens array can be used for reconstructing the light field captured by a single camera. But to go beyond this classical approach new recording modalities and prior knowledge are required for faithful 3D reconstruction. In this talk we will motivate the usage of alternate exposure imaging for dense motion estimation and shape priors for 3D reconstruction for this task based on our recent work in the field of optical flow estimation and 3D reconstruction of astronomical nebulae.

Summary of the talk

In this talk we will present some of our recent work in the field of image-processing and 3D reconstruction done at the Computer Graphics Lab at the TU Braunschweig and motivate its applicability to microoptics. The talk will be divided into two main parts: Alternate exposure imaging and volumetric reconstruction of astronomical nebulae.

In the first part of the presentation I will talk about a new image recording modality to compute optical flow between images. Optical flow is used in many 3D reconstruction and image-based rendering algorithms to estimate motion fields. Traditional optical flow algorithms rely on consecutive short-exposed images. In this work, we make use of an additional long-exposed image for motion field estimation. Long-exposed images integrate motion information directly in form of motion-blur.

Most previous approaches work best with pinpoint-sharp images as input which depict a dynamic scene at two discrete points in time. From sampling theory it is known that temporal aliasing occurs if the maximum 2D displacement in the image exceeds one pixel, as the short-exposed images do not capture any motion information by themselves. To overcome this problem multiscale optical flow methods pre-filter the images globally in the spatial domain because the motion is a priori unknown. This, however, removes any high spatial frequencies which should only be suppressed in the direction of local motion.

There exists a simple way to achieve correct temporal pre-filtering: exposing an image sensor for an extended period of time. For moving objects, high frequency components are only suppressed in the direction of motion. Additionally, long-exposed images bear the advantage that occlusion information enters into the image formation process. A scene point contributes to the motion-blurred image for exactly as long as it is not occluded.

These observations inspired us to extend traditional optical flow estimation. We obtain dense, robust 2D motion fields by capturing images of the same scene with different exposure times, Fig. 1. As input our method requires images taken such that

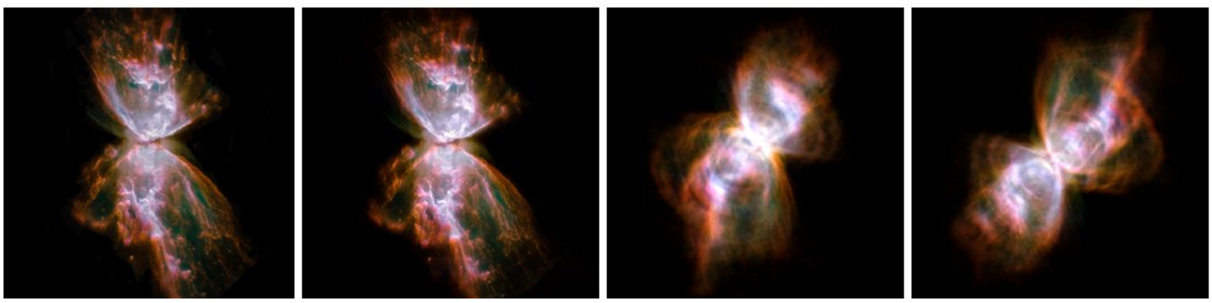
an intermediate, long-exposed image I_B is enclosed by two short-exposed images I_1 and I_2. This way, we have additional information available: anti-aliased motion information from the long-exposure image and the complete high spatial frequencies from the short-exposed images.
In order to exploit the information provided by the additional long-exposed image, we derive a suitable model for the formation of the motion blurred image I_B, based on integration of sub-paths in the short-exposure image I_1 and I_2 and a specialized TV-L^1 optimization scheme.

The second part of the talk will be, apposite to the location and its famous planetarium, about our work on 3D reconstruction of astronomical nebulae. The 3D visualization of astronomical nebulae is a challenging problem since only a single 2D projection is observable from our fixed vantage point on Earth. We generate plausible and realistic looking volumetric visualizations via a tomographic approach that exploits the spherical or axial symmetry prevalent in some relevant types of nebulae. Our approach is based on an iterative compressed sensing reconstruction algorithm that we extend with support for position-dependent volumetric regularization and linear equality constraints. The applicability of our single image 3D reconstruction technique is demonstrated for several astronomical imagery from the Hubble Space Telescope and allows for interactive walkthroughs. The resulting volumetric data is visualized using direct volume rendering.

The talk will conclude with a discussion on how these different ideas could also be potentially useful for and applied to microoptics to hopefully spread new ideas and techniques.

(a) (b) (c) (d)

Fig. 1: Alternate exposure images: (a) exposure timing diagram of (b) a short-exposed image I_1 followed by (c) a long exposed image I_B and (d) another short-exposed image I_2.



(a) (b) (c) (d)

Fig. 2: Single-Image 3D reconstruction of astronomical nebulae: (a) Original input image of the Butterfly Nebulae (NGC 6302). (b) Reconstructed 3D nebulae from the original viewpoint. (c-d) Novel viewpoints based on our 3D reconstruction.