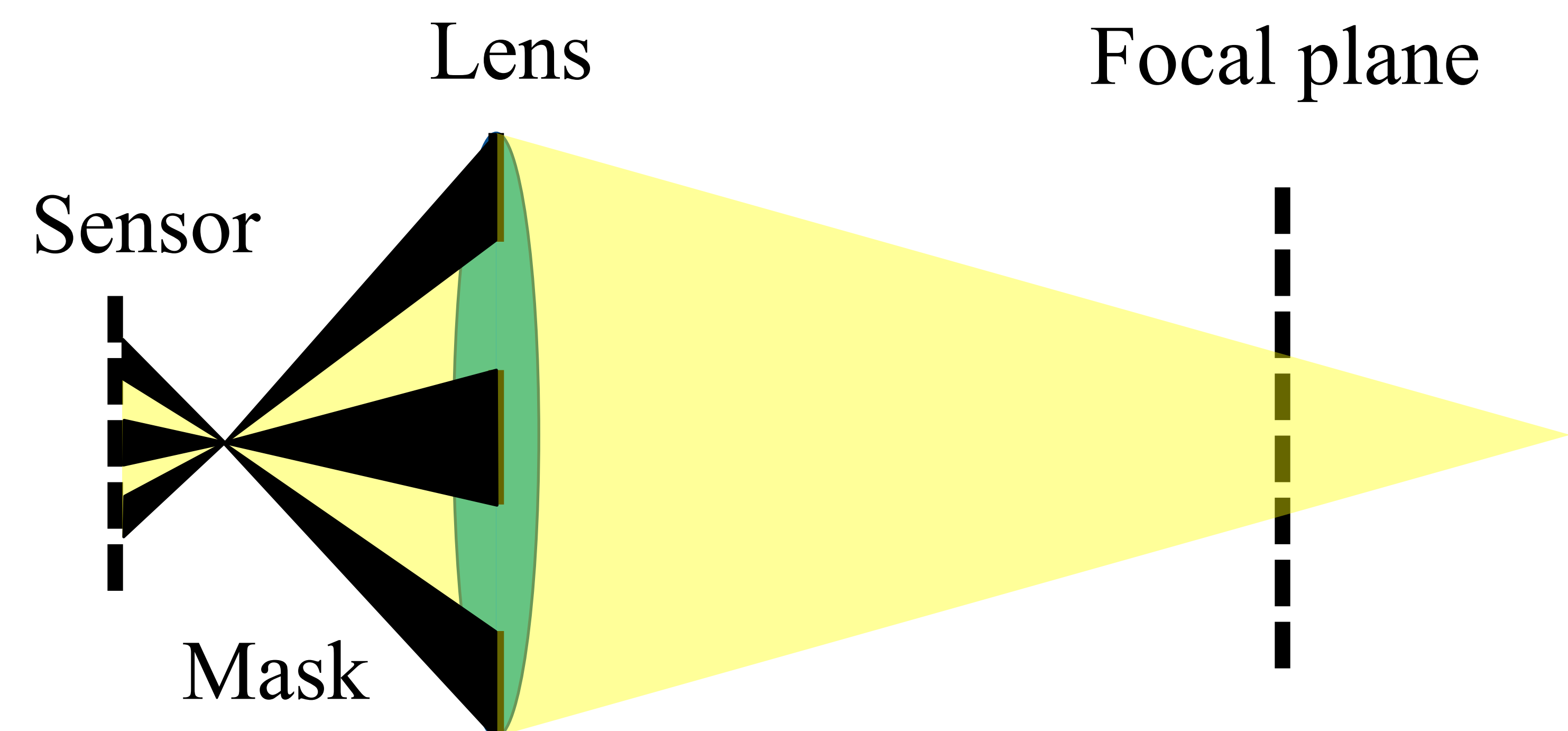


Introduction

Coded Aperture Ranging (CAR) is an imaging technique that can extract both depth information and an all-focused image from a single captured image by making a minor modification to a conventional camera system. Unlike other camera systems that require additional apparatus for depth perception, CAR systems require only a single camera and a partially masked aperture. The masked aperture enables the generation of a depth map just from a single image via Depth from Defocus techniques. The depth map can then be used to create an all-focused image from the original blurred image. This technique has applications in systems where size and weight constraints are paramount and image depth map generation is necessary.

Depth from Defocus



- Blur in an image is created due to depth away from the focal plane.
- Amount of blur is a function of depth only.
- Coded Aperture amplifies depth discrimination over conventional aperture.

PSF Estimation

- Image formation is modeled as a convolution with additive noise:

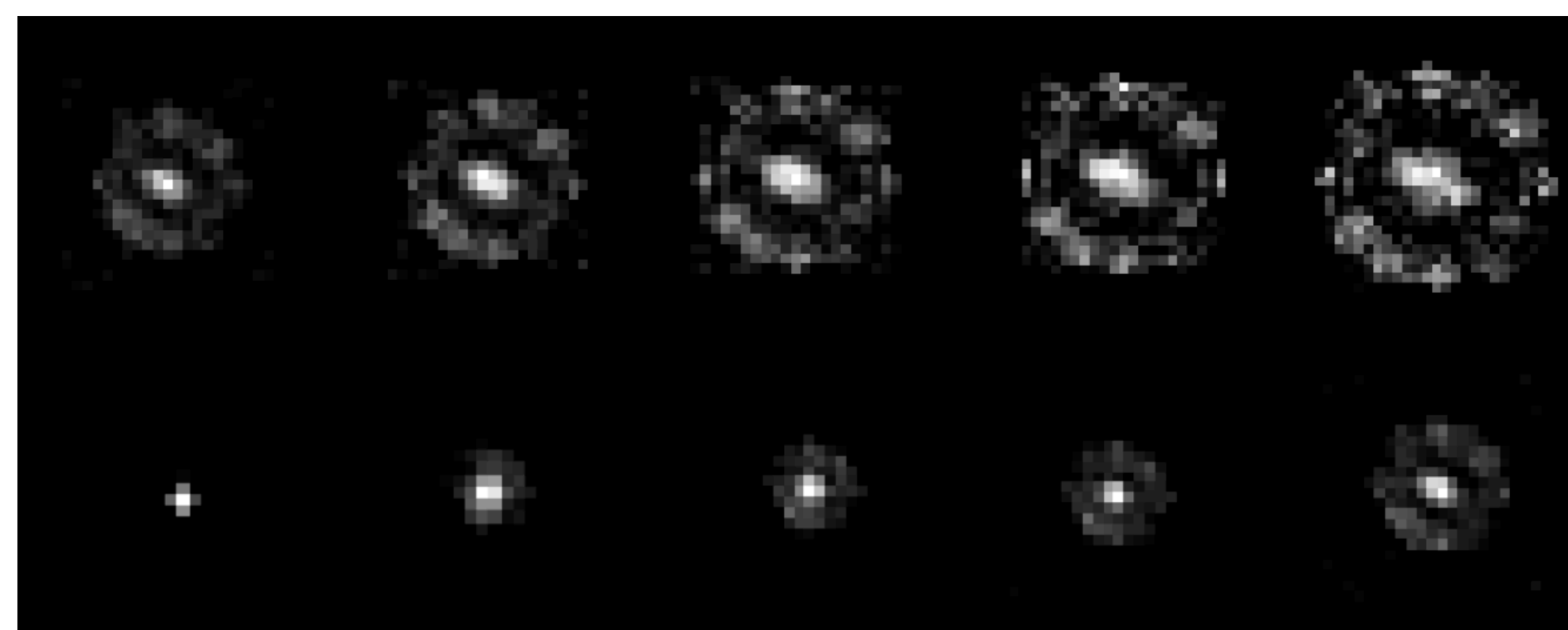
$$y = f_k * x + \eta$$

- Thus, finding the blur kernel can be done via a quadratic program that minimizes the reconstruction error as well as a regularization term:

$$f_k^* = \arg \min_{f_k} \lambda_1 \|y - f_k * x\| + \lambda_2 \|\nabla f_k\|$$

Blur Calibration and Depth Determination

- First, the focus of the camera is locked (at 2 m) and a focused image of the calibration target is taken.
- The camera then moves further from the calibration target at regular intervals to take blurred images of the calibration target.
- Pairs of blurred and focused images are used to estimate the blur kernel corresponding to the distance of the camera from the target, using the algorithm mentioned in the PSF estimation section.

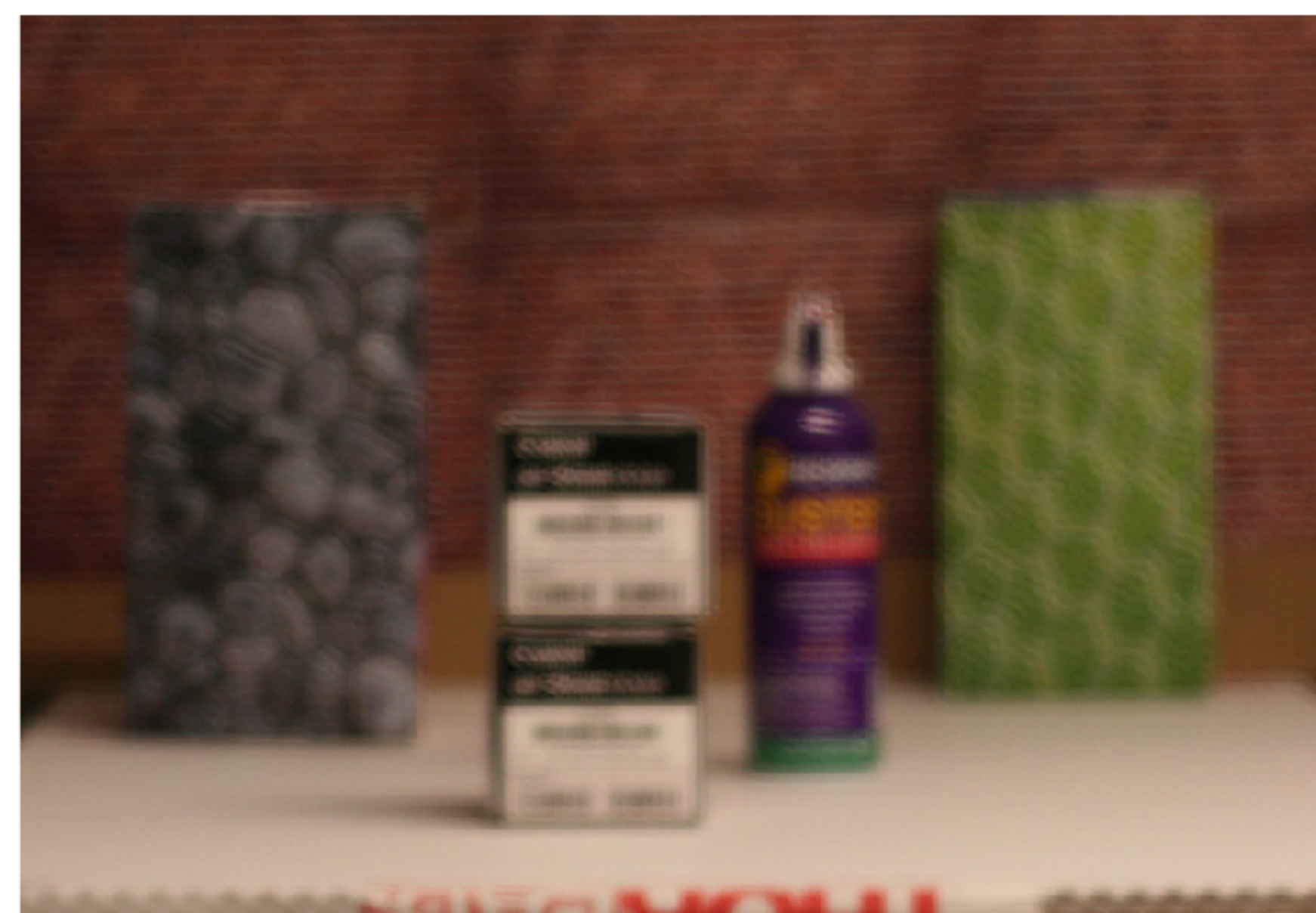


- As shown in the figure above, the estimated blur kernels are functions of the depth and the aperture shape. The larger kernels correspond to larger calibrated depths.
- The next step involves deconvolving the captured image with each of the blur kernels.
- Deconvolution with sparse priors is used to provide sharp images:

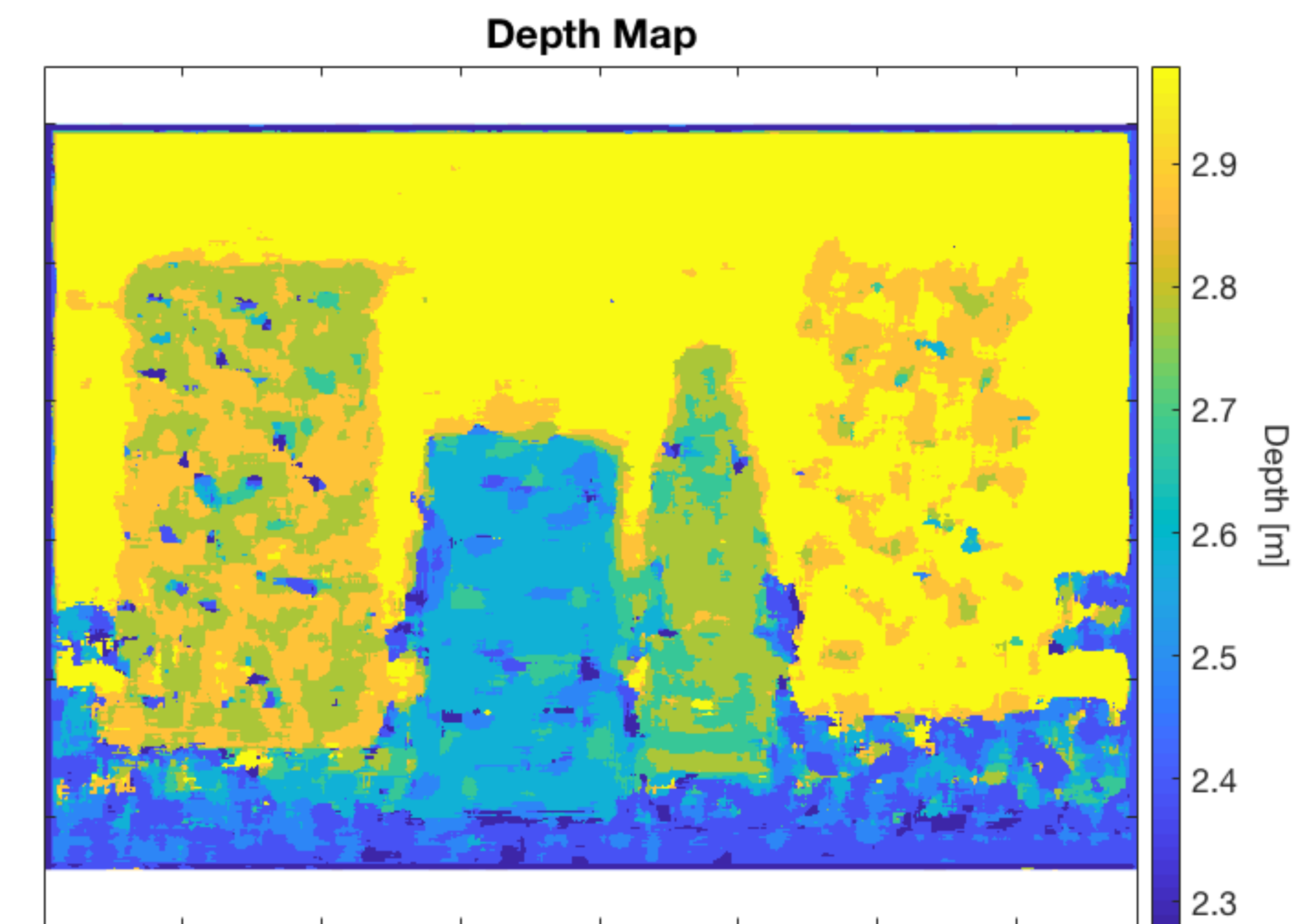
$$x^* = \arg \min_x |C_{f_k} x - y| + \sum_{i,j} \rho(x(i,j) - x(i+1,j)) + \rho(x(i,j) - x(i,j+1))$$

$$\rho(z) = |z|^{0.8}$$

- Regions where the depth value matches the blur kernels' will appear sharp, and vice versa. Therefore depth for each local window is chosen based on the blur kernel that minimizes the reconstruction error after deconvolution.



Experimental Results



Raw depth map shows clear image segmentation between foreground and background as well as among objects. Resolution of ~20 cm is achieved.

Conclusions and future work

Given the right aperture mask as well as deconvolution algorithm, one can perform reliable depth estimation from monocular cameras with coded apertures. Furthermore, the depth estimation step takes only a few seconds on a modern CPU since the majority of the work is off-loaded onto the calibration step, which is a fixed overhead. Future work include demonstration of the Coded Aperture system on a smaller form factor such as a Raspberry Pi camera module. Also, further work on improving the depth resolution as well as trade studies on applications in spacecraft imaging will be conducted.

Acknowledgments and References

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