Compact Digital Pinhole Camera

Max Rose*, Manfred Baierl**, Andrea Koch*, Klaus Bobey*
*Faculty of Natural Sciences and Technology, Göttingen University of Applied Sciences and Arts, GERMANY
**GAMB Cross-Media-Design, Frankfurt, GERMANY
mailto:max.rose@n.hawk-hhg.de

A compact digital pinhole camera is shown which gives a preview of pinhole photographs before their final exposure. Optimum pinhole diameter and image distance are determined experimentally. Vignetting from sensor microlenses can be seen to dominate for large Field of View. The limits on miniaturization of digital pinhole cameras are discussed.

1 Rediscovery of the pinhole camera

Since the digital cameras have replaced analogue ones, almost everywhere, digital pinhole cameras are becomming attractive as well. Research has been done to find optimum pinhole diameter for maximum resolution of such a camera [1, 2].

However, pinhole photography has become more attractive within the last decade, as can be seen by the increasing submissions of pinhole photographies to the *Worldwide Pinhole Photography Day* (WPPD) in Fig. 1. Pinhole cameras offer unique properties like very large depth of focus and distortion free imaging at large *Field of View* (*FoV*) among other more art related properties [3].

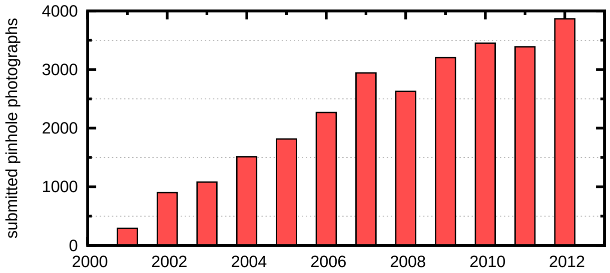

Fig. 1 *Height of bars indicate number of submissions of analogue and digital pinhole photographs for the annual WPPD online galleries [4].*

2 Advantage of digital pinhole cameras

There is the *LiveView* feature of digital cameras which allow convienient preview of the pinhole image before final exposure. This is not possible with classical viewfinders for the photographer's eye due to the low brightness of the image. To have *LiveView* available for digital pinhole cameras low F-Number ($F/\#$) and low light amplification from image sensors are required. While the $F/\#$ depends on physical dimensions, or more precisely on the image distance and pinhole diameter, the appreciably low light amplification is sensor technology related.

3 Digital pinhole camera design

Two major design parameters are readily accessible for optimization of the set up of a digital pinhole camera. First, the pinhole diameter D, and second the image distance b. The mirrorless digital camera body and its main components such as the pinhole, the image sensor and the image distance in between are shown in Fig. 2.

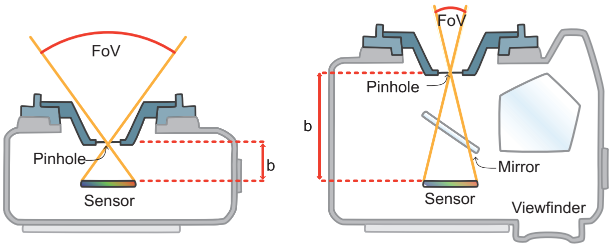

Fig. 2 *Compact mirrorless system cameras (left) allow short image distance b hence small $F/\#$, while conventional set up with viewfinder (right) and mirror do not allow short image distance b.*

3.1 Optimum pinhole diameter

Optimum pinhole formulas derived by various investigations [1, 2] do only differ in a numerical factor in front the square root of the wavelength and image distance product:

$$D_{opt} = s \cdot \sqrt{b \cdot \lambda}\,. \tag{1}$$

It is reasonable to express the numerical factor s in terms of an optimum Fresnelnumber

$$s = 2 \cdot \sqrt{N_{F,opt}} \tag{2}$$

with

$$N_{F,opt} = \frac{(D_{opt}/2)^2}{b \cdot \lambda}\,. \tag{3}$$

This helps to compare pinhole cameras on basis of the Fresnelnumber. It is found that the optimum pinhole diameter is located in the transition region between Fraunhofer and Fresnel diffraction. Visual inspection of real scenery photographs from Fig. 3

suggests a maximum of resolution in the image at $N_{F,opt} = 0.758$.

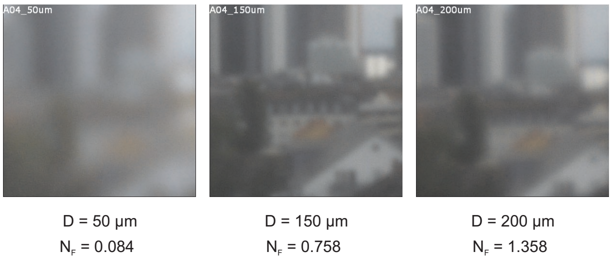

Fig. 3 *Three digital pinhole photographs with constant image distance 14 mm and different pinhole diameters, hence different N_F. Fraunhofer region $N_F \ll 1$ (left), most detail (middle) and Fresnel region $N_F > 1$ (right).*

3.2 *Improved $F/\#$ of compact pinhole cameras*

Optimization for low $F/\#$ to enable *LiveView* functionality can be achieved with a small image distance b. Optimum pinhole diameter and image distance have a fixed relation according equation (1). With $F/\# = b/D_{opt}$ it follows that

$$F/\# = \frac{\sqrt{b}}{2 \cdot \sqrt{N_{F,opt}} \cdot \sqrt{\lambda}} \quad (4)$$

is a function of the square root of the image distance b. As is shown in Fig. 4 the $F/\#$ goes in the desired direction of lower values, if b is decreased.

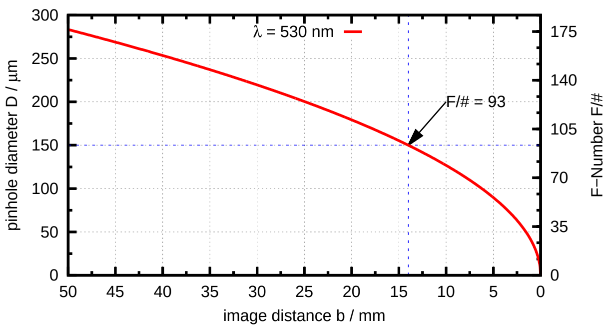

Fig. 4 *Relation between $F/\#$ and b for the presented compact digital pinhole camera.*

3.3 *Vignetting of image sensor with microlenses*

As can be seen from Fig. 2 the sensor size determines the *FoV* for a fixed image distance. For large *FoV* as they occur in the presented pinhole camera, oblique rays are incident on the sensor. The sensor is usually equiped with microlenses to increase the effective quantum efficiency, hence sensitivity of each pixel. The angular characteristic of those lenses results in vignetting. Fig. 5 shows the captured irradiance distribution in one direction across the sensor. For comparison the fundamental $\cos^4$-law is also plotted. For $\pm 15°$ the meassured irradiance follows the theoretical limit of the $\cos^4$-law closely. For angles at $\pm 38°$, which correspond to the sensor edge of the set up, the $\cos^4$-law predicts 3/8 of the central irradiance. At this angle the meassured irradiance is three times lower at 1/8.

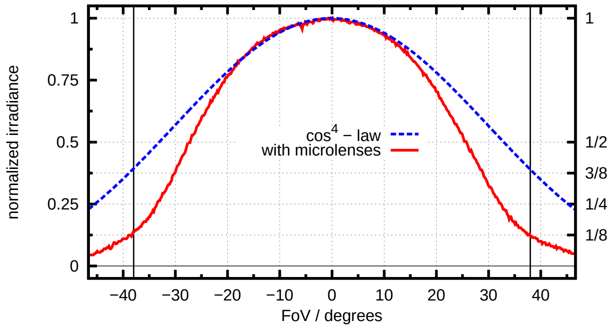

Fig. 5 *Meassured irradiance distribution of homogenous illuminated planar surface (lambertian) across the image sensor (17.3 mm x 13 mm) with microlenses.*

4 Concluding remarks and outlook

The WPPD galleries show statistics on how pinhole photography is growing. It is considered that digital pinhole cameras do also contributing to this rise. *LiveView* of digital cameras can significantly simplify the composition of a photograph. A compact pinhole camera design which is proposed to take advantage of *LiveView*. Based on a real scene test, the best pinhole diameter is 150 µm at an image distance of 14 mm and according to that $F/\# = 93$ can be achieved. The vignetting for the presented pinhole camera is three times stronger at the corners of the image as predicted by the $\cos^4$-law. It was found that microlenses do only have negative effect on vignetting for *FoV* above $\pm 15°$.

Why not choose even smaller image distances to further reduce the $F/\#$? First, it is questionable if this is neccessary because even motion picture recording is possible with $F/\# = 93$ on a sunny day. Secondly, since one does not switch to UV photography the wavelength isn't reduced. For images in the visible spectrum there is a loss of absolute resolution present with decreasing $F/\#$. This is due to increasing diffraction effects which get more pronounced because the optimum pinhole gets accordingly smaller (see Fig. 4).

To further reduce $F/\#$ of the compact digital pinhole camera it becomes neccessary to make use of digital image processing such as image reconstruction to soften the diffraction effects on resolution.

References

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[4] G. Kemp, "Worldwide Pinhole Photography Day," (2012). URL `http://www.pinholeday.org/gallery/`.