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Accurate pinhole camera apertures using insect pins

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Abstract

Pinhole camera photography is explored using a set of entomology pins due to their known pin diameters and availability in a variety of sizes. A procedure to prepare removable-lens digital cameras for pinhole photography is described. A video is included showing a set of ten insect pins and how to fit the camera with pinhole apertures. Formulas are given that estimate optimum sizes for pinholes based on camera sizes. Finally, a sample pinhole photo is included.

Introduction

In photography, light is usually focused by a converging lens in a camera. In this way the aperture is large enough so that a photo can be taken in a fraction of a second. In contrast, the pinhole camera uses a pin-sized aperture instead of a lens. See figure 1 for the image formation where light from an object passes through a small opening [1]. If the hole is too small, the image will blur due to diffraction. If the hole is too large, the image becomes blurred as light from a single object point reaches many points in the sensor plane. Although pinhole photography usually requires long exposure times because of the small size of the optimum aperture, an advantage is that objects at all distances from the pinhole are in focus, i.e. a pinhole camera has infinite depth of field. ‘Most likely the earliest recorded description of pinhole optics, although cryptic in nature, comes from Mo Ti in

China, circa 400 B.C.' [2]. The phenomenon is called the *camera obscura*. The name comes from Latin where *camera* is room or chamber and *obscura* translates as dark. A room-sized camera obscura can be easily be made by students [1]. See [2] for the interesting historical accounts of the camera obscura by observers Mo Ti, Aristotle, Ibn al-Haitham (Alhazen), Leonardo da Vinci, Francis Bacon, and others.

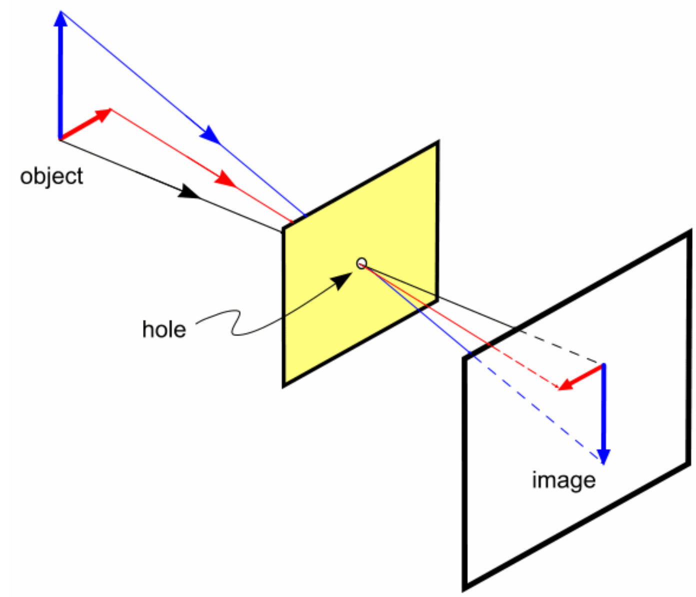


Figure 1. Formation of image on a screen as light passes through a small hole. If the hole is too small, diffraction will cause the image to blur. If the hole is too big, light from a single point on the object reaches many points on the image screen, causing blur.

Physics teachers have noted the relevance of the pinhole camera in introductory courses for decades. Albert V Baez, father of legendary folk singer Joan Baez, used the pinhole camera in the 1950s as an introduction to geometrical and physics optics, as well as photography [3]. By 1970 pinhole camera experiments became even more popular with the readily available single-lens reflex camera (SLR) [4]. The SLR was designed so that the lens could be easily removed for another lens. Therefore, it was easy to fit the camera with a pinhole opening. Today the digital camera is ever present. A few years ago Rachel Lancor and Brian Lancor wrote an article describing 'how the classic pinhole camera demonstration can be adapted for use with digital cameras' [5]. In the next section another adaptation method, using pins commercially available in a variety of sizes, is presented and the reader can choose from these equally-effective approaches.

Adapting a camera for pinhole photography

Figure 2 illustrates eight steps in adapting a digital camera for pinhole photography. For this procedure, one needs a removable-lens camera, an extra camera body cap, electrical tape, a disposable aluminum cookie tray, and an insect pin. The first step is to remove the lens. Then drill a hole into an extra camera body cap. A diameter of 10 mm (3/8 inch) works well. A small piece of aluminum about 20 mm x 20 mm (roughly 3/4 inch square) is cut from a cookie sheet using a utility knife. A pin is then used to make a pinhole. Four pieces of electrical tape are placed on the cap, then peeled back so that the piece of aluminum with the hole can be placed underneath. Watch our accompanying short video to see the construction in action [6].

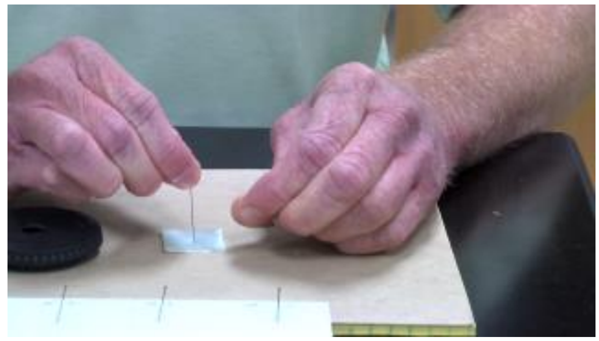
Insect pins

Entomologists use different size pins to mount insects according to their size and classifications on boards for viewing [7]. Pin sets with specific diameters can easily be purchased for making pinholes. See figure 3 for a set of ten pins. The pin sizes are 000, 00, 0, 1, 2, 3, 4, 5, 6 and 7; the respective diameters in microns are 250, 300, 350, 400, 450, 500, 550, 600, 650 and 700. Students can make pinholes knowing the diameter of each aperture. They can then take a series of pinhole photos to see which diameter gives the best image, which is considered in the next section.

a) lens removed from the camera body

b) hole drilled in an extra body cap

c) cutting aluminum from a cookie sheet

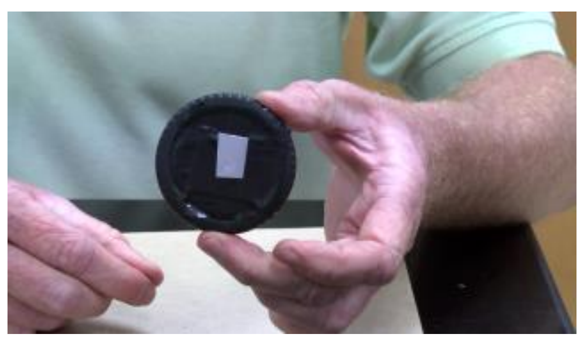


d) making a pinhole in the aluminum

e) attaching four strips of electrical tape

f) cap with removable electrical tape

g) peeling back tape for aluminum



h) aluminum with hole held by the tape

Figure 2. Eight steps in preparing the camera for the pinhole. (a) Lens removed from the camera body, (b) hole drilled in an extra body cap, (c) cutting aluminum from a cookie sheet, (d) making a pinhole in the aluminum, (e) attaching four strips of electrical tape, (f) cap with removable electrical tape, (g) peeling back tape for aluminum, (h) aluminum with hole held by the tape.

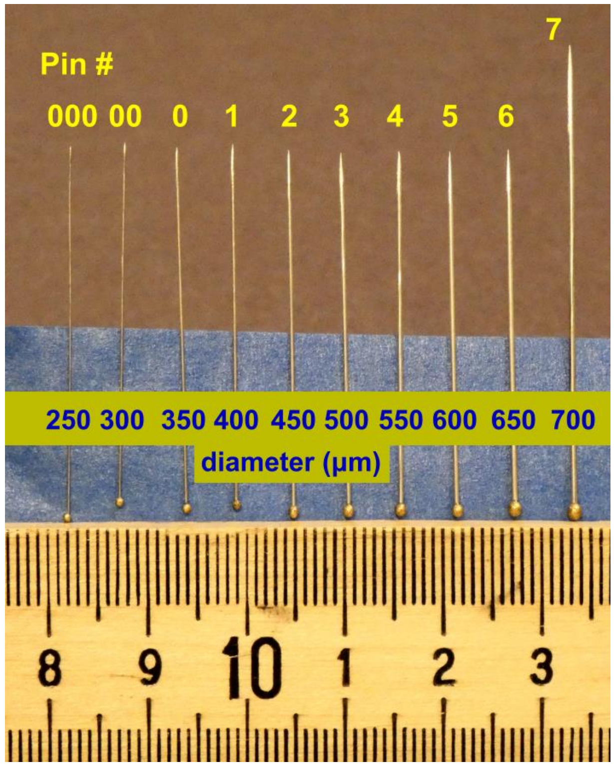


Figure 3. Pins with standard diameters used by entomologists.

The best pinhole size

The formula for the best pinhole size when the subject distance is much greater than the pinhole to plane of focus is of the form

$$d = \sqrt{k f \lambda} \ , \tag{1}$$

where d is the diameter of the pinhole, f (referred to as the focal length) is the distance from the pinhole to the plane of focus, λ is the wavelength of the light, and k is a factor depending on the criterion used [8]. 'There is no such criterion which is obviously the correct one' [8]. For the smallest theoretical diameter 'based on the Airy disc' $k = 2.44$; for the largest pinhole satisfying the Rayleigh criterion $k = 3.66$ [9].

The usual wavelength used in equation (1) is in the middle of the visible spectrum where the eye is most sensitive to light: $\lambda = 550\ \mathrm{nm}$. One of our digital pinhole cameras, made for the Sony

Alpha a6000 mirrorless digital camera, had a focal length of 37 mm with a focal length extender. The optimal pinhole per the Airy and Rayleigh criteria respectively are

$$d_{Airy} = \sqrt{2.44\, f\, \lambda} = \sqrt{2.44 \cdot 37 \cdot 10^{3}\ \mu\text{m}\ \cdot 550 \cdot 10^{-3}\ \mu\text{m}} = 223\ \mu\text{m}\ , \quad \text{(2a)}$$

$$d_{Rayleigh} = \sqrt{3.66\, f\, \lambda} = \sqrt{3.66 \cdot 37 \cdot 10^{3}\ \mu\text{m}\ \cdot 550 \cdot 10^{-3}\ \mu\text{m}} = 273\ \mu\text{m}\ . \quad \text{(2b)}$$

The average gives $d = \frac{1}{2}\left[d_{Airy} + d_{Rayleigh} \right] = 248\ \mu\text{m} = 250\ \mu\text{m}$, which corresponds to pin 000 in figure 3. Indeed, our most clear results were with this pin.

An example of one of our pinhole photos, illustrating the great depth of field of the pinhole camera, is given in figure 4. Note that the distant bricks and lettering of the nearby book are both in soft focus. The photo required about a 1 min exposure because of the small aperture size and therefore small amount of light passing through. Pictured in the photo of figure 4 is O Suzette Ogbon, girlfriend of coauthor photographer Gerson Morales when the photo was taken. She had to remain very still during the entire exposure time.

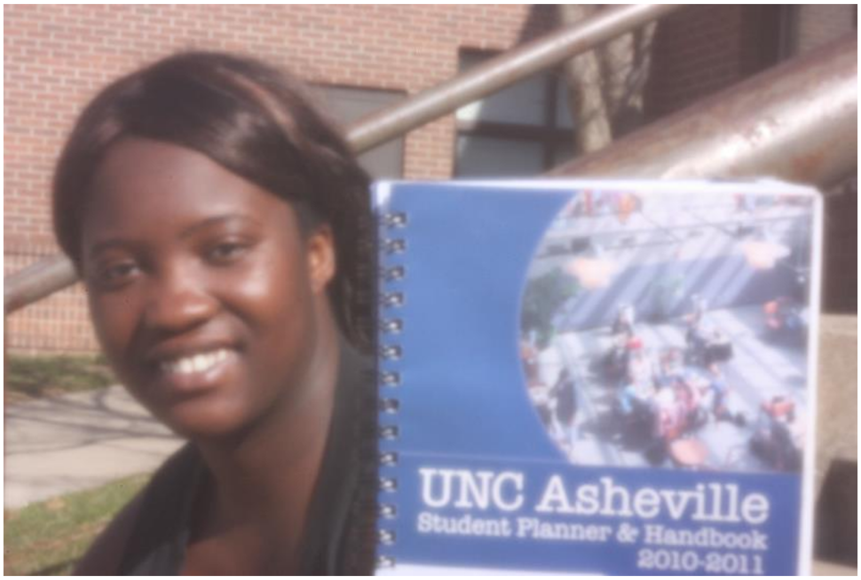


Figure 4. Pinhole camera photo taken by coauthor Gerson Morales of his girlfriend O Suzette Ogbon. Suzette had to remain as still as possible for the exposure time of about 1 min. Note that both the distant bricks and nearby booklet are in soft focus.

Conclusion

This paper adds another pinhole camera approach where insect pins are used. These inexpensive pins enable students to easily make calibrated aperture openings for use in pinhole photography. Detailed instructions are provided in this paper and associated video [6] that show how to prepare a camera for pinhole photography. For other constructions see [5, 10]. Two theoretical ideal aperture diameters are given using the Airy disc and Rayleigh criteria. Our best empirical diameter agrees with the average of these two theoretical models and corresponds to insect pin 000. The ideal formulas assume distant subjects compared to the pinhole to camera sensor distance. An example photo is included with subject Suzette Ogbon, taken by coauthor Gerson Morales. Today, Gerson and Suzette are husband and wife.

Acknowledgement

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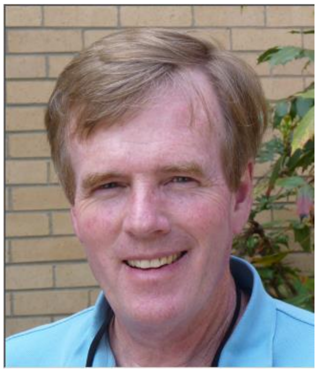

Herb Pomfrey is retired from the University of North Carolina at Asheville (UNCA), USA, where he worked as a Biology Instructor and Lab Manager for over three decades. While at UNCA he collaborated with a colleague on conducting a bug camp for youngsters during many summers, funded by the Burroughs Wellcome Fund.

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