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Optimized conditions of Schlieren photography

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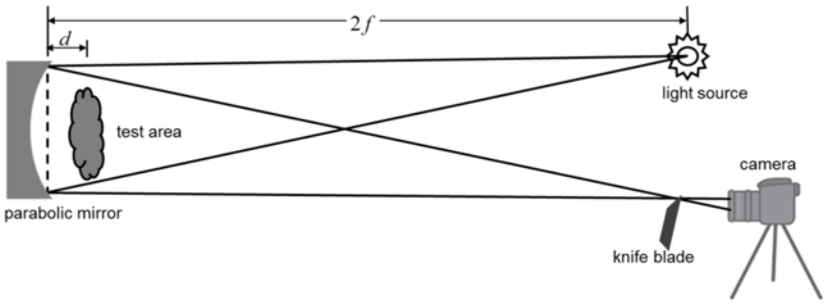
Abstract. Schlieren photography is a technique used to capture air movement based on differences in fluid density. Air with higher temperature has lower density than the surrounding air with lower temperature, leading to different values of refractive index. This work aimed to determine optimized conditions for schlieren photography to capture air movements in several situations. Schlieren photography was set up by using a single off-axis parabolic mirror with a 14.1cm diameter and a focal length of 131.2 cm. The air movement was captured in hi-speed mode with a Nikon V1 at 400 frames per second with a resolution of 640×240 pixels. The camera was set at ISO 400 at f/5.6 and used with a 70 – 300 mm zoom lens. Optimized conditions include percentage of light blocked by a knife edge, distance of test area to the mirror, illuminance of the light source, and ambient temperature.

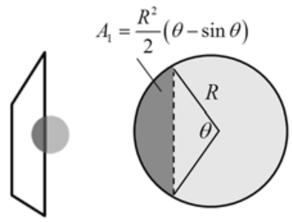
1. Introduction

The word "schlieren" comes from the German word "schliere" meaning strip-like pattern. Schlieren photography is a physics phenomenon based on light deviation due to localized differences in the indices of refraction of transparent media [1], as such this method has been widely used in studying fluid dynamics, particularly air convection. Schlieren optical systems can be divided into lens systems and mirrors systems. The lens systems can be setup using either a single lens or double lens. The mirror systems consist of the Z-type double mirrors system, the single-mirror coincident system and the off-axis single-mirror system [1]. This off-axis system is easy to setup and inexpensive, however optimization of this system has not been reported in the literature. This study aims to determine the optimized conditions for taking schlieren photography with the off-axis single-mirror system.

2. Methodology

In this off-axis single-mirror system, a light source from a small LED in a mobile phone was placed $2f$ from the edge of a parabolic mirror 14.1 cm in diameter with a focus length of approximately 131.2 cm. Light was reflected from the mirror surface into the camera, as such, the sharp edge of a blade had to be used to block a portion of the light entering the camera, as seen in Figure 1 (a). The factors investigated to explore their effects on the sharpness of schlieren imaging consists of the amount of light blocked from the blade, the distance of the test area from the concave mirror, the brightness of the light source, and the ambient temperature of the test area. The movement of the air captured through a 70-300 zoom lens by a Nikon V1 camera in hi-speed video mode at 400 frames per second (ISO 400, f/5.6) to record videos at a resolution of 640×240 pixels. The camera was focused at the test area with fixed setting at a 200-mm zoom.





(a) (b)

Figure 1. Diagrams of (a) schlieren optical system and (b) the point of light being blocked by the knife edge, where A_1 is the unblocked area and $(\pi R^2 - A_1)$ is the blocked area.

3. Results and discussion

3.1. Percentage of light blockage

Finding the percentage of light blocked by the knife edge can be achieved by placing the blade in front of the mirror at a distance equal to $2f$ where the area of light would be approximately the same size as the point source, as shown in Figure 1 (a). Once placement has been setup, the knife edge can be moved across to change the amount of light blocked, as seen in Figure 1 (b). The ratio of blockage is calculated from the area $(\pi R^2 - A_1)$ to the whole area of light πR^2, measured from a photo. This whole area were used to calculate the chord length of that circle. Then, the knife was adjusted to obtain that chord value. s Testing occurred at room temperature of 25^{0}C and relative humidity of 37% with the Nokia LED Lumia520 as the light source and the test area located at $d = 10$ cm from the mirror.

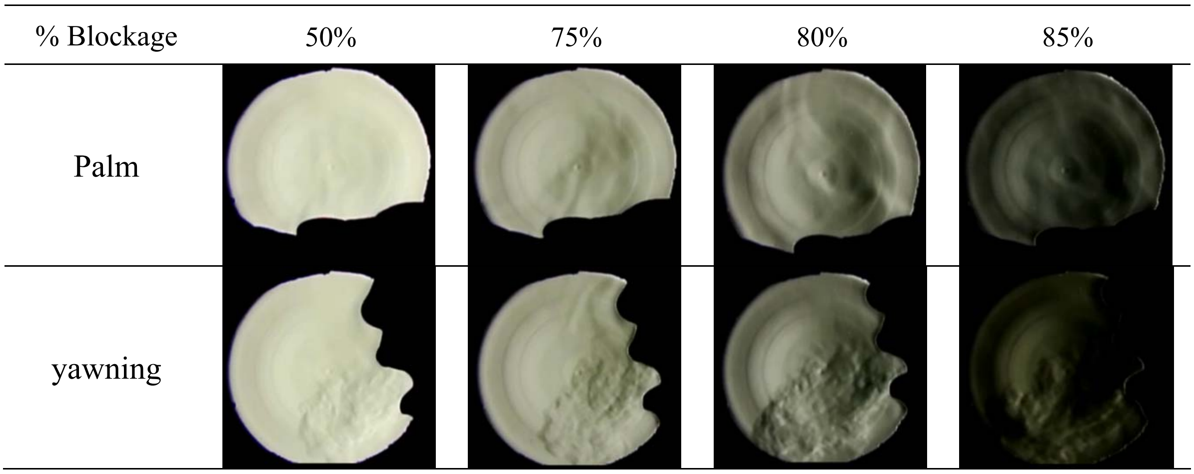
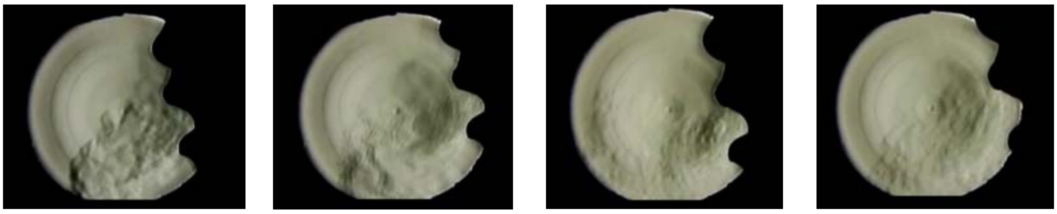


Figure 2. Schlieren images taken at different percentages of light being blocked when capturing heat radiated from a palm and air flow when yawning

From figure 2 it was found that different percentages of light resulted in differing schlieren image quality. Without a knife edge to block the light the resulting images were too bright, making it impossible to see the flow of air movement. By moving the knife edge to block part of the light the images became visible. At 50% blockage the images were still too bright, though they became increasingly clearer as the percentage of light blockage was increased up until 80% where even heat radiated from a palm could clearly be seen. Increasing the percent of light blockage to 85% resulted in insufficient light intensity entering the camera and therefore creating schlieren images too dark to clearly see air flow.

3.2. Distance of test area to the mirror

Determining the effect of the distance of the test area from the concave mirror on the image can be achieved by positioning the tester at different distances d (as shown in Figure 1 (a)) from the mirror. The measurement was taken from the tip of the tester's nose to the edge of the mirror to determine the best position for the clearest schlieren images. The results of schlieren imaging of human body heat, yawning, and coughing at 80% light blockage were then recorded, although only the results for yawing are shown in Figure 3.



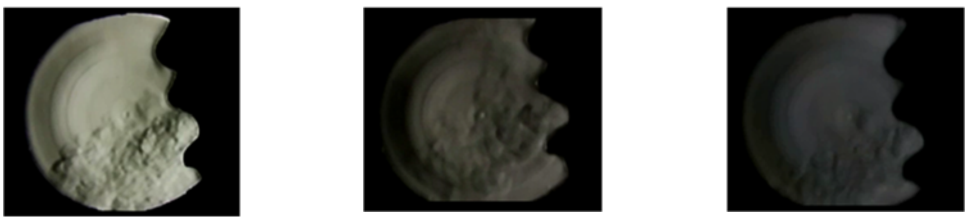
d = 10 cm d = 30 cm d = 50 cm d = 70 cm

Figure 3. Schlieren images of person yawning at four different distances from test area to the mirror

Moving the test area away from the mirror resulted in a decrease in sharpness of the schlieren images as well as overlapping or distortion of the picture. If the test area is further from the mirror, then the numbers of rays reaching the mirror decrease and so less numbers of rays reaching the knife edge. This affects the sharpness of the images.

3.3. Illuminance of light source

The brightness of the light source affects the image; as such in this section light sources were varied. In this research, three LED light sources were chosen to determine which light source would result in the clearest schlieren image. The illuminance was measured at a distance of 5.00 cm from the light source using a Vernier light sensor. Figure 4 shows schlieren images of a person yawning in a room at a temperature of 25^0C and the relative humidity set to 37%. The images were taken at 80% light blockage using a high speed ISO 400, f/5.6 video camera to record results.



$(16.01 \pm 0.01) \times 10^4$ lux $(9.18 \pm 0.01) \times 10^4$ lux $(2.28 \pm 0.01) \times 10^4$ lux

LED (Nokia) Super-bright LED LED

Figure 4. Schlieren images of a person yawning using three different light sources

The measured brightness was found to be directly related to the intensity of the light source. High intensity of the light emitted from a point source creates high contrast and detailed images, as shown in figure 4. The LED light source from the mobile phone which had the highest intensity provided the clearest schlieren image. Contrarily, the light sources with lower brightness values resulted in low quality images.

3.4. Ambient temperature
Temperature of the test area was found to affect the schlieren image quality. The room temperature was adjusted to a different value using an air conditioner as the temperature controller. An infrared camera was then used to capture the temperature of human skin. Schlieren images were taken of heat radiating from a person's palm at different room temperatures of 25.0^{0}C, 22.5^{0}C and 20.0^{0}C while the person's skin temperature was cooled down using a cooling pad to 36.6^{0}C, 34.5^{0}C and 33.4^{0}C. The relative humidity inside the room was set to 37% and the images in Figure 5 were taken at 80% light blockage using a high speed ISO 400, f/5.6 video camera to the record results.

$T_{room} = 25.0^o C,\ T_{skin} = 36.6^o C$ $T_{room} = 22.5^o C,\ T_{skin} = 34.5^o C$ $T_{room} = 20.0^o C,\ T_{skin} = 33.4^o C$

Figure 5. Schlieren images of air flow above a palm at different skin temperatures T_{skin} in different room temperatures T_{room}

Figure 5 shows that the difference between the ambient temperature and temperature of the test subject can affect the quality of schlieren images. In theory, the higher difference in temperature causes a higher density gradient [2] and should result in the light bending or refracting further. The images in figure 5 looked different but not significantly different. This might be due to insignificantly difference of pressure gradient of air because the bright and dark regions represent areas with different indices of refraction due to different pressure gradient of air.

4. Conclusions
The optimized conditions for schlieren images using an off-axis mirror system to capture air movements above a person's palm and yawning were 80% of light blocked by the knife edge, 10-cm from the test area to the mirror, and using the light source from the LED in the mobile phone. The higher illuminance of the light source proved to provide better image quality; as such the image taken with the phone LED with $(16.01 \pm 0.01)\times 10^4$ lux provided the best schlieren image. For the last factor, we found that ambient temperature had no effect on the image quality but rather the difference between the ambient temperature and test subject's temperature. The larger the temperature differences caused higher air density gradients. These findings will be used in setting up schlieren systems for studying air movement in relation to health sciences.

Acknowledgements
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