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Investigating the Effect of Color Mask on Sensitivity for the Color Schlieren Imaging

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Abstract

This work aims to investigate influence of the color mask for color schlieren technique. To demonstrate the effect, a series of experiments by changing the color mask shape are carried out. The applied color mask is a round mask with three RGB (red, green, and blue) colors gaps which is first presented by Settles, G. S. in 1980. In this work, experiments used a digital color mask instead of a film mask. The applied digital color mask is prepared in computer and projected by an LCD projector. The major discussed parameter is ratio of the outside and inside mask diameters. With the new technique, the digital color mask can be easily varied in computer directly and projected conveniently. In this work, the best color mask with outside diameter ca. 10 mm and inside diameter ca. 8 mm that has the highest sensitivity for color schlieren imaging has been successfully found. In general, the larger inside diameter, the higher sensitivity. The inside diameter has the limitation while the passing light intensity is too weak.

Keywords: color schlieren technique, color mask, LCD projector

1. Introduction

Schlieren techniques are basic and valuable tools for scientific and engineering disciplines which are often used to obtain the two dimensional refraction index gradient distribution within a transparent object [1-3]. Many studies have been done on this subject over the years [4-7] and its based theory is also described in many literatures [2,8]. Equation (1) shows the major relationship for the utility of schlieren technique that index of refraction (n-1) is proportional to density of object (ρ)

$$n - 1 \propto \rho \tag{1}$$

where K is called Gladstone-Dale constant and equation (1) Gladstone-Dale equation [5,8]. Actually, K is not exactly constant, but weakly dependent on the wavelength of the transmitted light. In most cases this dependency could be neglected.

In some K values for different objects are shown (e.g. air: $K = 2.26 \times 10^{-4} m^3/kg$ at ambient conditions for $\lambda = 600nm$). The light has different velocities in different objects which has the different index of refraction and has the different travel direction by means of the Snell's law.

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To calculate the other physical parameters, e.g. temperature, pressure and so on, can easily use the intensity and density distribution by means of the relationship of equation (2) [9].

$$I \propto \frac{d\rho}{dx} \tag{2}$$

By means of the nature of light source, the schlieren technique is simply categorized as monochrome and color types [2]. For monochrome schlieren any white light can be used as the light source. Certainly, a monochrome light source, e.g. LED light source, or for a special purpose, e.g. short time measurement, a laser light source can also be applied for monochrome schlieren technique. A coherent light source has strong diffraction effect by passing a sharp line which is applied as knife edge for schlieren technique. Ting in 1997 [7] presented a short time schlieren technique by using ruby laser as light source and provided a solution to reduce the disturbance from diffraction effect. To reduce the disturbance from diffraction effect, a progressive light transparent line was used [7]. The progressive light transparent line has successfully reduced the diffraction effect by using a coherent light source.

In 2011, Chen et al. presented full scale schlieren technique without expensive parabolic mirrors. The experiment setup used modular structure fluorescent lamps of Philips-865 penetrated through the linear grating color mask with alternated red, green, and blue colors. The area of light source and its test section are 2×2 and 1×1 m_2 respectively. The results show colorful burning candle, acetone gas flow out of bottle and the culture dish, burning alcohol burner, and nozzle compressed block flow[10]. In 2011, Hung et al. further presented the cutoff grids ration influence the full scale schlieren image quality. The applied cutoff grids are with 50, 60, 70, 80, and 90% of the cutoff light percentage respectively. The test objects are burning candle, LPG flow ejected into air, and burning alcohol. The results show that the cutoff grid with 60% received the best visualization image[11].

The schlieren technique also can use in leakage check. In 2009, Tang et al. used a 1 m diameter to visualize human coughing with and without wearing a surgical or N95 mask. The result showed that the mask blocked human coughing airflow to move forward into the surrounding air [12-14]. In 1999, Settles presented propane leaking from a 6 mm hose and leaking ratio between 1 ml/sec to 50 ml/sec under test section roughly 4 × 10 foot field-of-view [15]. In 2013, Ting et al. used micro color schlieren technique to detect micro holes leakage. Using different liquefied petroleum gas (LPG) leaking flow rates integrated with different micro hole diameters of 1130, 176, 75, 45.6, 35.32, and 27.5 μm. The results indicate that the smallest leaking flow images from micro hole of 27.5 μm with leaking pressure difference of 5 torr with leaking flow rate of ca. 0.015 ml/sec and micro hole of 35.32 μm with leaking pressure difference of 1 torr with leaking flow rate of ca. 0.011 ml/sec[16].

Color schlieren technique normally uses a color mask contrast to the white light as colorful light source. To compare the monochrome with color schlieren technique, the color schlieren provides more information than monochrome technique. It's clear that the monochrome displays only a 8 bit solution while the color schlieren, e.g. the RGB color mask, has 24 bit solution. The color schlieren technique uses a color mask in different types. The first round RGB film was presented by [3] which is used in this paper.

Due to the determination of sensitivity for color schlieren imaging by using color mask shape many different shapes of color mask are used for color schlieren technique in literatures [2-3]. This work has done a series of experiments for investigating the effect of color mask on sensitivity of the color schlieren imaging. To be tested color mask, a round RGB color mask is selected. Based on the new technique which is presented in Ting et al. 2004 [6] by using a digital color mask, the experiments were tested over 40 different masks. With digital color mask, the three RGB colors are exactly defined in the computer which gives the best way for further quantitative evaluations [10].

2. Experimental Setup

The typical color schlieren technique uses the full spectrum white light source and a film color mask to generate color profile. Fig. 1 shows a typical Z-arrangement with color schlieren setup.

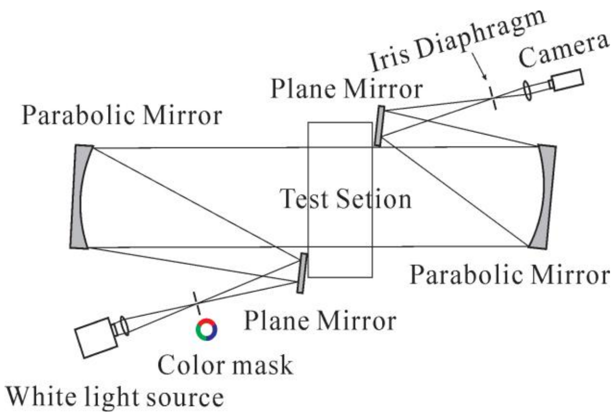

Fig. 1 Typical experimental setup for color schlieren technique

The color schlieren technique sets a color mask on the left focus point to generate the color profile and the light runs through the test section. The simple and colorful mask uses RGB colors, where RGB serves as red, green and blue which are the basic color components of visible white light.

The three colors are mixed in the test section and ideally the color of mixture is white. In reality, this is impossible. The light in the test section by means of the different index of refraction during flow disturbance in the test section is refracted. The light is refracted and cut by the iris diaphragm which shows the intensity distribution on the film and refers to the flow density distribution. The flow is visualized on the film with different density distribution or refers to the light intensity of photo. Fig. 1 indicates that the color mask is set on the left focus point and generates the white light source as three different colors.

It is inconvenient to generate the film color mask by the previous arrangement using the real mask. An LCD projector projects the color mask automatically can provide the improvement. Fig. 2 shows the setup of the new technique by using an LCD projector to produce the color mask on the left focus point. The other part of the arrangement is principally the same as in fig. 1. In this paper, the ”Panasonic PT LB10U” LCD projector is applied as light source for the measurements. To serve as the testing model, a burning alcohol lamp is used in this work. Fig. 3 shows photo of the applied alcohol lamp. During testing time, the burning alcohol lamp is set at the test section. The flame changes the air density by means of change of the air temperature.

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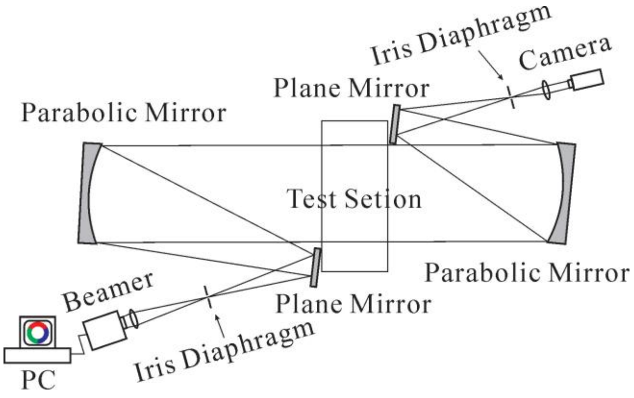
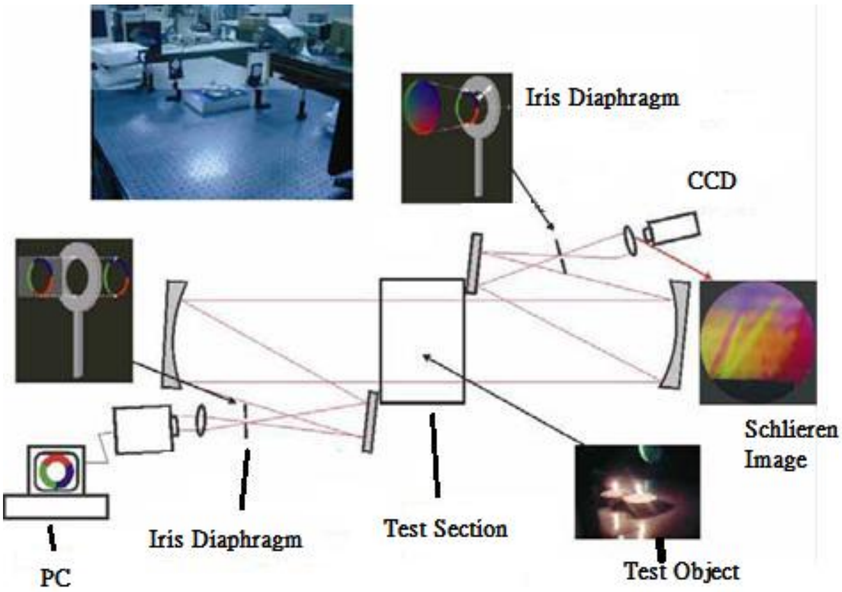


(a) Schematics of experimental setup for automation color schlieren technique



(b) Photo of experimental setup for automation color schlieren technique

Fig. 2 Experimental setup for automation of color schlieren technique

Fig. 3 Alcohol lamp

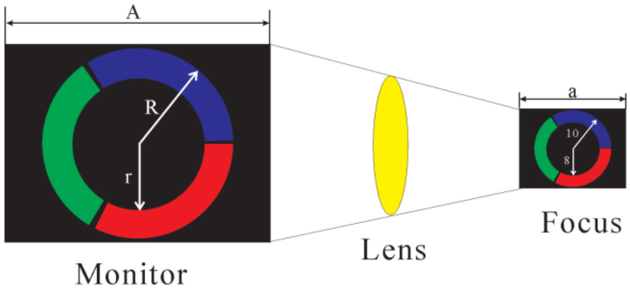


Fig. 4 Determination of digital color mask between monitor and focus point

One problem to be resolved is how to determine the mask size on the focus point. As previously stated the applied color mask is a round RGB mask. The size and shape of color mask will influence the sensitivity by the visualization. This work gives a series of works for investigating of influence of color mask for color schlieren technique. The size and shape of a film color mask can be exactly generated while the digital color mask will be controlled by focussing. Fig. 4 shows the scalar ratio between mask in monitor and on the focus point. This is the simple consideration to determine the digital mask size.

To be clearer, the width of monitor compares to the width of focus point which becomes the following relationships (3),

$$\begin{aligned} &\frac{A}{a}=\frac{R}{10}=\frac{r}{8}, \\ &\Rightarrow R=10\times\frac{A}{a}, \\ &\Rightarrow r=8\times\frac{A}{a}, \end{aligned} \tag{3}$$

where A is the width of monitor, R the outside diameter of digital color mask, and r the inside diameter of digital color mask.In this work, the round RGB color mask with various outside and inside diameters is used. By equation (3), the color mask in monitor can determine the real size of digital color mask. It is convenient to change the color mask during test by using the new technique.

3. Results and Discussion

An important condition for influence of sensitivity by color schlieren imaging among many other reasons is the different color mask shape and its size. To do clearly the influence of color mask for color schlieren imaging, this paper does a series of works to find a best color mask with round shape which is defined in [9]. Table 1 shows the run conditions, where $Ø_o$ and $Ø_i$ are outside and inside diameters. During test, the outside diameter $Ø_o$ is first fixed, only changed the inside diameter $Ø_i$. Thus, by changing the outside and inside diameter of color mask the serial works are carried out.

Table 1 Run conditions

$Ø_o$[mm]	$Ø_i$ [mm]
7	3, 3.5, 4, 4.5, 5, 5.5, 6
8	3, 3.5, 4, 4.5, 5, 5.5, 6, 6.5, 7
9	3, 3.5, 4, 4.5, 5, 5.5, 6, 6.5, 7, 7.5, 8
10	3, 3.5, 4, 4.5, 5, 5.5, 6, 6.5, 7, 7.5, 8, 8.5, 9
11	3, 3.5, 4, 4.5, 5, 5.5, 6, 6.5, 7, 7.5, 8, 8.5, 9, 9.5, 10
12	3, 3.5, 4, 4.5, 5, 5.5, 6, 6.5, 7, 7.5, 8, 8.5, 9, 9.5, 10, 10.5, 11
13	3, 3.5, 4, 4.5, 5, 5.5, 6, 6.5, 7, 7.5, 8, 8.5, 9, 9.5, 10, 10.5, 11, 11.5, 12
14	3, 3.5, 4, 4.5, 5, 5.5, 6, 6.5, 7, 7.5, 8, 8.5, 9, 9.5, 10, 10.5, 11, 11.5, 12, 12.5, 13

Fig. 5 shows photo of the burning alcohol with the color mask outside diameter under 7 mm and inside diameters under 3, 3.5, and 4 mm. The photos show the schlieren images more murky and duck due to the outside diameter is not bigger enough to pass more light.

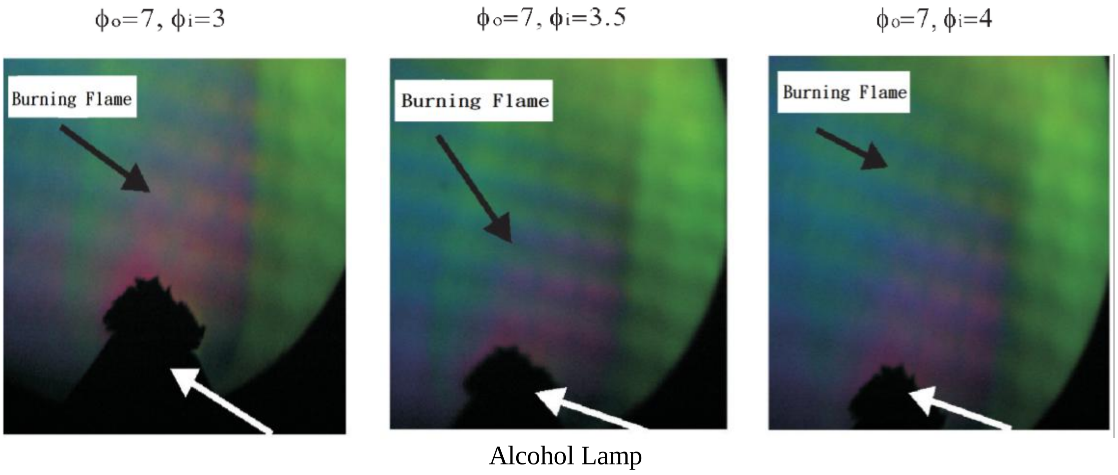


Fig. 5 Color schlieren photos with outside diameter $Ø_o$ = 7 mm

Fig. 6 shows photo of the burning alcohol with the color mask outside diameter under 8 mm and inside diameters under 5.5, 6, and 6.5 mm.

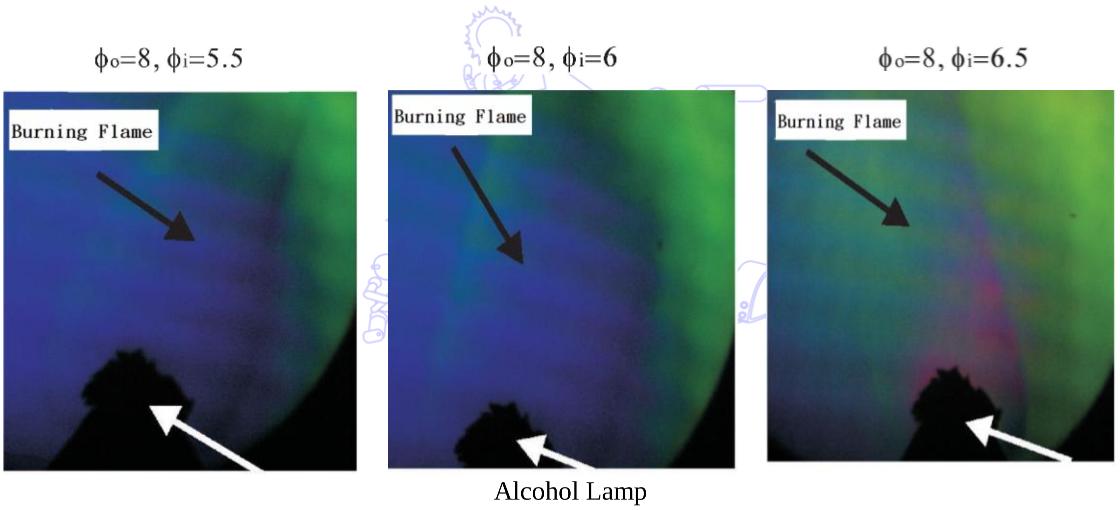


Fig. 6 Color schlieren photos with outside diameter $Ø_o$ = 8 mm

Fig. 7 shows photo of the burning alcohol with the color mask outside diameter under 9 mm and inside diameters under 6.5, 7, and 7.5 mm. The results show that the color schlieren images are more clearly than figs. 5-6.

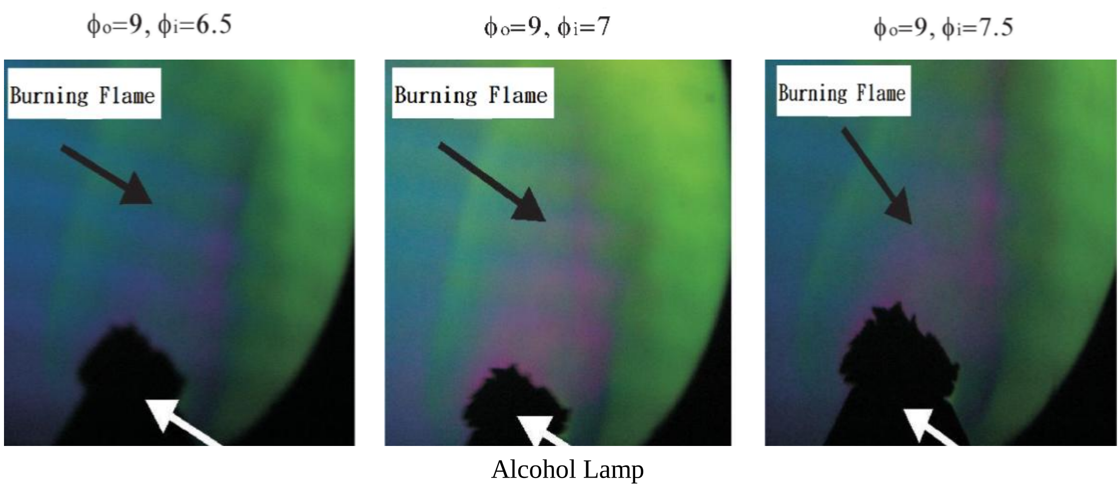
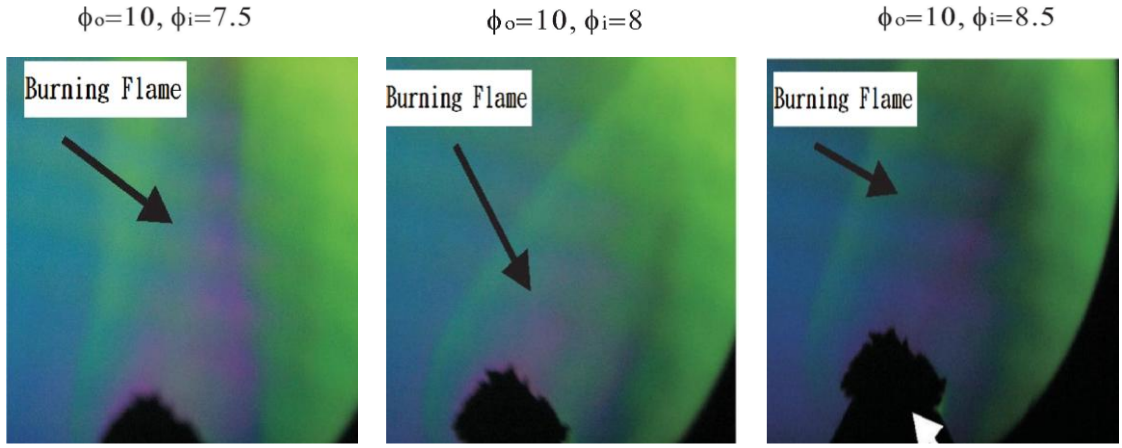


Fig. 7 Color schlieren photos with outside diameter $Ø_o$ = 9 mm

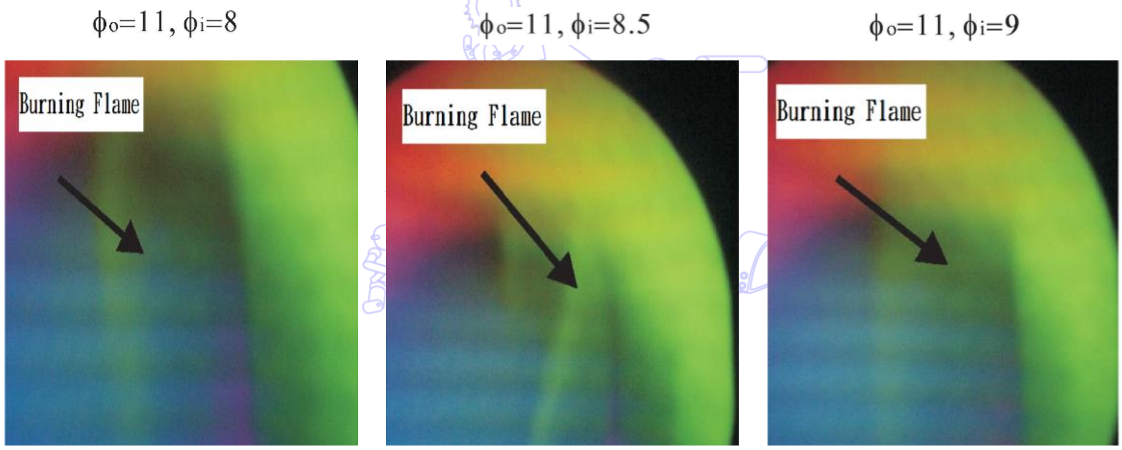
Fig. 8 shows photo of the burning alcohol with the color mask outside diameter under 10 mm and inside diameters under 7.5, 8, and 8.5 mm. The results show the color schlieren images are more clearly in this study. Color mask outside diameter under 10 mm and inside diameters under 8 mm obtains the most clearly, colorful, and stereoscopic heat flux.



Alcohol Lamp

Fig. 8 Color schlieren photos with outside diameter $Ø_o$ = 10 mm

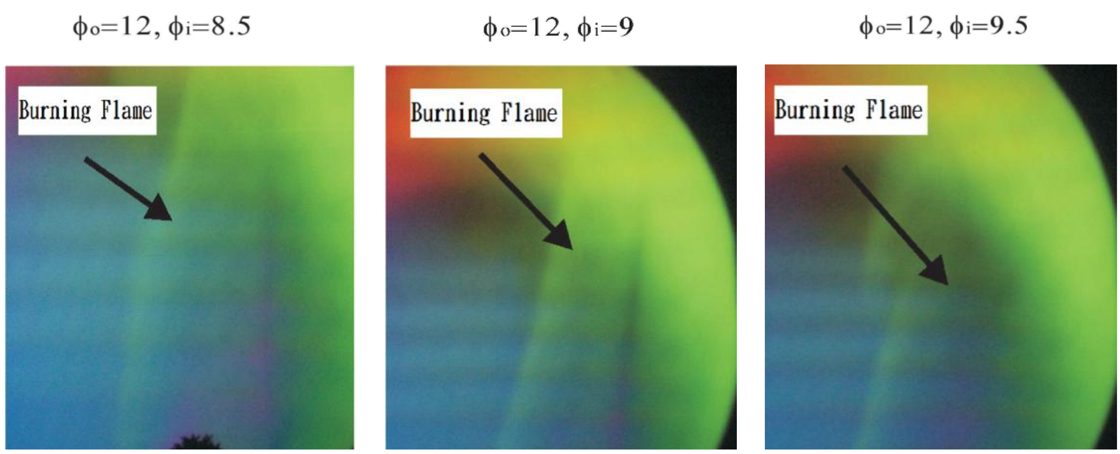
Fig. 9 shows photo of the burning alcohol with the color mask outside diameter under 11 mm and inside diameters under 8, 8.5, and 9 mm. The results show that the color schlieren images are too bright than figs. 5-8 too harder to read the flow details.



Alcohol Lamp

Fig. 9 Color schlieren photos with outside diameter $Ø_o$ = 11 mm

Fig. 10 shows photo of the burning alcohol with the color mask outside diameter under 12 mm and inside diameters under 8.5, 9, and 9.5 mm.



Alcohol Lamp

Fig. 10 Color schlieren photos with outside diameter $Ø_o$ = 12 mm

It’s clear that the previous figs. not only show the visualized flame, but also some other color blemish which comes from the mixture problem of three RGB colors. Fig. 11 shows the illustration of the mixture problem. The round RGB color mask has three small gaps for fitting the three colors on the focus point. The three colors from the gaps will relax after the focus point and mix each other. For a short focus length lens shows larger none homogenization in the test section than a long focus length which stays at the boundary position.

Figs. 5 - 10 show the color schlieren photos which are captured by using different size of color masks. The results show that ca. 2 mm of the color gaps receives the better sensitivity. Among the results, fig. 8 with $\O_o$ shows more clear flow visualization than the others and farther more $\O_i = 8$ is better than $\O_i = 8.5$. The color gaps with 2 mm is the limitation while the passing light intensity is too weak. For bigger color gaps the mixture of three RGB colors in the test section is more like the white light. It is bad to display the different colors from the mixture of three colors by color schlieren imaging.

The reason for the mixture problem in the current setup is that two short focus length lens were used to produce the parallel light. For a short focus length lens the three color gaps has not enough length to relax the color gaps as a big light source. Fig. 11 shows the effect graphically.

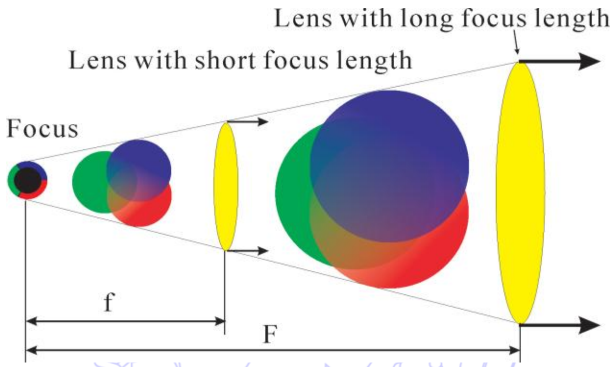


Fig. 11 Mixture of RGB color for different focus length lens

4. Conclusions

Color schlieren technique using the LCD projector to generate the color mask on the focus point is experimentally carried out in the paper. The influence of sensitivity by changing round color mask shape for color schlieren technique is also discussed experimentally, where the larger inside diameter, the higher sensitivity is. The inside diameter has the limitation while the passing light intensity is too weak. A best round color mask with outside diameter ca. 10 mm and inside diameter ca. 8 mm is found during the serial tests. That is, a color mask with outside diameter ca. 10 mm and the width of three color gaps ca. 2 mm has the best sensitivity by using this experimental setup.

Acknowledgements

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