Application of Fluidic Control within a Plano-Convex Singlet Lens

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This paper focuses on designing a computer code for the purpose of developing a systematic method for continuous control of the focal length of a plano-convex fluidic lens and utilizing the code for studying the optical behavior of a plano-convex fluidic lens. A syringe, which was controlled by a syringe pump controller, was utilized for fluid control. The code decreased the operation time for the syringe pump controller by replacing the manual push of buttons with a few clicks on a computer. By utilizing the code, the focal length of the fluidic lens was measured as a function of the curvature of the lens' flexible membrane. This was accomplished for three lasers of differing wavelengths (red: 633 nm; green: 543 nm; blue: 488 nm). A graphical relationship was found for the three wavelengths: as the lens curvature increased, the focal length decreased. In addition, as expected, the longer wavelength outputted a longer focal length per lens curvature.

Keywords: fluidic lenses, focal length, wavelength, fluidic control

1. Introduction

Fluidic lenses are an emerging field in optics research. Unlike standard zoom lenses, which depend on mechanically moving optics to adjust focus (e.g. focal length), fluidic lenses offer the capability of changing focal lengths while eliminating the need to adjust lens position**.** Fluidic lenses offer a wide variety of applications, and fabrication techniques are almost limitless[1]. They can be utilized in applications, such as free-space optical communications, adaptive optics, corrective eyewear, and cell phone cameras. These optical devices allow designers in various fields new and innovative opportunities to improve the performance, accuracy, throughput, reliability and overall cost of their devices[1].

Fluidic lenses are based on a flexible membrane and fluidic pressure. A flexible membrane encloses a specific amount of fluid. The hydrostatic pressure is manipulated to control the curvature of the flexible membrane[2]. Hence, when the hydrostatic pressure in the liquid-filled lens cavity is altered, the curvature of the membrane surface morphs to either a concave or convex surface[3], altering the optical wavefront of light passing through the membrane. As a consequence, a variable focal length is achieved.

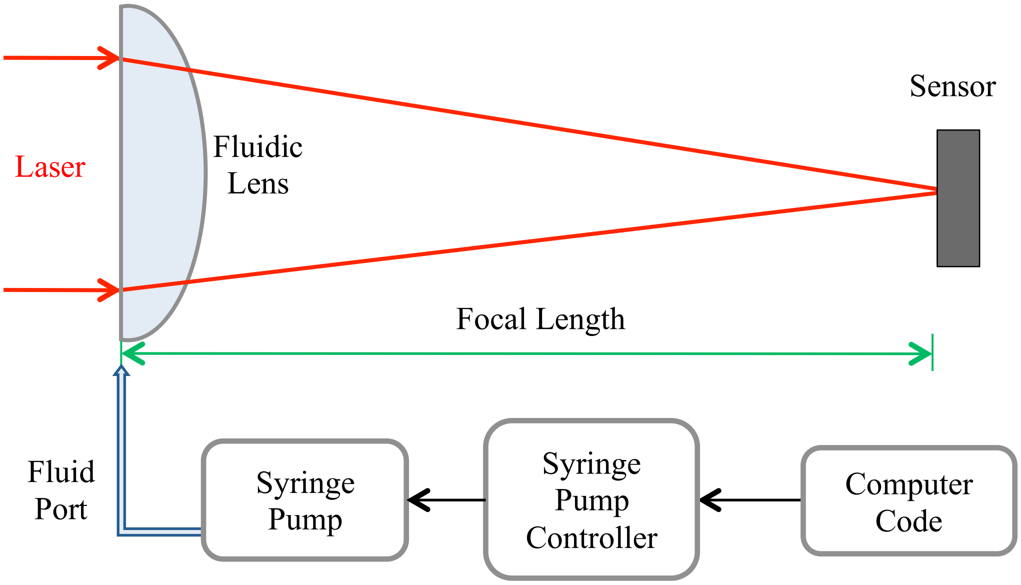

Figure 1. Schematic of the experimental setup.

2. Experimental Methods

The elastic membrane discussed was composed of polydimethylsiloxane (PDMS). We chose the PDMS as the membrane material due to its exceptional optical properties and elastic behavior. In addition, it is highly transparent in the range of visible light[4]. We made the PDMS in a clean room by pouring a mixture of PDMS and its curing agent on a glass mold. A vacuum was applied to remove air bubbles. The mixture was heated for a specific amount of time, removed from the mold, cured, and mounted into a holder.

The optical behavior of a fluidic lens was studied by varying the amount of deionized (DI) water housed inside the cavity of the lens. Adjusting the amount of fluid was accomplished by computationally manipulating a syringe pump controller with a MATLAB computer code. The syringe pump controller manipulated the axial displacement of a plunger located inside a cylindrical tube. The plunger and tube made up a 500 μL syringe. The amount of fluid infused or withdrawn from the lens cavity was influenced by pulling or pushing the plunger along the tube. This achieved both positive and negative power corrections with the lens. A fluid port, which transferred the DI water into and out of the fluidic lens, connected the syringe to the fluidic lens. Figure 1 illustrates the schematic of the experimental setup.

The focal length of the fluidic lens was measured as a function of the curvature of the membrane. The code was designed so that the position of the plunger in the tube corresponded to a specific curvature of the lens. The exterior of the glass tube consisted of markings from 0 to 500 μL. The code was constructed so that the syringe pump controlled the syringe by displacing the plunger in unit steps; moving the plunger one unit step translated to inputting or extracting 12.5 μL of DI water from the lens. Inputting a negative value withdrew fluid while a positive value infused fluid, which increased the lens'

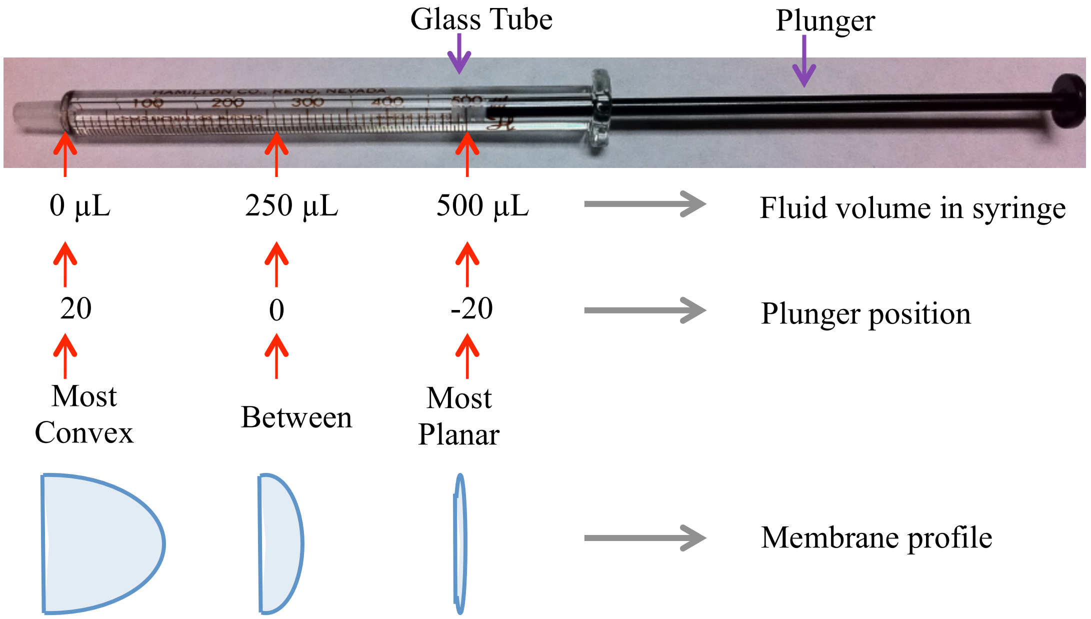

Figure 2. Plunger position relative to the amount of volume in the syringe (μL) and lens membrane profile. The plunger in the syringe shown is in the plunger position at -20.

curvature. The code was designed so that the user could input values from -20 to 20, allowing for the maximum value of 20 steps the plunger could shift relative to our zero point.

Our study samples focused on the cases where the lens surfaces were convex due to the replication of a plano-convex lens. The step position at -20 was where the lens was approximately planar; this correlated to the case where the plunger was at the 500 μL mark in the syringe tube. The step position at 20 was where the lens was at its most convex or 0 μL of fluid was left in the syringe. The case where the plunger was at the 0 step position, or zero point, was a convex surface between planar and most convex; this was also the marked center of the syringe where the plunger was placed at 250 μL. The three cases can be seen in Figure 2. This method, which allowed the continuous change in focal length of a fluidic lens, drastically decreased the time and effort to operate a syringe pump controller by replacing the manual push of buttons on the pump.

By utilizing this code, the graphical relationships between the focal length and the plunger position for different wavelengths were measured. Since varying the wavelength alters the focal length according to the optical properties of light, three lasers of different wavelengths (red: 633 nm; green: 543 nm; blue: 488 nm) were expanded and collimated through our testing apparatus. Forty-one separate focal lengths at forty-one curvatures were measured for each laser wavelength as the light passed through the fluidic lens. Because accuracy is of most importance, three trials were performed for each of the forty-one positions measured per wavelength and averaged to determine the best focal length.

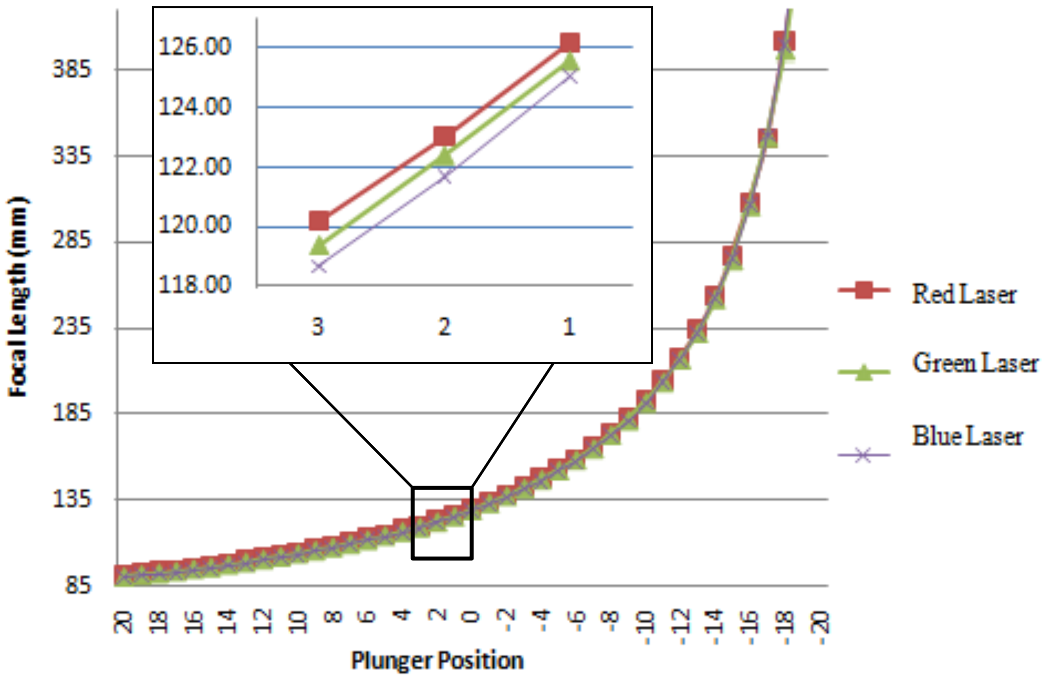

Figure 3. Focal length versus the plunger position for the three different laser wavelengths (red: 633 nm; green: 543 nm; blue: 488 nm).

3. Results and Discussion

Figure 3 illustrates the focal length, mm, versus plunger position in the syringe for the three different emitting wavelengths. There are a total of 123 data points in the plot, with 41 points for each laser. Each of the 41 points is an averaged value of three trials. The separate graph for plunger positions at steps 1, 2, and 3 demonstrate the relationship between the three laser wavelengths.

As previously discussed, the plunger position at 20 corresponds to a convex lens, whereas the position at -20 corresponds to a planar lens. As fluid is extracted from the lens, or as the lens becomes less convex, the focal length increases. In the negative region, this relationship is much more drastic. On the other hand, as we shift to positive plunger positions, or when the lens becomes more convex, the change in focal length is less drastic. This phenomenon produces a relatively linear change in focal length with higher amounts of fluid in the lens chamber. The opposite occurs in the negative plunger position values; if the lens is close to planar, the change in focal length drastically increases. This non-linear curve correlates to the shape of the membrane; as the lens curvature becomes planar, the equal amount of fluid extraction offers greater variation in focal position.

Figure 3 also shows that the accuracy of our designed system allows for the distinction of wavelength focal position related to dispersion. Matching to dispersion theory, the focal length of the red wavelength is longer than the focal length of the green wavelength, which in turn is longer than the blue wavelength focal position. At any plunger position, or at any curvature of the lens, the red laser will always have the furthest focal length relative to the shorter wavelength. Hence, as the wavelength increases, the focal length increases, and vice versa. Because refraction is wavelength-dependent within the same material, such as DI water, the fluid's dispersion is a significant factor in analysis and fluid selection within plano-convex fluidic lenses.

4. Conclusion

In this project we focused on designing a computer code for controlling the focal length of a plano-convex fluidic lens and utilizing the code for studying the optical properties of the lens. Our method for controlling the change in focal length of the fluidic lens drastically increased efficiency in analysis. The results showed the correlation between linear extraction of fluid volume and nonlinear focal positions. In addition, the measured results confirmed the significance of fluid selection due to wavelength dependent dispersions.

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