Designing of Liquid Crystal Beam Steering Working Parameters for Augmented Reality Applications

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ABSTRACT

Due to the increasing demand of AR and VR devices in daily life, there are many inventions to improve their disadvantages. In this paper, we use liquid crystal with special cell structure to develop image deflection elements which can be used to increase the viewing angle of AR/VR devices. In the research process, we find the structural parameters by the Taguchi method. From the recall tables, we can understand how these parameters impact on the optical phenomenon, and the tendency and physics principles are what we want to know. According to the experimental method, we can use the concept of machine learning to rise research efficiency.

1 Introduction

AR and VR devices create the unprecedented visual experience, but there are some problems should be solved to get the better using experience. One of the main problems is the narrow viewing angle which leads the discontinuous of images and makes some users feel dizzy. In order to improve the narrow viewing angle, we combine the ideas from the light deflection and pupil tracking to expend the visual angle of human eyes. The theory shows if the optical steering angle is larger than 6.8 degrees, the visual angle will be expanded twice. [1] Based on the theoretical conclusion, the target optical steering angle is set at 7 degrees in this paper.

The development of the light steering device is the most important issue in this paper. Because it is an imaging device, how to make the light with highly uniform steering direction and high efficiency are the main challenges. In this paper, we show the mechanism of light deflection by using the birefringence of liquid crystal (LC), and the steering angle is controllable by change the driving voltage which makes the refractive index of LC layer to be a prism-like distribution. [2-4] From the distribution, we can calculate the steering angle and predict the quality of imaging. Besides, the driving condition also impact on the switch frequency of LC layer which also makes users discomfort. That is why we set the minimum switch frequency is 75 Hz. The high-speed switching technology of LC is applied in this paper.

In our design, it is a complex combination consisting of many structural parameters and driving conditions. To rise the efficiency of optimization, we applied Taguchi's method to find the most suitable parameters combination. From the recall tables, we can understand how each parameter impacts on the optical performance, and realize the physics mechanism and know the tendency of experiment. During the process of development, the work of analysis and the determination of parameters tendency would be solved by machine learning in the future, and the research efficiency would be improved again.

2 Theory

In this paper, the diagram of device structure design is shown in Fig. 1 which is a three-electrode structure in unit pitch, and there is a dielectric wall between each unit structure which is used to reduce the LC fringing field effect. There are many adjustable parameters in the design, including the structural parameters and driving condition. In order to find the best combination of parameters, it is necessary to define these parameters and set suitable levels, and uses Taguchi method to optimize these parameters.

Following are the structural parameters we set for Taguchi method: the thickness of LC layer, saying cell gap d, the width of the electrode W, the gaps between electrodes x and y and the thickness of PI film t. The structure diagram is shown as Figure 1. Besides, we found the dielectric wall also impact on the LC driving so much, so it also is one parameter for Taguchi method. The material of electrode is ITO with high transparency and conductivity, and dielectric material wall is silicon nitride. The levels we set are shown in Table 1. The other driving condition is followed the previous simulation result. The first electrode voltage is set to 2V, the second to 3.5V and the third from 6V to 15V. It brings many benefits to research, such as reducing the number of parameters. Setting the third electrode is unknown also let us find the best driving voltage.

Based on the setting parameters and levels, the suitable orthogonal table for Taguchi method is L18 table. Because of the limitation of process, we replace the time-wasted and expensive process with simulation software. The analysis is performed by TechWiz, a liquid crystal simulation software, which can solve the equations and show the pointing vector field under specific driving conditions in a unit pitch. The pointing vector field can be used to calculate the effective refractive index then be derived to the steering angle.

As to concerning the calculation of the steering angle, the diagram is shown as Figure 2. There are two parallel rays assumed to incident perpendicularly the liquid crystal cell with thickness d. The two rays are separated with width l, and the effective refractive index of one ray in liquid crystal layer is n_a, and the other is n_b. According to the Huygens principle, the light will advance along the equivalent phase front, and we can calculate the optical path difference to derive the steering angle. The relation we deriving is given by

$$l*\sin\theta = d(n_a - n_b)$$

The steering angle can be calculating from the TechWiz simulation results.

Considering the quantification of imaging effect, the linearity of the distribution of refractive index has been used to determine the quality of imaging. The linearity is defined by the correlation between the distribution and the perfect straight line in the work area of components. If the correlation is closed to 1, it means the distribution is highly prism-like and the steering angle will be uniform, and the imaging effect also will be very good.

3 Results and Discussion

In this paper, the key results on the optical effect from the change of operating conditions would be shown. At first, if we only want to know how the operating voltage impact on the optical effect, the steering angle is higher with the operating voltage increasing, and when the operating voltage is 8V, the steering is 6.91 degrees. However, considering the imaging effect, the linearity is lower with the operating voltage increasing (the operating voltage is larger or equal to 7V). When the operating voltage is 7V, the linearity is 0.9975. Therefore, 8V is the best operating condition for the optical effect.

Expect for the operating conditions, the structure design also impacts the steering angle. For these parameters which make the pitch length longer, they are negative to the steering angle. It is easily to understand by the prism-like model. If the prism bottom is longer and the height is fixed, the slope of prism will be shorter and make the steering angle decreasing. The width of electrode is the most critical factor of them. As for the cell gap, 4 um is best for our design. If the cell gap is larger than 4 um, the Δn is shorter and make the steering angle decreasing, but when the cell gap is smaller than 4 um, the steering angle is increasing with the cell gap larger. It is caused that the cell gap has influence on Δn. If the cell gap is too large, the electric field would be weak.

The second point is how to improve the linearity. The second interval y almost determines the linearity. At high operating voltage, it is dominating the linearity and we can almost overlook the influence from other parameters. Under high voltage condition, if there is a big space makes the rotation of LC molecules smoothing, the linearity will be higher. That is why the second interval dominates the linearity. But when the voltage is low, meaning 6V or 7V, the width of electrode and the first interval also can influence the linearity. Concluding, these parameters which directly impact on the pitch length have significant impacts on the linearity. Especial for the high operating voltage condition, the second interval is the main factor for linearity.

Based on these points, the best structural parameter combination found by Taguchi method is shown as Table 2. From the simulation result, the steering angle is predicted to 6.91 degrees under 8V operating voltage with better imaging effect.

Expect for the LC simulation result, we also consider the diffraction effect by the design of electrodes. The true position of the steering angle is determined by the deflection caused by the structure. [5] For the best design found by Taguchi method, the first order diffraction would locate at 4.06 degrees and the second one would locate at 8.07 degrees. Combined with the LC simulation, the most of energy would be transferred to the point at 8.07 degrees, although the imaging effect will be sacrificed little, which is conforming to the target steering angle.

4 Conclusions

In this paper, we success to design a beam steering component which is able to improve the disadvantages of AR/VR. Taguchi method can be applied to components development and the efficiency of development will be increasing a lot. Just need to choose suitable parameters and orthogonal table. Besides, Taguchi's method can also illustrate how these parameters affect the results, and also helps to correct the component parameters.

In the design, the most critical parameter with strongest influence is the width of electrode. Is has great influence on the two optical indicators at the same time. The weakest factor is the thick of PI film. The result not only shows the line width scale of process is very important to achieve a bigger steering angle, but also says the rubbing layer, PI film, having merely influence on the optics.

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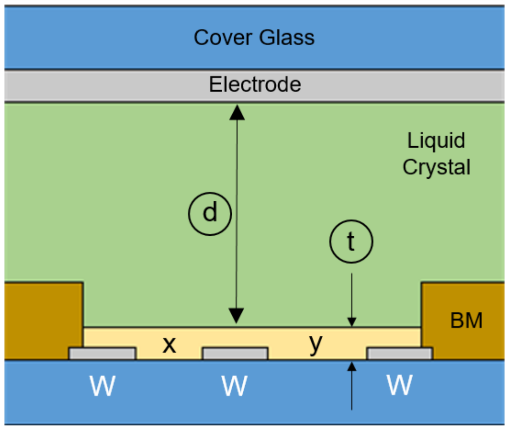

Fig.1 Structure for LCBS Device

Table 1 Design Parameter

Dimension / design / Level	Cell Gap d (um)	width W (um)	gap x (um)	gap y (um)	PI Thickness t (nm)	HK
1	3.75	1.0	1.0	1.0	30	Yes
2	4.00	1.5	1.5	1.5	50	No
3	4.25	2.0	2.0	2.0	80	

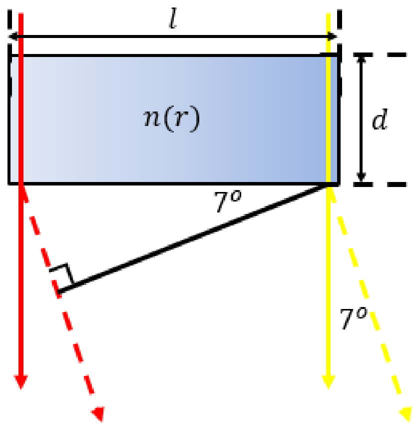

Fig. 2 The diagram of beam steering theory

Table 2 The Best Parameter Combination of Design

Cell Gap d (um)	Width W (um)	Gap x (um)	Gap y (um)	PI thickness t (nm)	HK
4.0	1.0	1.0	1.5	30	Yes