Beam steering with Light activated liquid crystal Elastomers

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Abstract

Optical-wireless communications (OWC) is a promising alternative to radio frequency communication. A significant challenge with OWC systems is steering the beam in free space. In this paper we propose an alternative solution for optical beam steering using actuating liquid crystal elastomers to move a lens. Liquid crystal Elastomers are a type of material which are capable of temperature-induced repeatable deformations in a controllable manner by having molecular orientation. In this paper we propose a novel possibility to create a light-controlled lens system. We constructed a light sensitive liquid crystal elastomer which, because of the molecular alignment, can control the exact shape and position of the optical lens. A photothermal dye transfers the light to heat for the deformation. We will use the Multiphysics COMSOL program to model the programmable lens. This model uses both the solid mechanics module to model the lens deformation and the ray optics module to model the paths the light rays take through the lens. We will describe the position of the lens and the resulting beam spot at various temperatures. Finally, we will heat up part of the programmable lens to achieve a higher level of control of our laser beam.

Introduction

The demand for higher capacity in wireless communications is growing year by year. The current radio wave-based technologies are straining to keep up with the demand. An alternative to solve this bottleneck is the use of infrared light for optical wireless communications (OWC) [1]. OWC offers higher privacy, capacity independent of the amount of users and has unlicensed bandwidth [2]. One of the remaining challenges of this emerging technology is achieving fast and precise beam steering to follow the end users when on the move [3]. There are several strategies to achieve beam steering. For example, using optical phase arrays [4], wet lenses [5], gratings [6], or mechanical arrays [7]. Fig. 1 shows one proposed OWC solution, where a pencil beam of a laser from the ceiling points towards the device. This beam is capable of following the device throughout the room thanks to a beam steerer. In this paper we introduce a new alternative for beam steering by using liquid crystal elastomers to control and position the lenses.

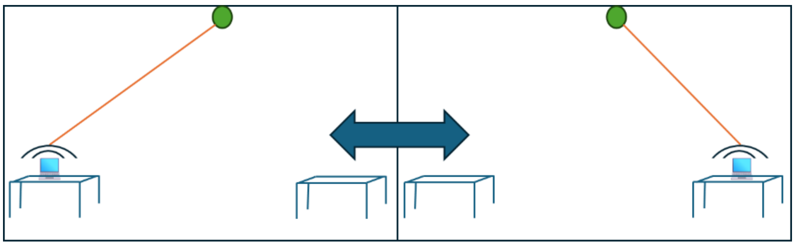

Figure 1. A schematic of optical wireless communication application where an optical narrow beam is steered from the ceiling to follow the user movement in a room.

Liquid crystals are a type of material which have various interesting properties, such as their optical [8] and anisotropic properties [9]. The liquid crystal elastomers (LCE) exhibit anisotropic deformations, when the molecular structure has been carefully aligned, during a temperature phase change which can be used for designing soft robots [10]. By increasing the temperature the liquid crystals undergo a phase change contracting in one direction and expanding in the remaining two directions. This behavior is reversible and easily controllable by changing the temperature. The direction of the contraction is dictated by the molecular alignment, which is achieved when all the long thick molecules are pointing in the same direction. This alignment can be achieved by using layers [11] or rheological force [12]. A 3D printer is capable of exerting the required rheological force. When the LCE is pushed through the nozzle the polymer chains are aligned along the printed line, which will afterwards exhibit reversible anisotropic deformation during a temperature induced phase change. Different methods are being explored for the actuation of LCE such as using light [13] and electricity [14] to cause the reversible contraction. By carefully crafting the structure of the liquid crystal many soft robotic structures can be made. A lens with Polydimethylsiloxane and liquid crystal to change the focal length has for example been designed [15]. For beam steering the light needs to be controllable not just with the focal point of the beam but also its position in the x and y dimensions. As such we will keep building on this concept.

In this paper we propose a new method of beam steering by using LCE to control the position of a lens by changing the temperature using light. We showcase a novel design to move a lens through a 2D field to allow for more complex beam steering first in a model and then contrast them with the gained experimental results.

Results – Model

COMSOL is a Multiphysics modeling program. It combines the Solid mechanics physics of the LCE deformation during a temperature induced phase shift with the ray optics module calculating the progression of the rays through the deformed lens. COMSOL uses the finite element model to calculate the new geometry. The model consists of 4 rectangular slabs, as shown in Figure 2a. The alignment can be changed by changing the coordinate systems of each slab, so the contracted direction would always be the x-coordinates. In the middle there is a sphere cap which functions as a plano-convex lens.

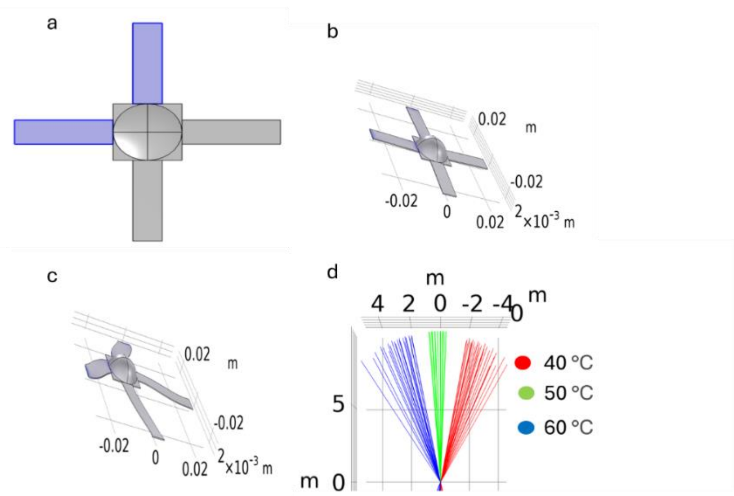

Figure 2. a) Geometry of the beam steering device. The two blue slabs are liquid crystal elastomers, which deform when heated. The two grey slabs are ecoflex which are very stretchy. The middle in the cross is the glass

plano-convex lens. b) Position of the lens at 30 °C. c) Position of the lens at 60°C. d) Beam rays with a 130 m^{-1} curvature lens. The curvature is calculated as 1/radius of lens. The simulated rays at 40 °C are red. At 50 °C they are green. At 60 °C the rays are colored blue.

The first step of the model calculates the deformation of the LCE. To calculate the deformation of an anisotropic material we need the elasticity matrix. The matrix is fairly complicated but the model can be further simplified. Because each slab of the LCE has a plane of symmetry the material can be considered orthotropic instead. The calculate the deformation with that simplification we only need the Youngs modulus, density, shear modulus and the Poisson ratio instead. Both the flexible polymer slabs of Ecoflex as well as the glass sphere is isotropic and thus the deformation can be calculated with the Young's modulus and the density.

The second step is calculating the path of the rays through the deformed lens. The program uses Snell's law and also the Fresnel equations to calculate the rays. Also required is the refractive index of the material through which the rays will be travelling.

The initial position can be seen in Fig. 2b when the system is at 30°C and then the final position is shown in Fig. 2c when the system is at 60°C. The two liquid crystal slabs have deformed and are pulling the entire system into the top left corner. If the laser is positioned at the top left corner the laser will travel through the whole lens when the temperature increases, which is how beam steering is achieved.

The effect of the curvature of the rigid lens can be seen in Figs. 3a-b. We modelled the same four-slabbed lens system with a different curvature of the lens. The resulting shift in the pattern at a distance of 2 meters from the lens as well as the angle (Fig. 3d) is dependent on the curvature (of focal distance). This modelling offers us a way of obtaining the required angular range and spot size based on the model.

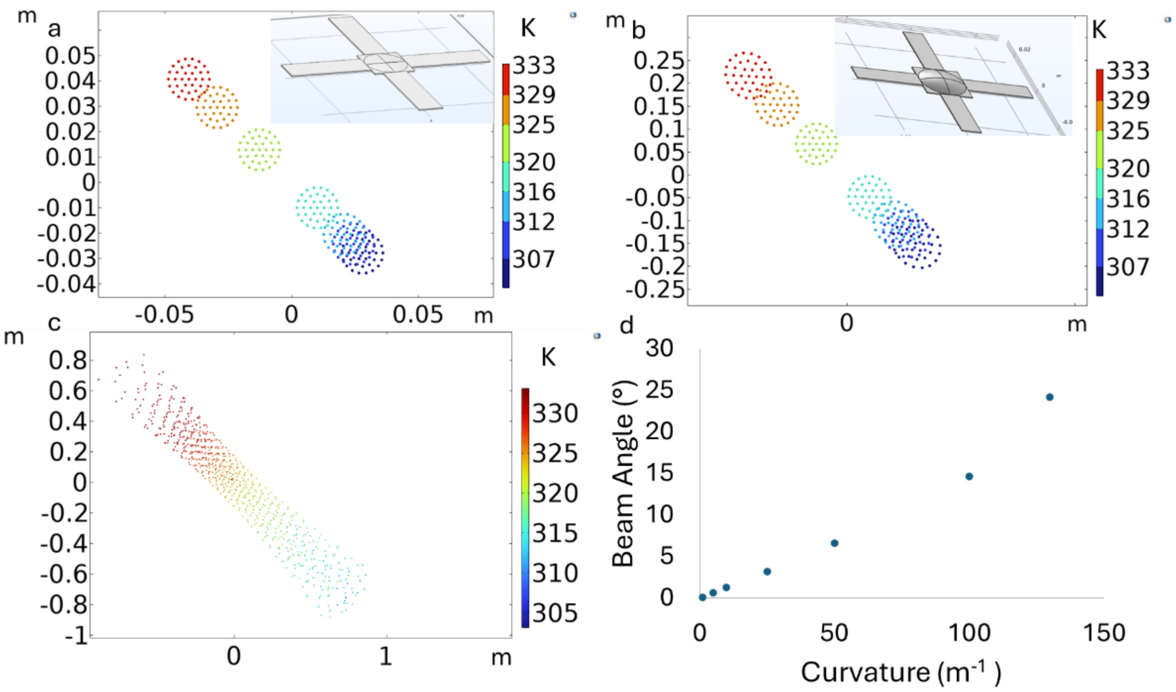

Figure 3. a) Spot diagram of the system at 2 meters with a lens curvature of 10. b) Spot diagram of the system at 2 meters with a lens curvature of 50. c) A full spot diagram at 2 meters with each temperature modelled. d) Graph plotting the maximum beam angle with the curvature of the lens.

Finally, we modeled each degree of the LCE slab with a lens curvature of 130 m^{-1} as shown in Fig. 2c. The proposed programmable lens can steer the beam depending on the temperature of both LCE slabs in a 0.8 meter square at that curvature.

Discussion & Conclusions

Our model shows that with our proposed soft actuator we can control the angle of a laser beam by changing the temperature of the system. For a lens with a curvature of 130 m-1 the achieved angle is from -24° to 24°. These steering angles should be enough to cover a part of the room. In a practical scenario, the beam steerers should be placed on the ceiling with a grid of 2.0-2.5 meters, hence we believe that a medium-to-large size room can be accommodated by our solution. It should be noted that different maximum beam steering angles can be achieved by changing the curvature of the rigid lens. For the future we will make prototypes of our model and compare the results and finally construct a controller for our light actuating beam steering device.

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