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OPTICAL ILLUSION DESIGN BASED ON FOUR CONVEX LENSES SYSTEM AND CLOAKING AREA CHARACTERIZATION

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ABSTRACT

A set up of optical illusion based on 4f system and characterization of cloaking area have been carried out. The cloaking area is an area where the object is placed on the area as if it disappears from view; the set-up of cloaking area is located at the top of the third lens. The distance between the lens and the cloaking, which is generated from 4f system, depends on the size of the focal point and the size of the lens used. The larger the focal point of the lens used the wider the distance between the lenses and the larger the size of the diameter of the lens, the cloaking range will be increasingly wide, and vice versa. From the experimental results that we obtained that the cloaking area for set up using FL (focusing lens) 100, 50, 50 and 100 mm with a diameter of 3.6 cm lens is ± 2 cm, whereas for the set up using lens FL 150, 100, 100 and 150 mm with lens diameter 2.54 cm is ± 1 cm.

ABSTRAK

Telah dilakukan set up desain ilusi optik berbasis sistem 4f dan karakterisasi area cloakingnya . Area cloaking ini adalah daerah dimana objek yang ditempatkan pada daerah tersebut seolah-olah menghilang dari pandangan, pada set up ini area cloaking terletak pada 1/3 bagian atas lensa. Jarak antar lensa dan area cloaking yang dihasilkan pada sistem 4f ini bergantung pada besarnya titik fokus dan ukuran lensa yang digunakan. Semakin besar titik fokus lensa yang digunakan maka akan semakin lebar jarak antar lensanya, dan semakin besar ukuran diameter lensanya maka range cloakingnya juga akan semakin lebar, demikian sebaliknya. Dari hasil penelitian diperoleh besarnya area cloaking untuk set up dengan panjang fokus lensa (*focusing lens*) 100, 50, 50 dan 100 mm dengan diameter lensa 3,6 cm adalah ± 2cm, sedangkan untuk set up dengan panjang fokus lensa 150, 100, 100 dan 150 mm dengan diameter lensa 2,54 cm adalah ± 1 cm.

Keywords: Cloaking area; Lenses; Optical illusions; 4f

INTRODUCTION

Cloaking devices are system that utilize transformation theory and illusion technology. In principle, cloaking devices aim to totally or partly hide objects, so that the objects become invisible. (Fridman, Farsi, Okawachi & Gaeta, 2012). This basic technologies used by stealth aircraft, such as radar-absorbing dark paint, optical camouflage devices and other devices that require to minimize surrounding electromagnetic field (Fridman et al., 2012; Greenleaf, Kurylev, Lassas, & Uhimann, 2009; Lai, Chen, Zhang & Chan, 2009). There several types of cloaking devices are electromagnetic cloaking, spatial cloaking, space-time cloaking, far-distance cloaking, plasmonic shield, and many more as described in Schittny, Kadic, Buckmann & Wegener (2014) dan Choi & Howell (2014).

Choi & Howell (2014) demonstrated a ray optics cloak that is designed for continuously multidirectional angles in 3D. This is the first such device, for transmitting rays in the visible regime. It also uses off-the-shelf isotropic optics, scales easily to arbitrarily large sizes, has unity magnification, and is as broadband as the

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optical material used. Thus, many of the difficulties encountered in invisibility cloaking schemes so far are solved, albeit with edge effects that are present. Also provide a concise and effective formalism, using ray optics, to describe all perfect optical cloaks in the small-angle ('paraxial') limit. And apply a formalism to general optical systems up to four lenses, and show what systems can be considered 'perfect' paraxial cloaks for rays. This was the first technique utilizing visible light and portable integrated setup. In addition, they have shown that by using 4 lenses, they can generate perfect cloaking system in visible light.

In case of optical cloaking, several parameters that must be consider are type of lens, size of lens and focus length. These parameters are crucial in building optical cloaking system, especially in 4f (4 lenses) system. Size of object and image quality are also affected by those parameters. Figure 1 describes cloaking area on two, three and four lens configuration.

Choi & Howell (2014) stated that a 'perfect' cloak was applicable generally. We will now develop a formalism using geometric optics, to quantify this definition in the paraxial approximation. To first-order approximation, called the "paraxial approximation," light rays are assumed to deviate minimally from the center axis of the system. Hence, it is a small-angle approximation. In this regime, also known as "Gaussian optics" (Max & Emil 2010).

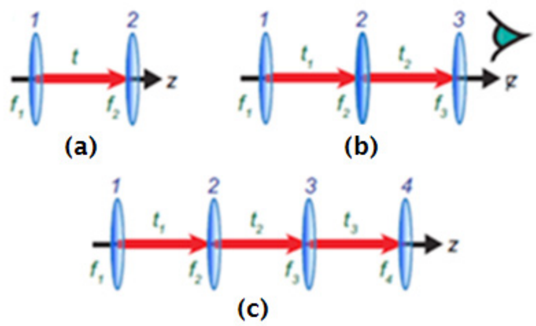


Figure 1. Area of paraxial optical cloaking for (a) two lens system, (b) three lens system and (c) four lens system. (Choi & Howell, 2014; David 2014).

The propagation of light rays through an optical system can be described by 'ABCD' matrices. Because a perfect cloaking device simply replicates the ambient medium throughout its volume, its ABCD matrix is just a 'translation matrix' as shown in Figure 2 (Bass, 2010; Choi & Howell, 2014).

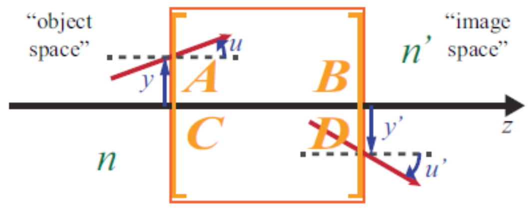


Figure 2. Illustration of ABCD matrix and optical path in paraxial approach with z-axis rotational symmetric when the light incident from left to right.

Detail explanation of "ABCD" matrix is described in Figure 2. The optical system (box in the center) can be described by an 'ABCD' matrix. This matrix maps the initial position (y) and paraxial angle (u) to those exiting the system (y',u'). The "object space" is the space before the ABCD system, with index of refraction n. Likewise, the "image space" is the space after the system, with index of refraction n'. In this diagram, value of y > 0, u > 0, y' < 0 and u' < 0 (Choi & Howell 2014). Since perfect cloaking system only replicate ambient media along the volume, ABCD matrix is called translation matrix (Max & Emil 2010; Choi & Howell 2014), as shown in Equation (1)

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix}_{perfect\ cloak} = \begin{bmatrix} 1 & L/n \\ 0 & 1 \end{bmatrix} \quad (1)$$

where is length of cloaking system, and n is medium refractive index. This condition will help in designing cloaking system (Choi & Howell 2014). Since ABCD matrix has determinat = 1, thus Equation (1) must have three conditions, B = L/n, C = 0, A = 1 and D = 1. In perfect cloaking system value of C = 0 (afocal). In this case the system has no power in the focus point, so that an infinite object in that area will be imaged as infinite object. This will help us in design, since afocal condition can be easily measured (Choi & Howell, 2014).

Choi & Howell (2014) mentioned that it is not obvious that an optical system can satisfy Equation (1), despite containing a cloaking region. The discussion and conditions for a 'perfect cloak' may have little meaning unless a physical solution actually does exist. We will now carefully build general optical systems, to see whether a perfect paraxial cloak can be designed with rays. We attempt to find the simplest nontrivial solution, so we will only consider rotationally symmetric systems with thin lenses, and in free space with n = 1. The ABCD matrix for one thin lens is given by

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix}_{lensa\ tipis} = \begin{bmatrix} 1 & 0 \\ -1/f & 1 \end{bmatrix} \quad (2)$$

where f is the focal length of the lens. In order to define the ABCD matrix value for two lens system as in Figure 1, the form of the matrix equation is written as

$$\begin{bmatrix} 1 & 0 \\ -1/f_2 & 1 \end{bmatrix} \cdot \begin{bmatrix} 1 & t \\ 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} 1 & 0 \\ -1/f & 1 \end{bmatrix} = \begin{bmatrix} 1 - t/f_1 & t \\ -(f_1 + f_2 - t)/(f_1 f_2) & 1 - t/f_2 \end{bmatrix} \quad (3)$$

While on a system using three lenses, the equations for ABCD matrices can be written as follows

$$\begin{bmatrix} 1 & 0 \\ -1/f_3 & 1 \end{bmatrix} \cdot \begin{bmatrix} 1 & t_2 \\ 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} 1 & 0 \\ -1/f_2 & 1 \end{bmatrix} \cdot \begin{bmatrix} 1 & t_1 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ -1/f_1 & 1 \end{bmatrix} \quad (4)$$

The value of can be determined by setting (Choi & Howell 2014), so

$$f_2 = -\frac{(f_1 - t_1)(f_3 - t_2)}{f_1 + f_3 - t_1 - t_2} \quad (5)$$

Similarly, in the three-lens system, cloaking cannot yet be formed, as the approximate approach is used, so Equation (5) becomes

$$f_2 = (t_1 - f_1)/2 \quad (6)$$

To set up four lenses as in Figure 1c, several conditions such as , and , in matrix ABCD must be fulfill, so that

$$t_1 = f_1 + f_2 \quad (7)$$

Using the Equation (7), the matrix ABCD becomes

$$\begin{bmatrix} 1 & f_1(-2t_1^2 + f_1(2t_1 + t_2))/(f_1 - t_1)^2 \\ 0 & 1 \end{bmatrix} \quad (8)$$

We can now set , and solve for

$$t_2 = 2f_2(f_1 + f_2)/(f_1 - f_2) \quad (9)$$

Based on Equation (9), we have finally found an exact solution for Equation (1). At least four lenses are required for a perfect paraxial cloak, for a rotationally symmetric lens-only system. With Equations (7) and (9), the total length is

$$L = 2t_1 + t_2 = 2f_1(f_1 + f_2)/(f_1 - f_2) \quad (10)$$

with

$$f_1 = (1 \pm \sqrt{2})f_2 \quad (11)$$

The purpose of this experiment is to design a continuous cloaking set up based on optical with a four lens system (4f), by arranging the spacing between lenses to form cloaking and characterizing the cloaking area.

METHOD

The experimental set up which used to create the optical illusion based on a four lens system (4f) is shown in Figure 3.

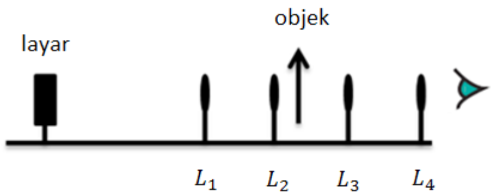


Figure 3. Set up an optical illusion experiment with a four lens system (4f)

In this set up the lenses are used there are two, namely convex lens with focal length of 100, 50, 50 and 100 mm with a diameter of 3.6 cm lens and lens with focal length of 150, 100, 100 and 150 mm diameter lens 2.54 cm. For lenses with a diameter of 3.6 cm set up (–) = 14,5 cm, (–) = 11,5 cm and (–) = (–). As for the lens 2.54 cm set up the distance is (–) = 18, 5 cm, (–) = 15,5 cm and (–) = (–). Set up the spacing between the lenses is the set up that produces the clearest shadow focus on the screen, such as the set up in Figure 3.

Once the experimental set up is obtained, that is, it produces the clearest focus of the shadow on the screen. The object to be observed is placed between the lens and , and the observation of the object is taken from the front of the lens . If the experimental set up is successful then the object is placed between the lens and at the third part of the lens, as if the object covering the lens will not appear on the screen (missing) or there is no object blocking the lens seen on the screen. To see the detail of the focused beam on each lens, place a laser pointer in front of the lens by adjusting its position from top to bottom to obtain when the groove or the direction of the light beam refracted to each lens.

RESULTS AND DISCUSSION

Based on the theory, the requirement of optical cloaking is to use four lenses with similar materials. The lens used should be of the same diameter as the minimum requirement, so that the refraction of the resulting light can be evenly distributed by the same size. The second condition is the value of and. The illustration of the light beam passing through the cloaking system with four lenses (4f) is shown in Figure 4.

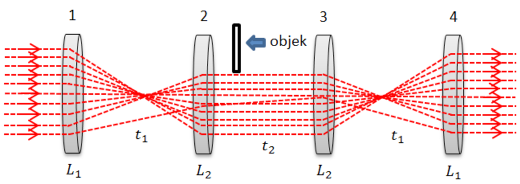


Figure 4. IIllustration of light beam on a perfect paraxial cloak that passes through four lenses.

The lenses used in this system's set up are convex lenses, since convex lenses are refractory in nature, unlike diverging concave lenses. The light rays that come parallel to the axis of the convex lens will be biased toward the focal point. The rays form a real image that can be captured on the screen and are positive. The amount of light refraction in a lens depends on the refractive index of the lens material, the magnitude of the focal length of the lens and the surface curve of the lens, whereas the refractive index depends on the fast ripple of light in the lens material. The thick convex lens will refract larger light than the thin convex lens. The focal length of the thicker convex lens is shorter than the length of the thin convex lens.

In this experiment used two types of convex lenses with different diameters, namely 3.6 cm and 2.54 cm. The distance between the lens depends on the size of the lens and the material or lens making material used, the larger the focal length of the lens used then the distance between the lens ,,, and will be wider, and the larger the diameter of the lens used then the cloaking area will be even greater as shown in Figure 4 and the experimental simulation results performed by (Choi & Howell, 2014), as shown in Figure 5.

Area cloaking with convex lens is limited to certain areas only, not 100% of the object to be observed can disappear (Kildishev & Shalaev, 2008; Chen et al., 2013). This is due to the limitation of the lens size and the magnitude of the focus of each lens after being incorporated into a set up of this optical cloaking system as well as the angle of observation (Chen et all., 2013).

Based on the illustration of the light trajectory in Figure 4 for this optical cloaking set, the light entering at the bottom of the lens and forwarded to the second lens is not about the upper third of the lens, this area is called the "cloaking region" where the object or object is placed on the area seems to be lost from the eye when viewed from the first lens. The limitation of cloaking is formed around the upper third of the lens diameter only in the region between (L_2 - L_3), or ± as shown in Figure 4.

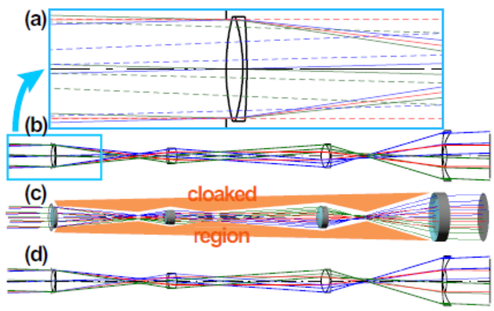
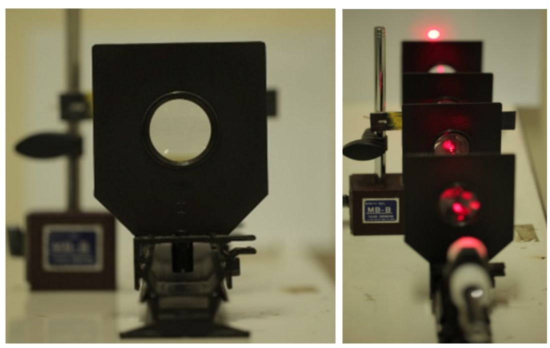


Figure 5. The result of simulating perfect paraxial cloak, using four lenses (4f) (Choi & Howell, 2014).



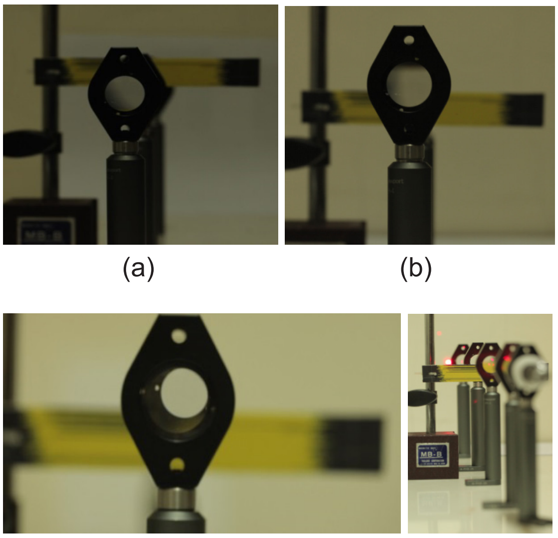
(a) (b)

Figure 6. Set up optical illusions with 4f, 3.6 cm diameter (a) with objects in area L_2 - L_3 (b) with laser beam pointers in front and fixed objects on L_2 - L_3.

The results of some observations for the set up of the optical illusion design based on the 4f system are shown in Figure 6 and Figure 7. In Figure 6 shows the result set up of the optical illusion of 4f system with a diameter of 3.6 cm lens.

From Figure 6a it appears that a rectangular paper object 15x1 cm in size (such as ruler size 15 cm) which is placed on the upper third of the lens (± 2 cm), as if missing or invisible when viewed from the front of the lens. Shooting is focused on the first lens. This proves that the set up of the 4f system by setting the distance according to the maximum focus scale has succeeded in forming a cloaking. The position of the observation angle also affects the resulting image (David, 2014).

In Figure 6b it is also shown that the same object as in Figure 6a, which is placed in the area - does not block the laser beam being fired, the fired laser beam can penetrate to the back of the screen. This event occurs because the laser beam is fired the path turns in accordance with the fall of the focal point of each lens that has been combined, so that the laser beam can penetrate to the screen without being blocked by the object on the cloaking area that is in the region between (- or ± . The pointer fired on the lens as shown in the illustration of Figure 4, in the upper third of the lens is not crossed by the light of the laser beam, so that the object is not exposed to laser light.



(a) (b)

(c) (d)

Figure 7. Results cloaking with 2.54 cm diameter lens (a) - (c) object position variation and shooting angle (d) laser pointer ray path on cloaking system

As for the set up with 2.54 cm diameter lens shown in Figure 7. In Figure 7a - 7c is shown the results of several variations of cloaking system image angle and object position variation.

In Figure 7a the observed object is placed at the top of the lens, while the objects in Figure 7b and 7c are at the bottom of the lens with the difference of the image taking position (photo) of the system. The object used is the same as the object to set up in Figure 6. The cloaking area that is formed is in the same area as the set up of the system with 3.6 cm lens diameter, differ only in the distance between the lenses due to the different focal length of the lens used. While Figure 7d shows the path of laser light passing through the system, the same as the treatment for the lens with a diameter of 3.6 cm. From this result can be said that the design of optical illusion with 4f system is proven to eliminate the object, in accordance with the purpose of research that will be done. Objects observed (between -) seem to disappear from the sight of the eye. Below is an experiment data table.

Table 1. Obeservation data of cloaking area

d lensa (cm)	$L_1 = L_4$ (mm)	$L_2 = L_3$ (mm)	$(L_1 - L_2)$ (cm)	$(L_2 - L_3)$ (cm)	$(L_3 - L_4) = (L_1 - L_2)$ (cm)	*Cloakig area* (cm)
3,6	100	50	14,5	11,5	14,5	± 2
2,54	150	100	18,5	15,5	18,5	± 1

The observed object position is placed on the upper or lower third of the used lens called the "cloaking region" located in the region between (- or ± , with the maximum limit of objects that can be stacked to set up the system with a 3.6 cm diameter lens of ± 2 cm, and for lenses with a diameter of 2.54 cm of ± 1 cm.The results of this experiment is in accordance with that has been done by Choi & Howell (2014), in their experiments explains that the cloaking object is only in certain parts only as shown in Figure 5.

The cloaking area for the set up using four lenses is between lens 1 and lens 2, and not all parts of the lens can remove objects, only in certain areas as seen in the light path in Figure 5.

CONCLUSION

The optical illusion design (cloaking) based on four lenses (4f) can be produced on condition of using lenses with similar materials, in this system using a convex lens with the same lens diameter and focal length value and The cloaking area occurs in the intermediate area - or ± in the upper third of the lens, the minimum constraint of cloaking formed for the convex lens with a diameter of 3.6 cm in this experiment is 2 cm, and for the lens with a diameter of 2.54 cm the cloaking area is 1 cm. The distance between the lens and the cloaking area generated in this optical cloaking set depends on the amount of focal point of the convex lens used.

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