Invisibility device with isotropic media using negative refractive index

Tomoshiro Ochiai*
School of Social Information Studies, Otsuma Women's University,
2-7-1 Karakida, Tama-shi, Tokyo 206-8540, Japan
**E-mail: ochiai@otsuma.ac.jp*

Recently, artificial materials like metamaterials attract a lot of attention in various research communities. These materials, by using an artificial structure, can have unusual optical properties, which materials in nature usually could not have. Using these artificial materials, it may be possible to realize so-called “Harry Potter invisibility device”. Of course, "Harry Potter invisibility device" is a scientific fiction so for. However, using such metamaterials to control well the direction of the electromagnetic field at will, we could make an object hidden inside "invisibility device”. As a consequence of that, nobody can see it including the device itself. Here, we will explain how to design invisibility device (optical camouflage technology) and introduce our recent research results [8,9].

History of the invisibility cloak is still not long. In 2006, Pendry and his colleagues theoretically proposed a method of designing invisibility cloak [1]. In this paper, the invisibility device is designed by identifying the curved space metric tensor with permittivity and permeability of the anisotropic media. It provides a proper distribution of permittivity and permeability for each position, so that the device can be invisible. However, it was not clear that there are easy methods to create a concrete material with such a permittivity and permeability.

In the same year, the same group succeeded in realizing a prototype invisibility device experimentally in the microwave region [2]. This prototype invisibility cloak is cylindrical and has cavity to hide some things in the center. In the device, metamaterials are arranged in a cylindrical shape and cover the cavity in the center. The reason why they focused on microwave region may be that the wavelength of the microwave is long enough to make the fine structure of the metal less than its wavelength. It is not easy to make metamaterial for visible light, comparing microwave region. Although this prototype is not transparent for visible light, it is transparent for certain wavelength of the microwave with specific polarization.

On the other hand, using different methods, Leonhardt designed the invisibility device in isotropic media [4,5]. It is known that there are inherent difficulties to construct isotropic invisibility device. The mathematical theorem known as Nachman theorem proves that "perfect" invisibility cloak without reflection and phase delay is impossible [6,7].

To obtain the blueprint of invisibility cloak, transformation optics is a useful tool. Usually, to obtain various physical quantities, we need to solve differential equations, which often have a variety of difficulties. On the other hand, by using coordinate transformation, transformation optics can determine the various physical quantities without solving ordinary differential equations. Cloaking devices are designed using transformation optics rather than solving Maxwell’s equation directly.

In a recent work, we proposed a new design of invisibility device with isotropic media by combining positive and negative refraction [8]. We call this type of design plus-minus construction. It enables us to get around the Nachman theorem and to provide perfect invisibility without reflection and phase delay. However, in order to make the invisibility device perfect, fine tuning is necessary for the refractive index distribution at the branch cut.

In [9], we provide more natural methods to design perfect invisibility. In this construction, we use three conformal mappings and plus-minus construction. The three conformal mappings enable us to avoid solving differential equation and get the refractive index distribution and the trajectory of light easily. We show that the plus-minus construction surprisingly cancels out the reflection without fine tuning, even if there is discontinuity of refractive indices at boundaries, which usually led to an inevitable reflection.

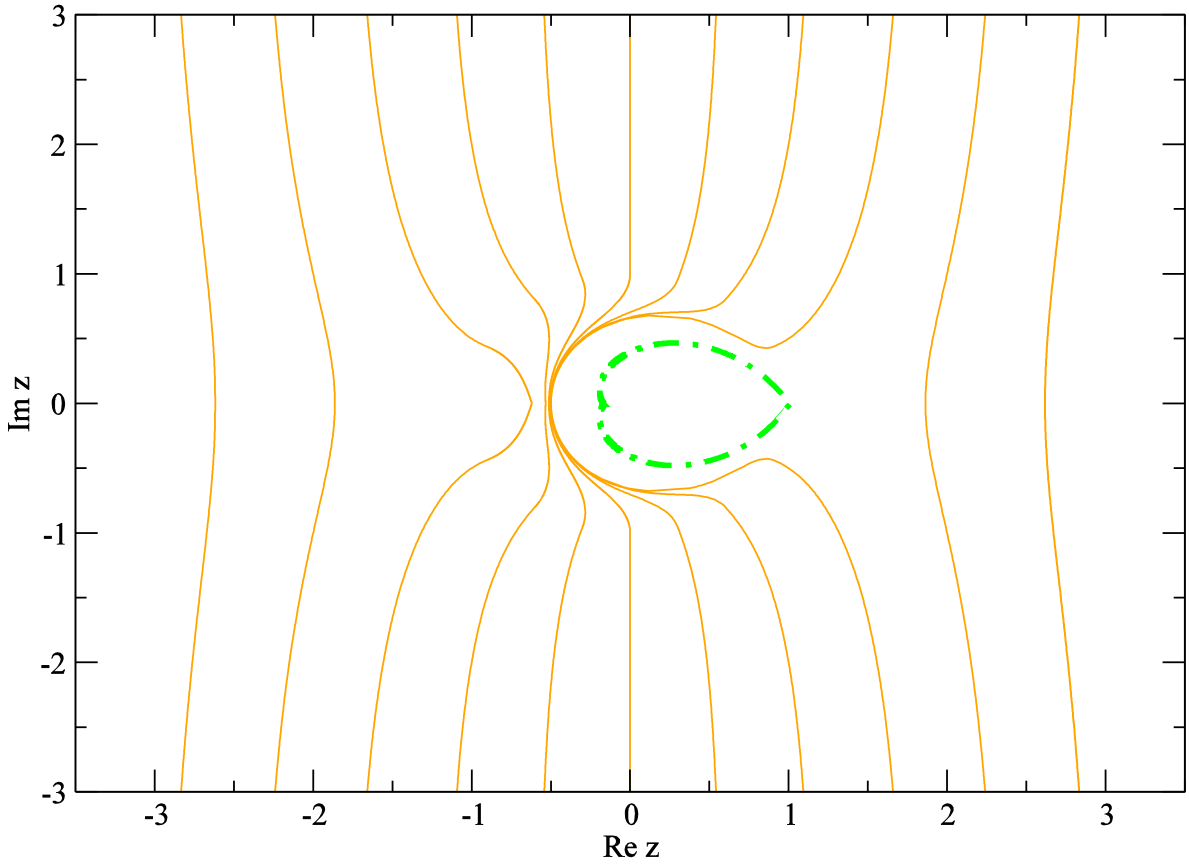

Figure: Trajectory of light in physical space

References

1. J.B. Pendry, D. Schuring and D.R. Smith, Science 312, 1780 (2006).
2. D. Schurig, J. J. Mock, B. J. Justice, S. A. Cummer, J. B. Pendry, A. F. Starr, and D. R. Smith, Science 314, 977 (2006).
4. U. Leonhardt, Science 312, 1777 (2006).
5. U. Leonhardt, New. J. Phys. 8, 118 (2006).
6. A. I. Nachman, Ann. Math. 128, 531 (1998).
7. E. Wolf and T. Habashy, J. Mod. Opt. 40, 785 (1993).
8. T. Ochiai, U. Leonhardt, and J. C. Nacher, J. Math. Phys. 49, 032903 (2008).
9. J.C. Nacher , T. Ochiai: J. Math. Phys.52, 012903 (2011)