AN INVITATION TO IMPACT-RELATED RESEARCH:

TRANSFORMATION OPTICS – FROM CLOCKING TO REVOLUTIONARY SATELLITE ANTENNAE

Prof. Yang (SEMS) Hao & JAVK

WHAT IS THIS ABOUT?

- ***Transformation Optics*** is a framework which exploits the coordinate independence of electromagnetism to design materials with exotic properties.
- In particular, it offers the door to the construction of antennae with ***invisibility properties.***
- The technique developed in an article in Sc. Rep. led to the construction of new antennae designs provides widespread high-width band at a fraction of other technologies.
- Brought to the market by a start-up (Isotropic Systems Ltd, ISL) and manufactured by Qnetiq.

SCIENTIFIC REPORTS

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Illusions and Cloaks for Surface Waves

T. M. McManus[1], J. A. Valiente-Kroon[2], S. A. R. Horsley[3] & Y. Hao[1]

SUBJECT AREAS:
ELECTRICAL AND ELECTRONIC ENGINEERING
APPLIED PHYSICS

[1]School of Electronic Engineering and Computer Science, Queen Mary University of London, E1 4NS, England, UK, [2]School of Mathematical Sciences, Queen Mary University of London, E1 4NS, England, UK, [3]Department of Physics and Astronomy, University of Exeter, EX4 4QL, England, UK.

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Ever since the inception of Transformation Optics (TO), new and exciting ideas have been proposed in the field of electromagnetics and the theory has been modified to work in such fields as acoustics and thermodynamics. The most well-known application of this theory is to cloaking, but another equally intriguing application of TO is the idea of an illusion device. Here, we propose a general method to transform electromagnetic waves between two arbitrary surfaces. This allows a flat surface to reproduce the scattering behaviour of a curved surface and vice versa, thereby giving rise to perfect optical illusion and cloaking devices, respectively. The performance of the proposed devices is simulated using thin effective media with engineered material properties. The scattering of the curved surface is shown to be reproduced by its flat analogue (for illusions) and vice versa for cloaks.

Correspondence and requests for materials should be addressed to Y.H. (yang.hao@eecs.qmul.ac.uk)

To date, almost all examples of TO[1–6] devices such as cloaking[7–12] and optical illusion[13–16] were concerned primarily with three-dimensional free space waves and although those devices were successfully modelled, their practical applications have been hampered by the fundamental limits of their required material parameters which were lossy, dispersive and narrowband. In an attempt to reduce the complexity of the required materials of the devices, we will investigate TO for two-dimensional surfaces, which do not rely upon any symmetry.

This Letter presents a general method to achieve illusion devices for surface waves, with the aim of utilising a flat, anisotropically loaded medium to perfectly recreate the total scattering characteristics of an arbitrarily, curved surface for all angles of incidence. For the cloaking device[17], a similar derivation to that of the illusion device is employed, and an anisotropically loaded, curved deformation is shown to behave as if it were a flat surface for all angles of incidence. The proposed illusion and cloaking devices, serve as proofs-of-concepts that can be adapted to other waves, e.g. acoustic.

The underlying theory of the proposed illusion device is as follows. Starting with a flat surface, upon which electromagnetic waves are confined (e.g. a thin waveguide) we add an anisotropic layer, which modifies the effective space through which the waves propagate. If done properly, this material distribution[18–21] will emulate the behaviour of a surface wave along a curved surface, thus giving rise to an illusion device. The proposed method is derived in the approximation of Geometrical Optics (GO). We write the electric field as an amplitude times a phase, $\mathrm{E} = \boldsymbol{a}e^{iS}$, and assume that the phase of the wave varies much more quickly than the amplitude or the properties of the medium. Maxwell's equations are then recast as

$$\nabla S \cdot \varepsilon \cdot \boldsymbol{a} = 0, \tag{1a}$$

$$\frac{1}{\omega}(\nabla S \times \boldsymbol{a})e^{iS} = \boldsymbol{B}, \tag{1b}$$

$$\nabla S \times \boldsymbol{\mu}^{-1} \cdot (\nabla S \times \boldsymbol{a}) + \omega^2 \varepsilon \cdot \boldsymbol{a} = 0. \tag{1c}$$

Assuming that the medium is in an electrically thin waveguide, the fundamental mode is uniform for the cavity and that E is always normal to the top and bottom of the waveguide, we have $\varepsilon_{zi} = \delta_{zz}$ and $\boldsymbol{a} = a\hat{\boldsymbol{z}}$. Then ∇S lies exclusively in the x-y plane, meaning that equation (1c) can be recast as

$$\frac{1}{\det(\tilde{\boldsymbol{\mu}})}\left[\mu_{xx}\left(\frac{\partial S}{\partial x}\right)^2 + 2\left(\frac{\partial S}{\partial x}\right)\left(\frac{\partial S}{\partial y}\right)\mu_{xy} + \mu_{yy}\left(\frac{\partial S}{\partial y}\right)^2\right] = \omega^2 \tag{2}$$

where

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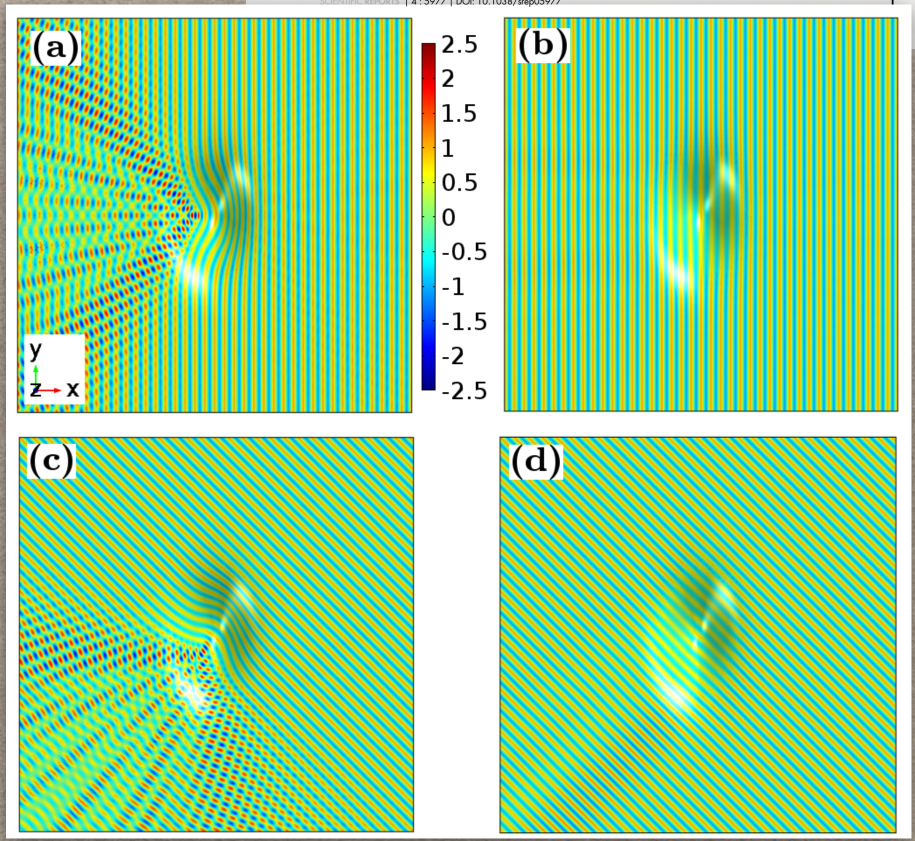

Figure 5.23: Plane wave propagating from right to left ($\theta_i = 0$), through a curved isotropic medium (a) and a curved, loaded, anisotropic medium (b). Plane wave propagating at $\theta_i = \frac{\pi}{4}$ through a curved isotropic medium (c) and a curved, loaded, anisotropic medium (d). All results are for E_z.

HOW THIS CAME ABOUT?

- The mathematics behind TO is the same used in **Relativity**.
- There was an email by a PhD student in SEMS looking for expertise in fields related to TO.
- Acted as second supervisor of this student. Got involved in the research. Invited to group meetings at SEMS and the consortium QUEST.
- My contribution: mathematical formulation of the problem and analysis of the results of the simulations.
- The connection to industry was done by the SEMS part of the team.
- Writing up of the case mostly done by John Moriarty and then taken over by professional writers.

TAKE AWAY: *Serenditipy!*

- Are there any potential collaborations in our engineering schools which require specific mathematical background?
- Be receptive to potential invitations.
- Gives a glimpse to a different type of research.
- **Thrill of seeing the construction of an object one helped to design!**
- **QMUL gives a lot of support to write the Impact case!**