

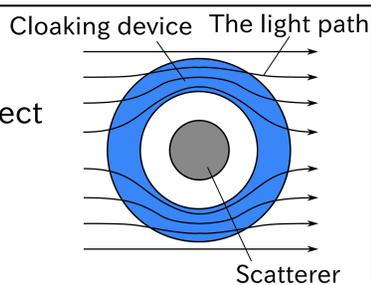
A level-set based topology optimisation of cloaking devices with the boundary element method

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Background

Cloaking :

Technology to make an invisible object by allocation of materials such as dielectric element.



Topology optimisation :

One of methods to determine the optimal configuration of engineering devices using computer simulations.

Topology optimisation can determine not only peripheral shapes of engineering devices but also their topologies.

We determine configuration of cloaking devices using the topology optimisation.

Optimisation problem of cloaking devices

Topology optimisation problem of cloaking devices :

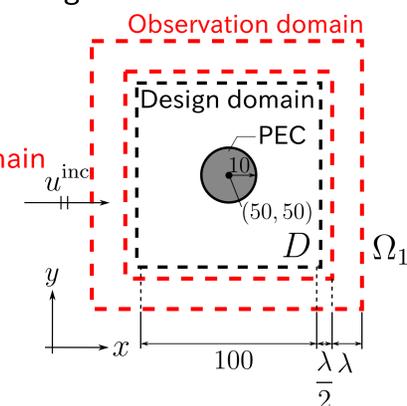
find $\Omega_2 \subset D$

such that $\min J(\Omega_2)$

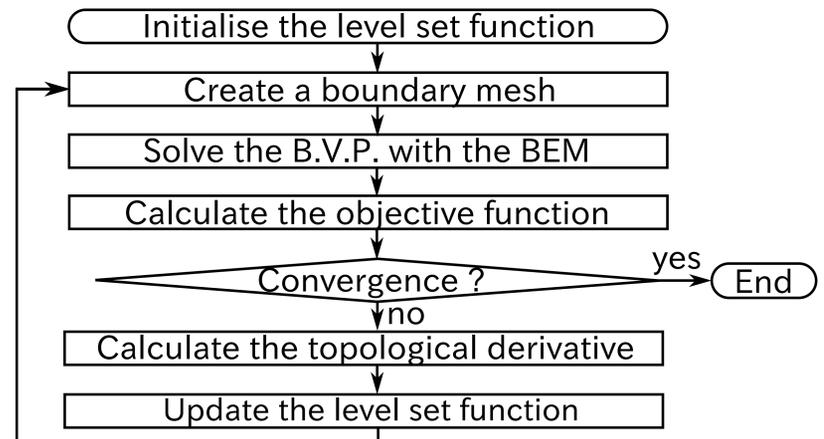
J : scattering field in the observation domain

subject to B.V.P. defined in Ω_1 and Ω_2

Ω_1 : vacuum domain
 Ω_2 : dielectric element
 λ : wave length



Flowchart of the topology optimisation



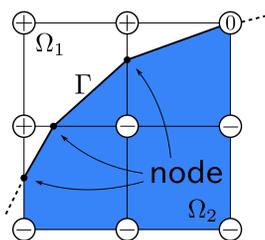
Configuration expression with the level set method

In the optimisation process, we express configuration of design objects by the following level set function ϕ which is defined in the design domain,

$$-1 \leq \phi(x) < 0 \quad x \in \Omega_2,$$

$$\phi(x) = 0 \quad x \in \Gamma := \partial\Omega_2,$$

$$0 < \phi(x) \leq 1 \quad x \in D \setminus \bar{\Omega}_2.$$



We generate a boundary mesh by connecting nodes at which linearly interpolated value of ϕ is zero.

Update of configuration

We update the level set function ϕ by solving the following reaction and diffusion equation with the FEM,

$$\frac{\partial \phi(x, t)}{\partial t} = K\mathcal{T}(x) + \tau \nabla^2 \phi(x, t) \quad x \in D \quad \star$$

$$\phi(x, t) = c > 0 \quad x \in \partial D$$

$$\phi(x, 0) = \phi_0 \quad x \in D$$

1st term of \star : determine direction and scale of the update

$\mathcal{T}(x)$: Topological derivative

2nd term of \star : control complexity of configuration obtained after the update

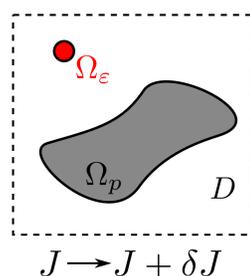
Calculation of the topological derivative with the BEM

Topological derivative : variation of an objective function J when an infinitesimal circle Ω_ϵ is allocated in D

$$\mathcal{T}(x) = \Re \left[\frac{2(\epsilon_2 - \epsilon_1)}{\epsilon_1(\epsilon_1 + \epsilon_2)} u_{,i}(x) \tilde{u}_{,i}(x) \right],$$

u : the magnetic field

\tilde{u} : the adjoint field of u



The B.V.P.s for u, \tilde{u} are solved with BEM and the topological derivative is calculated.

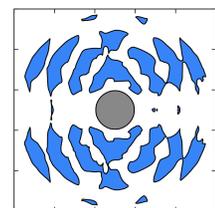
Optimisation result of cloaking device in TE polarised field

Topology optimisation with the following parameter :

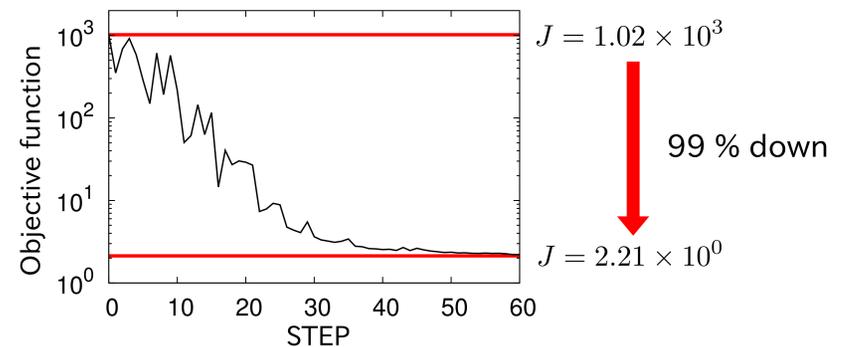
Relative permittivity of dielectric element = 2
wave length $\lambda = 20$

Initial configuration

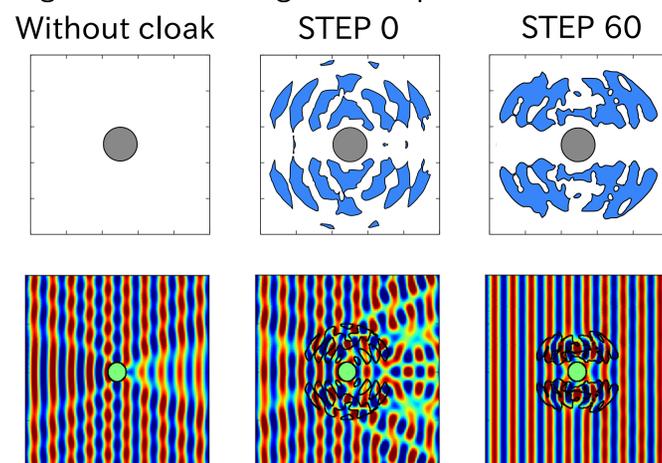
Initial configuration is determined as a domain in which the topological derivative in the case without cloak is less than 0.



History of the objective function



Configuration and magnetic response



At step 60, magnetic response around dielectric materials is almost the same as plane wave, which indicates that the obtained structure is showing a cloaking effect.