Designing Materials for Mechanical Invisibility Cloaks

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Abstract

Less than a decade ago, it was discovered that invisibility could be a real possibility. Originally it was for a type of "X-ray" technique, electric surface impedance tomography, where a voltage distribution is applied to the surface of a body, and resulting electric currents through the surface are measured, with a view to reconstructing the conductivity inside the object. Theoretically, the interior of the object could, under certain circumstances, hide (or "cloak") an embedded body in such a manner that even the fact that something was hidden would be undetectable. Soon similar phenomena were shown to be possible also for electromagnetic waves [1]. Also in solid mechanics, there is considerable interest in achieving "invisibility," however not primarily for hiding objects from sight. The applications in mechanics include protection of structures and parts of structures from potentially harmful transient waves and steady state vibrations (Figure 1). A suggested large scale application is that protection against seismic waves from earthquakes could be achieved by using cloaking to re-route the waves around sensitive infrastructure (Figure 2). Similarly ground waves from trains or other vehicles in rapid transit could possibly be redirected so as to protect buildings situated too close to the tracks or roads. At smaller scales, an application could be to re-direct elastic waves around e.g. clamping points for panels in vehicles or other structures, thereby achieving some noise control by entirely passive means. On the very small scale, protection of sensitive electronic components from vibrations might be accomplished by surrounding the components by a suitable mechanical cloak. The construction of mechanical cloaks requires fine-tuning of the elastic properties of the cloaking, so-called metamaterials [2]. Multiscale mechanics is the topic of connecting different length scales in mechanics. For solid materials, the macroscale response is defined through suitable microscale models that resolve the actual topology on the lower scale. The straight-forward question in multiscale mechanics (or micromechanics) is what the macro-scale response will be for a given structure on the micro-scale. One classical example is homogenization of elastic properties for micro-heterogeneous materials (ref.3). However, in an inverse setting, multi-scale mechanics (or homogenization) can also be used to design the microstructure such that a specific response on the macroscale is obtained. We describe some results on simulations of cloaking in solid mechanics. COMSOL Multiphysics has been used to simulate different material responses. In order to apply the anti-symmetric elasticity matrix properties that was needed, an expansion of the weak form in the software was made. To investigate the anisotropic material behavior a comparison to the isotropic material was made, in particular during tests regarding seismic wave propagation (Rayleigh waves) (Figure 3). The simulations indicate that there is a potential for cloaking objects for incoming seismic waves, both regarding force and displacement (Figure 4). In the next step, simulations of homogenization are required of micro-heterogeneous materials to find meta-materials suitable for producing the required macro-properties

for cloaking.

Reference

1. Emil Wolf, Progress in optics, Vol 52, p. 261-304, 2009.
2. Michele Brun et al., Achieving control of in-plane elastic waves, 2008.
3. Varvara G. Kouznetsova, Computational homogenization for the multi-scale analysis of multi-phase materials, 2002.

Figures used in the abstract

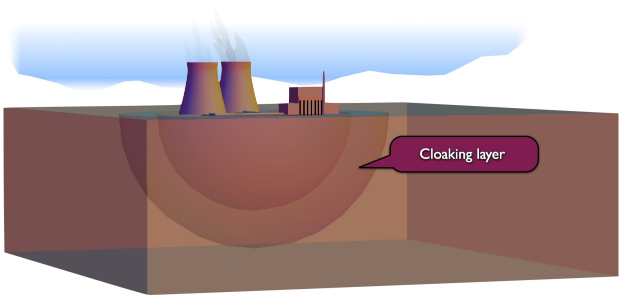

Figure 1

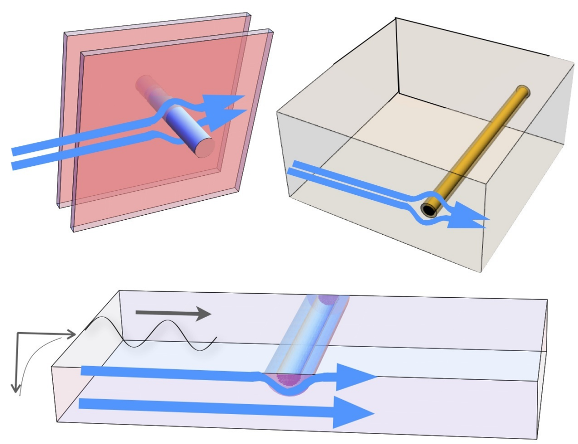

Figure 2

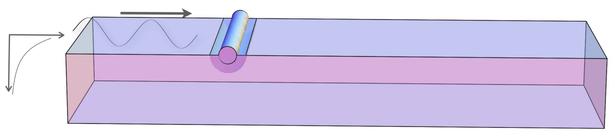

Figure 3

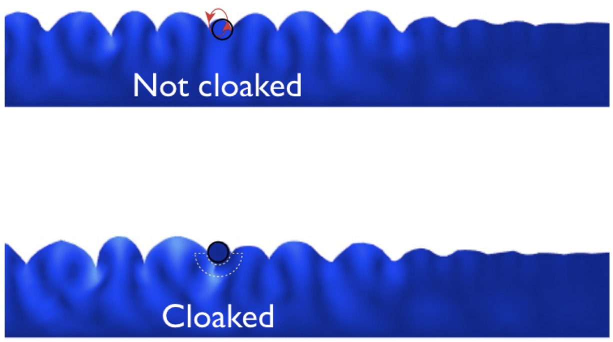

Figure 4