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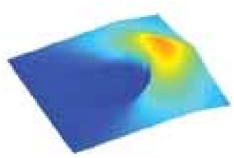
How to become invisible

David Miller

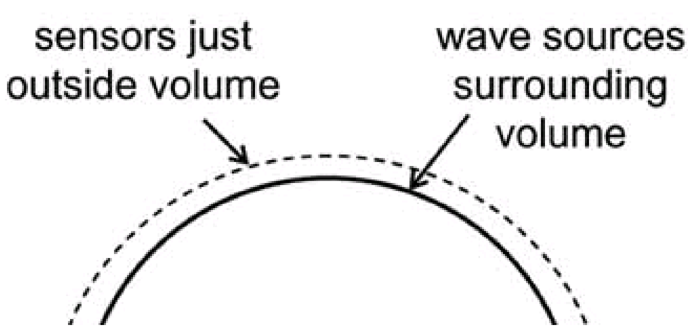
Wave detectors and sources distributed around a volume of space could render it and its contents impossible to detect.



In science fiction, space ships are 'cloaked' until they attack, and magic heroes wear an 'invisibility cloak' to sneak about undetected. But is invisibility really possible, even in principle?[1] The question is not just the stuff of fantasy. Cloaking against microwaves could mask objects from radar, and acoustic invisibility could make them disappear from sonar. Similarly, suppressing scattering or absorption of electromagnetic waves by buildings could eliminate dead spots in cellular phone coverage and radio reception.

From prior work, we know how sound waves might be made to appear to pass through a volume as if it were empty space, regardless of its contents.[2] The trick is to deploy just the right set of wave sources on the surface, as schematically shown in Figure 1. These sources cancel wave behavior inside the volume while leaving the wave outside unchanged. However, this scenario requires advance knowledge about the probing wave, and how to set the sources based only on measurements taken as the wave passes (a 'causal' solution) is not known. Yet recent work in electromagnetic cloaking[3,4] suggests an ingenious possibility. By surrounding a volume with a carefully tailored 'meta-material,' the wave can flow round the volume as if it were empty. This method works perfectly only for waves of a single frequency. 'True cloaking' that would make something completely undetectable even to previously unknown pulsed waves is yet to be achieved.

A key problem underlying earlier work is that true cloaking is impossible with source values based solely on 'local' measurements: if each loudspeaker source, for example, is controlled only by a nearby microphone.[1] Because all materials elicit a local response—inasmuch as displacement of electrons depends only on the field at that position—no material (or meta-material) can by itself provide true cloaking. No paint for perfect invisibility exists. Our work shows, however, that there is a way of setting the strength of any given source, based upon measurements at *all* the sensors around the volume.[1]



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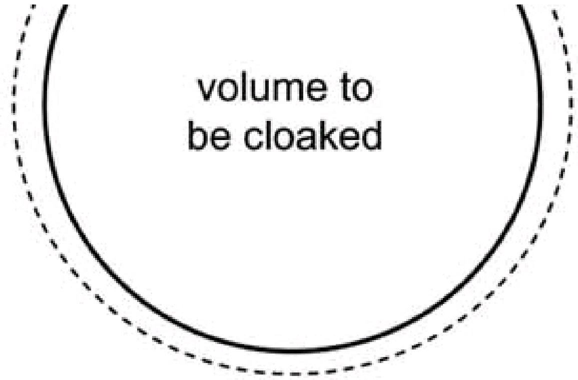

Figure 1. *A volume to be cloaked is surrounded by appropriate wave sources, whose values are set based on measurements from wave sensors just outside the volume.*

In Figure 1, sensors measure the local wave amplitude, f, near the surface, and sources on the surface itself have a set of amplitudes, p. Both for acoustic[1,2,4] and electromagnetic,[1,5] waves, we already know the (local) linear operators C that tell us the source strengths required to cancel the wave inside the volume based on the local values of the fields, such that p=Cf. These source amplitudes, however, also change the incident wave outside the volume, effectively 'scattering' it. Our solution for perfect causal cloaking is to use sources calculated by the following formula: $\mathrm{p} = \mathrm{C}(\mathrm{f} - \mathrm{GCf})$ Here G is the Green's function operator, which gives us the wave resulting from any given source. This approach essentially calculates the propagation of the wave through the volume and sets up sources that not only eliminate the wave from within the volume but also recreate the correct original wave at all points outside it (see Figure 2).

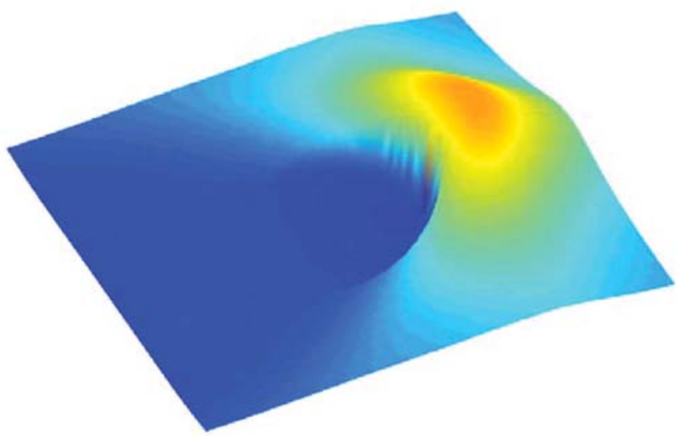

Figure 2. *Simulation of a pulse just after it has passed 'through' (from left to right) a 'truly cloaked' spherical volume. Height and false color represent the pulse amplitude in the equatorial plane.*

Is there also a snag with this approach? Yes and no. We need to perform some calculations, and the information about the wave still must flow across the volume. Both these events take time. For perfect cloaking, total time must be less than the travel time of the original wave. Slow sound waves present no difficulties other than practical ones, such as the number and form of the sources and power of the computer. For electromagnetic waves in a vacuum, however, we would always have at least some delay, which imposes a bandwidth limitation on perfection. It is also true that any scheme that relies on measurement should in principle be detectable quantum mechanically.[1] Although practical cloaking remains a prospect for the future, we seem a step closer to making the difficulties themselves disappear.

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DOI: 10.1117/2.1200702.0607