On Perfect Invisibility and Cloaking

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Abstract: Perfect invisibility even to pulses is possible in principle using sensors and sources around a volume and a new calculation formula, though would always be challenging for broadband electromagnetic waves and usually discoverable quantum-mechanically.

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For a volume and its contents be perfectly invisible to waves, the waves must appear to pass through the volume as if it were empty space regardless of the actual contents of the volume. A key question is whether there is anything with which we can surround or "cloak" a volume to achieve such perfect apparent transparency. Recently metamaterials have been proposed as cloaking coatings to give some such transparency at least for monochromatic waves [1,2]. Here we show first that, based merely on surrounding the volume with any material, any perfect invisibility to pulsed or non-monochromatic waves is impossible. There is therefore no "invisible paint" for perfect invisibility to pulses. Secondly, we show instead that a collection of wave sensors and wave sources surrounding a volume can make it completely invisible, provided the value chosen for each source is based on the measurements from all the sensors, and we give a fully causal formula for calculating the required source values [3].

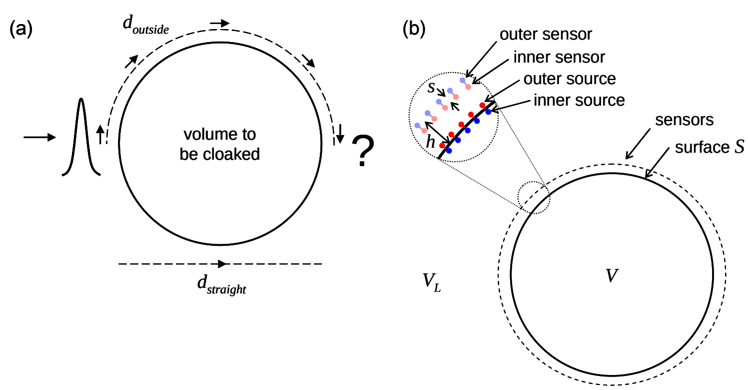

Fig. 1. (a) The path round a volume is necessarily longer than the path the pulse would have taken through the volume. (b) Scheme using wave sensors and sources for invisibility of the volume *V* and its contents.

Fig. 1(a) sketches a pulse incident on a volume to be made invisible. To make the contents invisible, we exclude the pulse from the volume. If we hope to achieve this invisibility solely on the basis of some material on the surface, and the response of the material is local (that is, the polarization or other such response of the material at some point depends only on the field or wave at or near that point in the material), then there is no way for the information about the pulse to flow to the far side of the volume fast enough, and the pulse will appear distorted on the far side, thus revealing the attempted cloaking. We can instead put sensors and active sources round the volume (Fig. 1(b)). If the values of the measured wave and of the sources at the surface are given by vectors of values f and p respectively, then the sources should be set to the calculated values $\mathsf{p} = \mathsf{C}(\mathsf{f} - \mathsf{G}\mathsf{C}\mathsf{f})$, where C is the local operator that gives us the source strengths $\mathsf{p} = \mathsf{C}\mathsf{f}$ that would cancel the wave inside the volume based on the local values of the fields, and G is the Green's function operator that gives us the wave resulting from any given source. For each source on the surface, this approach requires calculations based on the measured wave values at all sensors. It would work in principle perfectly for acoustic waves, but would usually be limited in bandwidth for electromagnetic waves because of any additional time required for calculations and for propagation of information across the volume. Since the method involves measurement, it would also be discoverable in the same manner as BB84 quantum encryption [3]. Nonetheless, this does offer an approach to perfect invisibility and clarifies limitations to any approach.

References

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