Deeply Sub-Wavelength Position Sensing with a Reverberation-Coded Aperture

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Accessing sub-wavelength information about an object is a fundamental challenge in all areas of wave engineering. Common approaches leverage evanescent waves via near-field measurements or by coupling them to the far field with near-field scatterers. However, such techniques inherently rely on invasive manipulations of the object's near field. Another notable idea is to use tailored coherent illumination from the far field to create super-oscillating hotspots. However, these techniques suffer from inherently low SNRs.

Here, we propose a method that relies on the sensitivity of wave chaos to geometrical perturbations, which is well known to be directly linked to the dwell time of the waves in the interaction domain [1]. We consider the prototypical task of localizing a sub-wavelength non-resonant scatterer and measure the field at a single-pixel detector using spectral or configurational degrees of freedom. The latter are implemented via random configurations of a programmable metasurface [2]. In both cases, the role of the cavity can be interpreted as coded aperture [3]: the spatial information about the object position is multiplexed across a set of diverse measurement modes. At first sight, this setup may resemble the well-known use of complex media as natural coded apertures based on their spatial or spectral diversity [4], [5]. The crucial difference, however, lies in a small detail: the object to be localized is *within* rather than *outside* the complex medium. Consequently, the waves interact with the object not once but countless times, hence developing a much larger sensitivity to sub-wavelength details.

We explore the link between the waves' dwell time, sensitivity and the achievable localization precision. We illustrate our idea with semi-analytical simulations and experiments in the microwave domain. In order to decode the sought-after sub-wavelength information from the multiplexed measurements, we deploy a simple fully-connected artificial neural network [6]. In our experiments, we use intensity-only information from a low-cost software-defined-radio (LimeSDR Mini) and achieve a localization precision of $\lambda/76$ [7].

References

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