

The Influence of Mutual Coupling in Quantum Sensing of Two-body Targets: Application of Characteristic Modes

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Quantum radars are a novel field of quantum technology, promising remarkable advantages in various basic tasks, such as target detection and recognition. One of the important problems is the recognition of two-body target and estimation of the distance between the bodies. For classical sensing, there are well-known limits for the resolutions defined by the wavelength of the probing electromagnetic field and parameters of the imaging set-up. When the inter-body distance become much smaller than the limiting value, the ability to discern it becomes lost (“the Rayleigh curse”). Illuminating the object with entangled quantum states emitted by quantum antenna and detecting reflected/scattered field correlation functions, allows one to mitigate “the Rayleigh curse”. The information content of such a measurement can be conveniently described by the Fisher information matrix providing bounds on the errors of the estimated target parameters.

In this talk we consider the simplest scheme of quantum-correlation based radar for target recognition/resolving. The quantum antenna source is formed by a pair of two-level identical dipole-dipole coupled emitters. Using Markovian approximation, dynamics of the density matrix of two emitters is described by the master equation. Both the object and the detectors are in the plane perpendicular to dipole moments. The field produced by the quantum antenna and transformed by the two-body target in the far-field zone propagates to a pair of detectors capable of measuring the second-order intensity correlations between different spatial-temporal locations. Conventionally, the description of this transformation is based on a model of two point scatterers while neglecting their electromagnetic interaction (inter-body coupling). In this talk, we present a more realistic model of quantum sensing taking into account the finite size of the target and the inter-body coupling. We consider 2-D and 3-D configurations comprising pairs of parallel infinitely long identical perfectly conducting cylinders and identical dielectric spheres, respectively. Our analysis is based on the Fisher information and derives the Cramer-Rao bound for the inter-body distance estimation. For electromagnetic field calculation, we solve the boundary-value problem and represent the scattering using the characteristic modes.

The characteristic modes for the two-body target are obtained as sums of cylindrical/spherical harmonics. The coefficients are found from infinite systems of linear algebraic equations formed using the appropriate addition theorems. The approximate analytical solution is obtained for the small-radius small-distant cylinders/spheres. The operator of the scattering field is represented by a sum of characteristic modes with coefficients equal to creation-annihilation operators of excited states of quantum emitters. The Fisher information is expressed through the observable values of quantum field operator products for entangled states of quantum emitters.

We present the results of simulation of the Fisher information dependence on the inter-cylinder distance. We show that the inter-body coupling dramatically changes the scenario of quantum sensing. We demonstrate that “the Rayleigh curse” is not present when resolving two small scatterers in our scheme. These results indicate that quantum radars can achieve super-resolution in two-body target detection and recognition.