Covariance Estimation of Polarized Signals with Application to Vector Sensor Imaging

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This work is motivated by the vector sensor imaging problem: estimating the magnitude, polarization, and direction of plane wave sources from a sample covariance matrix of vector measurements. A vector sensor measures the electromagnetic field at a single point using three orthogonal dipole elements and three orthogonal loop elements with a common phase center, producing a six-element measurement vector. This vector represents the full state of the electromagnetic field at the sensor's location, including complete polarization information and sensitivity to signals arriving from all directions. The signals are modeled in terms of a collection of independent point sources distributed equally in angle on the surrounding sphere, and we seek to estimate the covariance of these sources in order to produce an intensity and polarization map as a function of direction of arrival.

There are two main challenges in solving this problem. First, the vector sensor measurements are an affine function of the unknown covariance, necessitating algorithmic approaches to the solution. Second, the unknown covariance is not diagonal despite the assumption that the sources are independent. This is because an orthogonal two-polarization basis is needed to represent each source, and those two values can be correlated.

We present iterative algorithms formulated in terms of Stokes parameters to address these challenges, enabling efficient solution of the vector sensor imaging problem in particular and covariance estimation of polarized signals in general. Existing techniques rely on the Expectation-Maximization (EM) algorithm and restriction to a limited set of polarizations, whereas this work expands the scope to arbitrary polarizations through Stokes parameters and introduces the use of proximal gradient algorithms. We also provide examples of vector sensor imaging using these techniques and discuss potential applications to radio astronomy, solar imaging, and meteor radar.