Design and optimization of polarimeters based on liquid-crystal displays

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Optical instruments capable of measuring polarization properties without moving parts avoid misalignments and make fast measurements with high accuracy.

Polarimeters are the basic instrument for polarization metrology. Determining the polarization of electromagnetic waves, and their interactions with materials, is important to many fields, including remote sensing of the earth and astronomical bodies,\textsuperscript{1} cancer diagnosis, human eye imaging,\textsuperscript{2} and material characterization of samples.\textsuperscript{3} Polarimeters exist in several different designs: they may consist of a rotating waveplate followed by a polarizer,\textsuperscript{2,3} an array of polarization analyzers in the focal plane,\textsuperscript{4} or a beam splitter followed by polarization analyzers.

Recently, we and others introduced liquid crystals (LCs), which are capable of polarization modulation, into polarimetric setups.\textsuperscript{1,5–8} An LC panel acts as a variable retarder, whose phase can be controlled electronically. Such a setup presents two important advantages. First, there is no mechanical motion of the optical elements. The polarimeter makes a measurement after modifying the phase of the light beam by sending different voltages to the LC panel. The negative effects of misaligned static elements are avoided by carrying out and accurately calibrating the polarization analyzers. Second, the design is versatile: it allows us to implement a wide range of retarders with the same LC element.

Polarimeters operate by acquiring flux measurements using a set of polarization analyzers. Noise in the flux measurement will be propagated during the data reduction process that results in the polarization measurement (Stokes vector of light or Mueller matrix of a sample, depending on what you are measuring). To minimize the noise, polarimeter optimization is recommended during the design of the setup. We have minimized two different figures of merit, the condition number (CN) and the equally weighted variance (EWV) of the polarimetric measurement matrix that describes our system, by optimizing the LC retardances and the orientation of the optical elements.\textsuperscript{5}

We have studied polarimeters based on two different types of LCs: the parallel aligned LC (PA-LC) and the twisted nematic LC (TN-LC), which behave as a linear and an elliptical retarder, respectively. First, we analyzed a polarimeter based on two PA-LCs oriented at 0 and 45°, followed by a polarizer at 0°: see Figure 1(a). This system\textsuperscript{6} allows us to implement any polarization analyzer by choosing the appropriate pair of voltages to be addressed to the variable retarders. We have observed that for a...
given number n of polarization analyzers, the optimal configuration is that one that maximizes the volume enclosed by the polarization analyzers represented on the Poincaré sphere. In the particular cases of n=4, 6, 8, 12, and 20, the figure corresponding to the volume limited by the polarization analyzers is the regular polyhedron of the same number of vertices (i.e., the Platonic solid). In addition, we have shown that for all these optimized configurations, the CN is constant at the minimum of 1.73. We used the EWV to account for redundant data. We also found that minimizing the variance of a specific Stokes parameter can be helpful in applications where only the detection of a particular range of polarization states is needed.

It was important to design a dynamic polarimeter using a single LC panel: this simplifies the design and reduces light loss and costs. The TN-LC fulfills that requirement. Its helicoidal structure introduces a retardance, and rotates the polarization ellipse orientation of the incident light. The polarimeter based on a single TN-LC panel and a polarizer is restricted to a certain set of polarization analyzers, so finding the best polarimeter architecture was essential. In particular, we have observed significant improvement by introducing oblique incidence—see Figure 1(b)—by forcing light to perform a double pass through the LC device and by including a quarter waveplate in the system.

In conclusion, we have designed polarimeters based on LC panels. Through optimization of the setup, we achieved a CN of 1.73 for a dual PA-LC-based polarimeter and a CN of 1.98 for a single TN-LC-based polarimeter. Next, we plan to work with the ferroelectric LCs, which have a faster response time than other LC elements, and therefore the potential to speed up the measurement process.

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References