SCD Calibration

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Objective

Polarimetric calibration of the SCD Instrument

This formulation is based on:

seminal paper by del Toro Iniesta and Collados (dTI&C), "Optimum modulation and demodulation matrices for solar polarimetry", App. Opt., 39, 1637, 2000

and presentation by deWijn on "The Concept of Optimal Calibration"

The notation of dTI&C will be used here. The matrix dimensions are row x column

Theory

- The measurement process is defined by $I_{meas} = O\ I_{in}$
- I_{in} is the Stokes vector (I,Q,U,V) input to the polarimeter (4 vector)
- O is the modulation matrix (n x 4 matrix)
- n is the number of modulation states
- I_{meas} is the vector of measured intensities (n vector)
- For SCD, n = 4

Theory

- The goal is to obtain I_{in} from I_{meas}
- This process is called demodulation
- We can define $I_{in} = D\ I_{meas}$
- Where D is the demodulation matrix (4 x n)
- dTI&C find that it is not feasible in general to obtain D by taking the inverse of O

Theory

- Instead dTI&C compute D from O by first computing the matrix $A = O^T O$ (4 x 4 matrix)

- Then $D = A^{-1} O^T = (O^T O)^{-1} O^T$

- The matrix A also contains valuable information about the efficiency of the polarimeter which relates to the noise on the demodulated Stokes vector (see dTI&C)

- The efficiencies are computed from the diagonal elements of A by $e_i = 1/(nA^{-1}{}_{i,i})$

Calibration

- Computation of D requires knowledge of O which is obtained by the calibration process

- For SCD calibration, we will assume that we know the properties (Mueller matrix vs. λ) of the calibration optics

- The λ dependence is important since the SCD was designed to have high polarimetric efficiency over the entire wavelength range, but D varies greatly with λ (see Tomczyk etal, JOSA, 2010)

- We will also (initially) assume that the light entering the polarimeter is unpolarized with Stokes vector [1,0,0,0]

Calibration

- Following deWijn we can draw an analogy to the dTI&C procedure and define a calibration matrix

- $C = [I_{in,1}\ I_{in,2}\ \ldots\ I_{in,m}]$, (4 x m matrix) where m is the number of calibration states and $I_{in,j}$ is the Stokes vector produced by calibration state j (for SCD, m = 6)

- $I_{in,j} = MM_j\ I_C$, where I_C is the Stokes vector of light entering the calibration optics and MM_j is the Mueller matrix of calibration state j (we are assuming $I_C = [1,0,0,0]$ initially)

- The m sets of measured intensities for the calibration are then $I_{meas,j} = O\ I_{in,j}$ or $I_{meas\ n,m} = O\ C$

Calibration

- where $I_{meas\ n,m}$ is a n row by m column matrix containing the n intensities for the m calibration states

- deWijn defines a matrix E (m x 4) such that
  $O = I_{meas\ n,m}\ E$

- then $O = O\ C\ E$ and $C\ E = 1$.

- E is the nominal inverse of C computed by
  $E = C^T (C\ C^T)^{-1}$ (the diagonal terms of $C\ C^T$ provide calibration efficiencies)

- and O can be computed by $O = I_{meas\ n,m}\ E$

Calibration Procedure

1. create $C = [I_{in,1}\ I_{in,2}\ \ldots\ I_{in,m}]$ matrix (4 x m) from the calibration optics Mueller matrices using $I_{in,j} = MM_j\ I_C$, assuming $I_C = [1,0,0,0]$

2. compute the E matrix (m x 4) from the C matrix using $E = C^T\ (C\ C^T)^{-1}$

3. create the $I_{meas\ n,m}$ matrix (n x m) from the calibration observations comprised of the n intensities for the m calibration states (after bias and flat correction)

4. compute the O matrix (n x 4) from $O = I_{meas\ n,m}\ E$

5. compute $A = O^T\ O$, then $D = A^{-1}\ O^T$

Consistency Check

- It is possible to check the consistency of the calibrations using the additional clear observed as part of the calibration scheme
- Apply the D matrix to the clear observation
- It should yield a Stokes vector very close to [1,0,0,0]
- If it does not, substitute the clear Stokes vector for I_c , go back to step 1 and recompute D
- Iterate if needed

Apply

- Now that D has been computed, it can be applied to the measurements

- Bias subtract and flat field divide the intensity vector I_{meas} at each pixel

- Apply the D matrix to obtain the Stokes vector

- Note that D may vary across the image and may need to be computed at various spatial points and interpolated

- D will need to be computed for each wavelength region but should not vary appreciably across a spectral line

Next Steps

- I recommend that 1 main program and 5 subroutines be written to perform SCD calibration
- The 5 subroutines will perform the 5 corresponding tasks on the Calibration Procedure slide
- Steve will write:
  - SCD_Create_Cmatrix
  - SCD_Compute_Ematrix
  - SCD_Compute_Omatrix
  - SCD_Compute_Dmatrix
  - That correspond to steps 1, 2, 4 and 5 respectively
- AISAS will write SCD_Get_Cal_Data that will perform step 3

Next Steps

- AISAS will write the SCD_Calibration main program that will call all of these routines
- My goal is to have a draft of the 4 routines by the end of next week
- All of this is up for discussion
- Comments and feedback are very welcome
- It is strongly recommended that all involved become very familiar with the dTI&C paper