A reduction pipeline for the polarimeter of the IAG

Edgar A. Ramírez

December 18, 2015

Abstract: This is an informal documentation for an INTERACTIVE DATA LANGUAGE (IDL) reduction PIPELINE (version 16.1) that analyse polarimetric data acquired with the optical polarimeter drawer of the Instituto de Astronomía, Geofísica e Ciências Atmosféricas (IAG) of the University of Sao Paulo (USP) mounted on the telescopes of the Observatorio dos Dias (OPD) operated by the Laboratório Nacional de Astrofísica (LNA) in Brazil.

1 Essential steeps

1) Make sure that IDL can find the routines by setting the path to the /PIPELINEV16.1 folder. The easiest way to do so is setting the path within an IDL terminal. For example, if SOLVEPOL.PRO is in /home/user/, make it visible to IDL typing:

   idl> !PATH = Expand_Path('+/home/user/pipeline/') + ':' + !PATH

2) Modify the path to the location of the polarimetrystdstars.dat file (this file is located in the distributed PIPELINE's folder) in the beginning (after the coments) of the SOLVEPOL.PRO file. For example, if polarimetrystdstars.dat is in /home/user/pipeline/, modify the path to:

   solvepolDir = '/home/user/pipeline/'

And that's it...ready to run!

The SOLVEPOL, MERGE and FILTER procedures run in terminal mode. SOLVEPOL is the main procedure of the PIPELINE. MERGE and FILTER are procedures to analyse the data/catalogues produced by SOLVEPOL.

2 Run requirements

SOLVEPOL requires internet connexion to have access to the Guide Star Catalog (GSC; version 2.3), and to retrieve a Digital Sky Survey (DSS) image of the analysed field. The GSCv2.3 catalogue is used to calculate the zero point magnitude. The DSS image (red image from the first generation survey) is used to create the polarisation map.

The IDL Astronomy libraries (`http://idlastro.gsfc.nasa.gov`; astron.dir.tar.gz) and the Coyote Graphics Library (coyote_astron.tar.gz) are required too. Download the gzip'ed tar files and place them in a directory that IDL can read. The IDL Astronomy Library site gives detailed instructions.

The ASTROMETRY.NET software is also required (`http://astrometry.net/use.html`). If you don't have ASTROMETRY.NET in your system, you still can use SOLVEPOL in interactive mode (see section 6). The installation of the ASTROMETRY.NET software will depends on your local system (Linux, Unix, or Mac). Follow the instructions given in the ASTROMETRY.NET software site (`http://astrometry.net/doc/build.html\#build`) for your local operational system.

More information and a pilot example of the use of the PIPELINE can be find `http://www.astro.iag.usp.br/~ramirez/pipeline.html`.

3 Solvepol

SOLVEPOL is the main procedure. It reduces the images, performs the polarimetry, photometry and astrometric properties, and produces the final catalogue and plots.
The calling sequence for SOLVEPOL is:

solvepol, objectfile, nreads=nreads, flats=flatfile, bias=biasfile, deltatheta=deltatheta, fluxsigma=fluxsigma, polsigma=polsigma, fwhm=fwhm, astrometry=astrometry, oplotid=oplotid, chisqrt=chisqrt , chisqrtint=chisqrtint

objectfile is a string with the name of the the text file listing the objects' names. For example, if your images are c08ia0001.fits, c08ib0002.fits ... c08ih0008.fits, the list in the file should be:

c08ia0001.fits
c08ib0002.fits
⋮
c08ih0008.fits

The list can be done redirecting the names of the images to a file by typing in a terminal:

User$ ls object_suffix*.fits > object.list

where object.list is the output file, and object_suffix is the common suffix name of the images. In this example would be c08i. Therefore, you could type:

User$ ls c08i*.fits > object.list

The syntax to run the PIPELINE for this case would be:

idl> solvepol, 'object.list'

The following values are optional.

nreads is the number of images per waveplate position. The list file must have the nreads images observed on the first position of the waveplate, followed by the nreads images observed on the second position of the waveplate, and so on. For example, if you observed 4 images on each 8 positions of the waveplate, the list should be like this:

c08ia0001_1.fits
c08ia0001_2.fits
c08ia0001_3.fits
c08ia0001_4.fits
c08ib0002_1.fits
c08ib0002_2.fits
c08ib0002_3.fits
c08ib0002_4.fits
⋮
c08ih0008_1.fits
c08ih0008_2.fits
c08ih0008_3.fits
c08ih0008_4.fits

The PIPELINE corrects for any shift between images per filter, and median combine the corrected images. The syntax to run PIPELINE would be (If your images are flat and bias corrected):

idl> solvepol, 'object.list', nreads= 4

flatfile is a string with the name of the the text file listing the flat fields' names or a string with the name of the master flat (flat_bias_combine.fits).

biasfile is a string with the name of the the text file listing the bias frames' names or a string with the name of the master bias (bias_zero.fits).

If flats and bias are provided, the imaging reduction procedure is executed. Otherwise, SOLVEPOL assumes that the images are bias an flat field corrected, and proceeds with the polarimetric analysis. Suppose you want to perform data reduction. In that case, text files listing the bias frames' names and the flat fields' names have to be provided. The text files listing the bias and flats frames' names can be created as in the example above. To perform data reduction, the calling sequence to run SOLVEPOL would be:

idl> solvepol, 'object.list', flats = 'flat.list', bias = 'bias.list'

or if you have your master flat and master bias from a previous reduction:

idl> solvepol,'object.list', bias = 'bias_zero.fits',flats = 'flat_bias_combine.fits'

A window will pop-up showing the fit of the over scan region.

deltatheta is a number with the correction angle in degrees. If not provided, the default is set to 00.0 degrees (no correction). To calibrate the position angle the syntax would be:

idl> solvepol,'object.list', bias = 'bias_zero.fits',flats = 'flat_bias_combine.fits', deltatheta=90.0

fluxsigma is the ratio of the flux and sigma flux, $flux/\sigma_{flux}$. It indicates the signal over the standard deviation from the mean sky value to detect the sources. If black the default fluxsigma = 2 is used.

polsigma is the ratio of the polarisation and error of the polarisation, p/σ_p. If black, the default is polsigma = 1 is used.

fwhm is the average full width at half maximum of the stars on the field. The PIPELINE calculates the fwhm, but it can be set by the user too.

astrometry is a flag to indicate whether you have ASTROMETRY.NET or not. If you have it, set astrometry = 'y' or /astrometry. For example:

idl> solvepol, 'object.list',astrometry='y'
or
idl> solvepol, 'object.list',/astrometry

If you don't have it, leave it blank. The PIPELINE will prompt the user for the .fits file with the astrometric information to continue (see Section 6).

oplotid is a flag that gives you the option to overplot the ID of the stars on the polarisation map. To plot the IDs set oplotid = 'y' or /oplotid. If blank the ID's are not going to be plotted (default).

chisqrt is the limit to reject stars whom chi-square of the fit of their modulation is greater than chisqrt. A plot is displayed to check the chi-square of all the stars. By default chisqrt is set to 6.0.

chisqrtint is a flag to choose the chisqrt limit in interactive mode. Set chisqrtlim to 'y' or /chisqrtint to run interactively. If blank the pipeline will not stop and the limit of chisqrt will be the default (6.0) or the value indicated in chisqrt.

Once you've set all your parameters, press enter to run the PIPELINE. The PIPELINE calculates the shift between the ordinary and extraordinary images in pixels. If the PIPELINE finds zero for the shifts, the user is prompted to answer if it is correct or not:

Are x shift and y shift correct? (y/n):

If y, the routine continues. If n, the PIPELINE prompts the user for the correct values:

Give x shift:
Give y shift:

Type your values and press enter to continue. The PIPELINE will plot and print to eps files many plots along the processing of the images (see `http://www.astro.iag.usp.br/~ramirez/pipeline.html` and bellow for explanation).

3.1 Output of solvepol

Output	Description
bias_flat_<objname>.fits	Reduced images.
bias_flat_<objname>mediancomb_ <waveplate_position_number>.fits	Reduced and median combined images, only if nreads were activated.
/solvepol/bias_zero.fits	Master bias.
/solvepol/flat_bias_combine.fits	Flat corrected by bias.
textXYsorted.list	Text list with the detected stars sorted out by brightness. Input of ASTROMETRY.NET.
fakesky.fits	The masked out image (alternative input to ASTROMETRY.NET).
/solvepol/<objname>.find	Find stars.
/solvepol/<objname>.cut	Find stars rejecting the vignetting.
/solvepol/<objname>.pair	List of pairs of stars.
/solvepol/<objname>.phot	Photometry of the stars.
/solvepol/<objname>.pol	Polarimetry of the stars.
/solvepol/magnitall.out	Table with: zero point magnitud; ID X Y RA DEC MAG of all the find stars (before P/sigmaP & chisqrt filtering).
/solvepol/magnitsigmaall.out	Table like magnitall.out with the error in magnitude, MAGSIGMA, included.
/solvepol/GSC2_3.txt	Table with 4 columns: V–mag V–mag–error RAJ2000 DECJ2000, of the stars on the field from GSC 2.3 catalogue.
/solvepol/<objname>fintab.out	The final catalogue (see below)
/solvepol/objectscombined.list	Text file listing the images product of median combine (only if nreads were activated).
/solvepol/objectsreduced.list	Text file listing the reduced images (only the images were reduced).
solvepol.log	log file with all the information displayed in the IDL terminal.

Added to these files, ASTROMETRY.NET produces output files. SOLVEPOL produces eps files of the plots (displayed on the screen too) described bellow:

Name	Description
<objname>magnitud.eps	Distribution of magnitudes.
<objname>magvscatmag.eps	The measured magnitude *vs* the magnitude of the GSC 2.3 catalogue, with their respective error bars. A dashed line equality correlation, and the solid line is the best linear fit without considering the magnitudes with $> 3\sigma$ in the measured magnitude.
<objname>magvspol.eps	Polarisation percentage *vs* magnitude.
<objname>sigmamagvspol.eps	Error of the polarisation *vs* magnitude.
<objname>plotvec.eps	Polarisation map over the red DSS image. A polarisation bar is on top of the image for reference.
<objname>polarisation.eps	Distribution of the polarisation.
<objname>pvectors.eps	polarisation vectors over the X and Y position of the sources.
<objname>QvsU.eps	The Q–U plane.
<objname>theta.eps	The distribution of the position angle theta (in degrees).

The final catalogue: <objname>fintab.out, contains the following columns:

ID	X (px)	Y (px)	RA(J2000) (degrees)	DEC(J2000) (degrees)	RA(1950) (HR,MIN,SEC)	DEC(1950) (DEC,MIN,SEC)	MAG (mag)	MAGSIGMA (mag)	P (frac)	PSIGMA (frac)	THETA (degrees)	TSIGMA (degrees)	Flux_o/sigma	Flux_e/sigma

Where ID is the identification of the stars; X and Y the position of the stars in pixels; RA(J2000) and DEC(J2000) and RA(1950) and DEC(1950) are the Right Ascension and Declination of the stars in the J2000 system and the 1950 system, respectively; MAG the optical magnitude; MAGSIGMA the error in the optical magnitude; P the polarisation fraction; PSIGMA the error in the polarisation; THETA the position angle of the polarisation; TSIGMA the error in the position angle; and Flux_o/sigma and Flux_e/sigma the flux of a star over the standard deviation from the mean of the sky of the ordinary and extraordinary images, respectively.

If the field has a standard star, SOLVEPOL detects it and prints its polarimetric properties (both from the literature and the measure) as well as the plot of its modulation.

4 Merge

MERGE merges of 2 catalogues calculating the weighted mean of the magnitude, polarisation, theta, Flux_o/sigma and Flux_e/sigma. The catalogues must have columns in the same format than the final table of SOLVEPOL (<objname>fintab.out). MERGE scans the catalogues and match the stars by their position Ra(J2000) and Dec(J2000) within a box with 0.002 degrees side centred in the position of the source given in catalogue 1. The calling sequence for MERGE is:

MERGE, fintab1, fintab2

where fintabN is an ASCII file (string). For example, to run MERGE to merge two catalogues called fintab1.out and fintab2.out type:

idl> merge, 'fintab1.out', 'fintab2.out'

4.1 Output of merge

The output of MERGE is a catalogue result of the merge of the two input catalogues. The name of the merged catalogue is <the name of the the first catalogue> + <the name of the second catalogue> + merge.txt appended at the end. The merged catalogue has the same columns as the output of SOLVEPOL (<objname>fintab.out), but with the weighted mean of the magnitude, polarisation, theta, Flux_o/sigma and Flux_e/sigma of those stars that match in the inputed two catalogues.

5 Filter

FILTER performs filtering of a catalogue within the limits provided by the user in interactive mode. The catalogue must have the same format as the final table of SOLVEPOL (<objname>fintab.out). The calling sequence for FILTER is:

FILTER, fintab1

where fintab1 is an ASCII file (string). To run FILTER on a catalogue called fintab1.out type:

idl> filter, 'fintab1.out'

MERGE prompts the user to set the following limits and conditions (default values in parenthesis).

Give me pol/sigma_pol value (1.0):
Give me the maximum pol value (in fraction, not in percentage) (1.0):
Give me the minimum pol value (in fraction, not in percentage) (0.0):
Give me the maximum sigma_pol value (in fraction, not in percentage) (1.0):
Give me the maximum optical magnitud value -dimmest star- (25.0):
Give me the minimum optical magnitud value -brightest star- (−13.0):
Give me the minimum theta value (0.0):
Give me the maximum theta value (180.0):
Give me Flux/sigma_sky value (1.0):

Then, MERGE asks the following:

Over plot gaussian fit on the distributions (y/n):

Choose your choice and press enter to continue. If yes (y) a Gaussian is fitted to the distributions of polarisation, theta and magnitude, and the Guassian parameters printed on the terminal. After that, you have the option to plot the polarisation map. If you want the polarisation map you have to give the astrometric information:

Image with the wcs information (usally is wcs.fits of fakesky.new.fits) only if you want to create the polarisation map:

If the astrometric information is not given, the polarisation map is not going to be produced.

5.1 Output of filter

The output of FILTER is a filtered catalogue by the limits given by the user. The name of the filtered catalogue is 'the name of the catalogue' + '_filtered.out' appended at the end. The filtered catalogue contains the same number of columns as the '<objname>fintab.out' catalogue. FILTER displays plots on the screen and generates eps files.

6 The wcs

The astrometry is solved using ASTROMETRY.NET. For computers that don't have the ASTROMETRY.NET software installed, the PIPELINE asks for an image with the world coordinate system (wcs) information.

Give me the wcs.fits (output of astrometry.net):

The fits file with the wcs can be obtained from the ASTROMETRY.NET site (`http://nova.astrometry.net/upload`). I recommend that you upload the textXYsorted.list file or the masked image fakesky.fits, both generated by SOLVEPOL, to the ASTROMETRY.NET site because textXYsorted.list and fakesky.fits have one of the two images of the stars masked out, making the astrometric solution consistent with the x shift and y shift.

Once the ASTROMETRY.NET has processed the textXYsorted.list or the image fakesky.fits, download and give the wcs.fits or the fakesky.new.fits to the PIPELINE and press enter to continue.