MetroPSF 0.14

M. Usatov

maxim.usatov@bcsatellite.net

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1 Introduction

MetroPSF is an open source astronomical photometry program. It's goal is providing a convenient and intuitive graphical user interface to algorithms implemented in photutils (Bradley et al., 2020), in particular iteratively subtracted point spread function (PSF) photometry—a variant of the DAOPHOT algorithm by Stetson (1987) for PSF photometry in crowded fields.

MetroPSF can perform blind astrometric calibration of images via Astrometry.net service (Lang et al., 2010), request comparison photometry data from various catalogs in VizieR (Ochsenbein et al., 2000), match sources and perform differential photometry via linear regression fits to a weighted ensemble of sources. Such differential ensemble photometry method is described by Paxson (2010). It can also generate photometry reports compliant with British Astronomy Association's (BAA) Photometry Database submission guidelines.

The program is developed using Python's standard Tkinter graphical user interface and relies on a rather conservative subset of astronomical and data processing libraries to work that are typically well-maintained. The program is currently in the stage of a working prototype that requires further development and code refactoring. Feedback and suggestions are very welcome. MetroPSF is confirmed to work on Windows, Linux and FreeBSD operating systems and is, in principle, compatible with all operating systems capable of installing Python and the Astropy,[1] package for astronomy (Astropy Collaboration et al., 2013, 2018).

2 Installation

The MetroPSF distribution archive holds a single Python file with the program and the `requirements.txt` file to automate library installation. The installation steps are as following:

1. Install Python language interpreter from `https://www.python.org/downloads/`. For full memory access, 64-bit version is recommended. Unix-like operating systems may require installation via OS's package or ports manager.

2. Extract the MetroPSF distribution archive.

3. Run `pip install -r requirements.txt` command in the folder with MetroPSF files. This will automatically install all the required libraries.

Now you are ready to run MetroPSF. On Windows, double click on the program file. On Unix-like systems you may need to run it via `python` shell command.

3 Quick Start

A simple photometry workflow in MetroPSF can be described as following:

1. Load your FITS data using the File / Open menu.

2. Adjust PSF fitting width and height and full-width at half-maximum (FWHM) in the left-side panel. Provide your best estimates for the data. The rectangular fitting shape should contain stellar images of target magnitude.

[1]http://www.astropy.org

3. Double-check CCD filter and exposure time are set correctly in the left-side panel. These are taken automatically from the FITS header when present.

4. In the Photometry menu, select Iteratively Subtracted PSF Photometry. This performs background extraction, source location, Gaussian PSF fitting and flux determination. Photometry results with instrumental magnitudes are then saved in a file with the `.phot` extension added to the file name of the FITS data.

5. If your image does not have astrometic calibration, in the Photometry menu, select Solve Image. After solving you may want to save your FITS to preserve the World Coordinate System (WCS) header data.

6. In the Photometry menu, select Get Comparison Stars. This submits a request to the VizieR to download data for all the sources within the field of view, in the set filter. The sources obtained are matched automatically to those detected in the image in order to create a comparison ensemble. The matching radius is set in the left panel, by default equals $2''$.

7. Finally, in the Photometry menu, select Find Regression Model to build a linear regression fit to the ensemble. This allows to derive differential magnitudes from instrumental magnitudes. The linear regression fit is plotted in the right-side panel.

At this step, the photometry process is, in principle, complete. You can click on the sources detected in the image to obtain differential magnitudes, uncertainities and information on any matches with the selected VizieR catalog. Of course, real photometry will require adjustment of various parameters to fit seeing conditions, data and the nature of sources.

Note that filling pink input fields in the MetroPSF interface are required only for report generation, such as described in §4.4.1. They can be left empty if report generation is not intended.

4 Functionality

4.1 File Menu

4.1.1 Open, Save and Save As

This menu allows to open and save FITS files with images. Saving the file also saves FITS header currently in memory. WCS header data after the image is solved is appended to the existing header.

4.1.2 Load Settings, Save Settings As

For user convenience, it is possible to save MetroPSF session settings to an external file and load them later. Saved settings include all visible fields except CCD Filter and Exposure Start, which are pre-filled automatically when a FITS file is loaded; and Image Stretching settings for histogram stretching in the right panel, which are generally adjusted each time to a particular data.

4.2 View Menu

The view menu allows to Update the current view with the plot of the FITS data and overlaid photometry results, if available. Zoom items adjust the current view. Note histogram stretch sliders are available in the right panel to adjust the view of the data.

4.3 Photometry Menu

4.3.1 Iteratively Subtracted PSF Photometry

Performs the Iteratively Subtracted PSF Photometry procedure from PHOTUTILS. This is a variant of the DAOPHOT algorithm described by Stetson (1987) for PSF photometry in crowded fields. First, sources are found in the data via the IRAF's STARFINDER algorithm using a 2-dimensional circular Gaussian kernel to approximate PSFs. Local density maxima are searched for exceeding the threshold set in the Star Detection Threshold field in the left panel, above sky background. Overdensities at this step are expected to have PSF FWHM roughly similiar to the FWHM input in the left panel. Objects are expected to be sharper than the Lower Bound for Sharpness setting, which is by default set to 0.5 to avoid hot pixels. This setting can be lowered to detect sources with sharper response.

Next, a 2-dimensional low-resolution sky background map is constructed using the BACKGROUND2D class in PHOTUTILS. Sigma clipping with $\sigma = 3.0$ is used at this step. The low-resolution background map is then filtered via median filter and, finally, interpolated to the full image size. The median filter size is specified in the Background Median Filter setting in the left panel. The filter by default is set to 1 which means no filtering.

Finally, PSF photometry is performed on an image and sources detected, with sky background map subtracted first from the raw image. A 2D circular Gaussian model with variable σ is used for fitting. The PSF fitting is done using the Levenberg-Marquardt algorithm and least squares statistic for the amount of iterations specified in the Photometry Iterations setting in the left panel. The fitting is done using a box shape with side dimension specifed in the Fitting Width/Height setting.

Once photometry process is complete, the photometry results table is formed with x, y pixel centroids and fitted flux in ADU and instrumental magnitude per each source. All detected sources are marked with grey circles on the view. The photometry table is saved to the same file name as the FITS data with the addition of `.phot` extension.

4.3.2 Plot and Hide

These items allow to plot and hide photometry results. When photometry is plotted, it is read from the `.phot` file each time. All detected sources are shown in grey, while sources having catalog matches are shown in green, and those having matches in the AAVSO The International Variable Star Index (VSX) catalog (Watson et al., 2006) database are shown in yellow.

4.3.3 Solve Image

Obtains blind astrometric calibration of the current image via Astrometry.net service. No input or initial guess is required. A list of sources from the photometry results table is sorted by flux with brightest sources first, and the list submitted to the Astrometry.net server. A solution is obtained and converted to WCS header which is then used to convert image pixel coordinates to celestial coordinates.

4.3.4 Get Comparison Stars

Retreives a list of stars in the field of view from the catalog specified in the Comparison Catalog in the right panel. By default the AAVSO Photometric All Sky Survey (APASS) DR9 catalog (Henden et al., 2015) is used. MetroPSF can also work with the Gaia DR2 (Gaia Collaboration et al., 2018), the First U.S. Naval Observatory Robotic Astrometric Telescope URAT1 (Zacharias et al., 2015) and the USNO-B1.0 catalogs (Monet et al., 2003). It is also possible to specify a custom VizieR catalog[2] by selecting VizieR Catalog in the Comparison Catalog setting. For example, for The SDSS Photometric Catalog, Release 8 (Adelman-McCarthy & et al., 2011), enter "II/306" in the Vizier Catalog Number input field. It is assumed that VizieR provides coordinates via RAJ2000 and DEJ2000 columns in custom catalogs.

Sources found in the originial data with catalog matches are shown in green, and those without matches, in grey. The matching radius used in this procedure is set in the left panel, by default set to $2''$. Note that MetroPSF searches for catalog magnitudes using the filter string specified in the CCD Filter setting in the left panel. For example, with "V" as the input, MetroPSF will search for "Vmag" in the VizieR catalog. The CCD Filter setting is pre-filled automatically when the FITS file is loaded, but if the filter information is inaccurate or not present it is possible to specify the filter manually.

4.3.5 Find Regression Model

With photometry table containing magnitudes from a matching catalog, it is now possible to do a linear regression fit to derive conversion parameters between instrumental and differential magnitudes. The minimum and maximum ensemble magnitudes are specified in the corresponding settings in the left panel.

Ensemble weighting is specified in the right panel, which is by default set to use no weighting. With Raw Flux weighting, comparison mangitudes will be weighed proportionally to the measured source flux in the original FITS data at the coordinate centroid reported by the PSF fitting algorithm. Instrumental magnitude weighting will introduce weights into the fit equal to the inverse magnitudes from the photometry table. PSF σ weighting uses inverse of the fitted PSF σ.

It is possible to exclude stars from the AAVSO VSX catalog by selecting Ignore VSX Sources in Ensemble in the right panel. Note that stars with matching VSX object are plotted with yellow circles.

The photometry ensemble can be limited to a certain number of stars via the Limite Ensemble to setting in the left panel. This works only when a weighting option is selected. For example, with instrumental magnitudes selected as a weighting factor, only n brightest stars will be selected for the ensemble. By default the limit is set to $n = 1000$ and can be set to an arbitrarily high number, if desired, to include all stars into the ensemble.

Once the fit is done, it is plotted on the right panel. Linear regression coefficients and the fit's coefficient of determination, r^2, are reported in the console to analyze its goodness. The photometry results table (the `.phot` file) is automatically updated with differential magnitudes and errors. With the new data now it is possible to click on sources in the image and obtain differential magnitudes and uncertainites. Linear regression fit error, σ_{fit} is estimated as the mean of differences between the derived and the comparison catalog magnitudes for all the sources in the ensemble (Paxson, 2010). The total magnitude uncertainty reported is, then

$$\sigma_{total} \approx \sqrt{\sigma_{flux}^2 + \sigma_{fit}^2}, \qquad (1)$$

[2] A list of catalogs in VizieR can be obtained from http://cdsarc.u-strasbg.fr/cats/cats.html

where σ_{flux} is PSF flux fit uncertainty reported by the PSF photometry algorithm, translated into magnitude scale using the linear regression fit parameters.

When a source is clicked, the Gaussian PSF fit σ is also reported in the console, and a three-dimensional plot of FITS data at this coordinate is displayed in the right panel. If the fit σ exceeds the median of σ values by 20% then a warning message is displayed in the console to warn the user that, perhaps, CCD might have entered a non-linear regime with this source, or background subtraction was not entirely successful.

Note that it is possible to improve uncertainities by reducing the magnitude range of stars in the ensemble. However, the range must be kept reasonably close to the target source's magnitude.

MetroPSF will report magnitudes with rounding to decimal places set in the Decimal Places to Report field in the left panel.

4.3.6 Delete Photometry File

This menu item deletes the photometry results table—the `.phot` file. This resets all the data produced by the program for the currently open FITS file.

4.3.7 Display Background Image

Displays the background image used to subtract from the original FITS data for the photometry. Use the Update item in the View menu to return to the original data view. Note background images are not saved.

4.4 Report Menu

4.4.1 Generate BAA Report

MetroPSF can generate a text report file compliant with BAA Photometry Database submission requirements. The current file layout used is CCD/DSLR v2.01. For the report, differential photometry generated from the last mouse click on a source is used. Object name is set in the left panel, along with observatory and observer settings. Exposure Start Date is pre-filled from the FITS header automatically. MetroPSF generates a .txt report file with the filename equal to the currently open FITS file. For Chart ID, the current comparison catalog and the center of frame is reported, along with the field of view, expressed in minutes of arc.

4.5 Miscellaneous Functions

4.5.1 Report VSX Sources Nearby

Enabling this checkbox will make MetroPSF report any VSX catalog entries within 30″from the clicked source. This may be useful to retrieve information about, for example, past supernovae in the galaxy.

4.5.2 Image Stretching

In addition to linear stretching with sliders in the right panel, MetroPSF offers non-linear functions to modify screen transfer for user convenience when analyzing high dynamic range images. These functions include square root, log and the inverse hyperbolic sine, arcsinh. Note this modifies only the screen representation without changing the underlying FITS data.

5 Change Log

5.1 Version 0.14

- Reporting PSF flux fit error. Total photometry error reported now is the square root of sum of squares of the PSF flux fit error and the linear regression fit error.
- Load and save settings.
- BAA Photometry Database report generation.
- Added decimal places to report setting.
- Explicit UTF-8 declaration in the Python file.

5.2 Version 0.13

- Added ensemble limit option.
- Added Gaia DR2 to comparison catalogs.
- Added non-linear image stretching via square root, log and asinh.

5.3 Version 0.12

- Added ability to remove AAVSO VSX stars from the ensemble.
- Sources with AAVSO VSX match are plotted with yellow circles.
- Added reporting of nearby VSX sources.
- Added matching radius setting.
- Fixed loading of 16-bit FITS files.
- Various bugfixes.

5.4 Version 0.11

- Initial Release.

6 Final Notes

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