DIAPL2

Difference Image Analysis Package

Wojtek Pych

http://users.camk.edu.pl/pych/DIAPL/

email: pych@camk.edu.pl

Last update March 14, 2016

Table of Contents

1 Introduction

A Method for Optimal Image Subtraction was described by ***Christophe Alard and Robert H. Lupton in 1998, Astrophysical Journal v.503, p.325*** and by ***Christophe Alard in 2000, Astronomy and Astrophysics Supplement, v.144, p.363***. The **DIA** package is an implementation of this method written by Przemek Woźniak and described in ***P.R. Woźniak, 2000, Acta Astronomica, v. 50, p. 421***. The **DIAPL2** package by Wojtek Pych is a new version of **DIAPL**, which in turn has been an improved and more versatile version of **DIA**. In this implementation the input images can be automatically divided into smaller sub-images. This helps in a proper treatment of the rapidly variable PSF (Point Spread Function) in the processed images. It is designed to process direct imaging frames rather than drift-scan images.

This software has been originally written, compiled and tested running Fedora Core and Ubuntu Linux.

1.1 Instructions for the observers

It is important to follow some rules when preparing observational data for image subtraction. The basic ones are as follows:

- Relative shifts between images of the same field should be as small as possible. The larger the shifts the smaller effective field to be analyzed.
- Try to avoid rotation of the observed field. Current algorithms of the image registration used in DIAPL2 are capable to correct for small rotations up to few degrees only.
- The observed flux of the “constant” stars should be kept on similar level on all frames. This requires active tests of the observed flux at the telescope. This flux may depend on the transparency of the atmosphere etc.

1.2 Major differences between DIAPL and DIAPL2

- New algorithms in programs: `sfind`, `xymatch`, `resamplem`, `mstack`, `phot`
- Bad pixel mask with proper transformations throughout the whole pipeline
- New set of `bash` scripts instead of `tcsh` scripts
- Cross-correlation not used for astrometric transformations
- Modified lists of input parameters for many programs

2 Installation

2.1 Downloading the sources

The package may be downloaded from the following web-page: *http://ftp.camk.edu.pl/camk/pych/DIAPL*
The `diapl2_src.tgz` file is a gzip-compressed tar file, which contains the sources. It may be unpacked using a command:

```
tar -xvzf diapl2_src.tgz
```

Several subdirectories containing sources of the programs and default parameter files are created.

2.2 Compilation

The software has been prepared to be compiled using GNU C and C++ compiler on a PC running Linux. The compilation procedure is started using a command:

```
install.bash
```

If everything is correct there should be no error nor warning messages during this process. All the resulting binary executable files are moved into subdirectory: '`./DIAPL_BIN`'.

3 Typical run

3.1 A sequence of the scripts to be executed

Please read full description of the scripts in the appropriate sections of this manual.

1. `fwhms.bash`
   Calculate FWHM and background level for all images from the input list.
2. `mktpllist.bash`
   Prepare a preliminary list of template images.
3. `shifts.bash`
   Find linear shifts and light flux ratios between the images and the astrometric reference frame.
4. `template.bash`
   Prepare template images for the subtraction.
5. `subtract.bash`
   Subtract the template image from all of the images.
6. `findvar.bash`
   Find variable stars in the subtracted images.
7. `phot.bash`
   Calculate aperture and profile photometry of the selected objects in the subtracted images.

3.2 Detailed description of the process steps

3.2.1 Prepare the data and working directories

Original observational data should be gathered in a dedicated directory. This directory should be other than the working directory. This is because DIAPL2 software modifies input frames and writes them into working directory without changing their names. Putting the original data into the working directory would result in a loss of the source frames. Working directory is a place where everything happens.
In the beginning the user has to copy into this directory the following files:

- all of the script files from the source `SCRIPTS` subdirectory, together with `Func` subdirectory,
- all of the parameter files from the source `PARS` subdirectory.

After the whole processing is finished the results are stored in the working directory.

3.2.2 Edit the instrument parameters file

An example file: `instrument.par` is located in the `PARS` subdirectory of this distribution.

Keyword	*Description*
GAIN	Camera gain [electrons/ADU]
MIN_LEVEL	Minimum valid counts
SAT_LEVEL	Maximum valid counts This number should not be larger than maximum count from a given detector in the frames.
NX	Length of the X-axis side of the sub-images in pixels. This number should be selected accordingly to the size of the whole images. For instance: if the NAXIS1 in the input image is 1024, then NX=512 is much better than NX=500 because the latter one will result in the last column of sub-frames being too small for correct analysis. NX=520 would be acceptable but not optimal.
NY	Length of the Y-axis side of the sub-images in pixels. This number should be selected accordingly to the size of the whole images. For instance: if the

Keyword	*Description*
	NAXIS2 in the input image is 2048, then NY=512 is much better than NY=500 because the latter one will result in the last row of sub-frames being too small for correct analysis. NY=520 would be acceptable but not optimal.
MARG	Size of the overlapping strip between the sub-images. This number should be selected depending on the density of stars in the analyzed field and possible rotation between the images.
FITS	The default extension of the names of the FITS files.

3.2.3 Edit the setup parameters file

The file: `diapl_setup.par` is located in the `PARS` subdirectory of this distribution contains sugested values of the most of the parameters. Some of them however need to be adjusted to the actual case.
The user has to supply the following information:

Keyword	*Description*
DATA_DIR	Full path to the directory where the FITS files containing the input images are stored.
BIN	A path to the directory where the binary executable files from the DIAPL package are stored.
INSTRUMENT	A name of the file containing parameters for a particular instrument.
FIELD	The name of the analyzed field. This is a name prefix of the output photometric database.
REFIM	The name of astrometric reference image for the geometric transformation of the analyzed images.
IMAGES	The name of the input text file containing the list of the input FITS files with images to be processed.
TPLIMAGES	The name of the input text file containing the list of the input images to be averaged in order to create a template image for the subtraction.
REFWHM	The name of a text file containing the information of FWHM and background level in the reference image.
FWHMS	The name of a text file containing the list of frames with FWHM and background level calculated. This file is to be created by `mktpllist.bash`.
SHIFTS	The name of a text file containing the information on shifts between the images. This file is to be created by the `shifts.bash` script.
RIMAGES	The name of a text file containing the names of the frames transformed to the coordinates of the reference image. This file is to be created by the `subtract.bash` script.
MASK	A string or a single character to be added to the filenames of the images when the mask images are created.
TPLNAME	The name of the template image. The template image is created by the `template.bash` script.
EDGE	Stars lying closer to the edge of a frame than this number of pixels are not taken into account for PSF modeling and photometry.
MINSTARS	Minimum number of stars found in a given image to be accepted for further analysis.
RMTMP	Remove temporary files created in the scripts. Possible values are `"yes"` or `"no"`.
VERBOSE	Verbose flag for the scripts. Possible values are `"-v"` or `""`

Hint: REFIM The name of the reference image may be set after execution of the mktpllist.bash and selecting the best frame. In such a case the user has to ignore the warning messages in the earlier steps.

3.2.4 Prepare a list of images to be processed

The name of the file containing the list should be the same as set by the parameter `IMAGES` in `diapl_setup.par` (default `images.txt`). Since the path is set by the parameter `DATA_DIR` parameter in `diapl_setup.par` the list has to contain the file names only, without the path. The names of the images should be inserted one per line. This list should be placed in the working directory.

3.2.5 Prepare a text file containing the coordinates of bad pixels

The name of this file should be `bmask.par`.
The file should contain 4 columns with integer numbers defining bad pixel rectangles:

1. starting X-coordinate,
2. ending X-coordinate,
3. starting Y-coordinate,
4. ending Y-coordinate.

3.2.6 Execute the fwhms.bash script

The `fwhms.bash` script is prepared to create a bad pixel mask and calculate FWHM and background level for each of the images.

The first step in the processing of the images is to create a mask of bad pixels. The program `bmask` reads the bad pixel areas coordinates from an ASCII text file with the name defined by the parameter `BADPIX` in `diapl_setup.par`. Then it creates a FITS file for every frame containing the bad pixel mask.

In the next step an average FWHM of the point spread function and sky background level are calculated for images in the input list. Some input parameters should be set in the file `fwhm.par` (see the description of the `fwhm` program). The output file contains a list of all images for which FWHM and background level has been successfully determined – the name of this file is set by the parameter `FWHMS` in `diapl_setup.par`. The list consists of 5 columns with the following information:

1. file name,
2. mean FWHM,
3. background level,
4. median FWHM,
5. number of stars used in the average.

3.2.7 Prepare a list of template images

A preliminary list of template images may be prepared using the script `mktpllist.bash`. It is strongly advised to visually check the selected images for a presence of traces of satellites, large relative shifts etc. and then to leave the best frames only: small FWHM, low background level, low air-mass etc.

The script `mktpllist.bash` contains 2 parameters which may be adjusted:

- **BKG_PERCENT** – a percentage of low background frames to be selected
- **FWHM_PERCENT** – a percentage of small FWHM frames to be selected

The output file contains a list of potentially good template images – the name of this file is set by the parameter `TPLIMAGES` in `diapl_setup.par`. This list is a subset of the FWHM list.

3.2.8 Edit the setup parameters file: diapl_setup.par again

Insert the name of the astrometric reference file into `REFIM` parameter in `diapl_setup.par`.

3.2.9 Calculate linear components of the astrometric transformation between the images and the reference image

Use the script `shifts.bash`. Relative shifts between images from the FWHM list and the astrometric reference image are calculated. The name of the file containing the input list is given by the parameter `FWHMS` in

diapl_setup.par.

Relevant parameter files to be edited: sfind.par, xymatch.par

3.2.10 Create a template image

Use the script template.bash.
Images from the list of the template images are transformed to the position of the astrometric reference and then stacked to create a single template image. The final image may be free of cosmic ray traces, depending on the parameters in mstack.par. A PSF model depending on the position in the template image is calculated.
Relevant parameter files to be edited: sfind.par, xymatch.par, xygrid.par, resample2.par, mstack.par, getpsf.par.

3.2.11 Subtract a transformed template image from all images

Use the script subtract.bash.

The images are transformed onto the position of the astrometric reference image. Then the template is transformed to match the PSF of a given image and subtracted from it.
Relevant parameter files to be edited: sfind.par, xymatch.par, xygrid.par, resample2.par, aga.par

3.2.12 Find variable stars

Use the program vminmax to create a map of variability.

3.2.13 Compute the photometry of the selected objects

Prepare a text file with the list of stars to be measured in the format: number(int) X(float) Y(float).

The name of this file must begin with the prefix given by the FIELD parameter in diapl_setup.par, followed by the subsection number and the suffix ".coo".

Use the script phot.bash. The results are stored in the separate file for each sub-frame. The names of these files begin with the field name (parameter FIELD in diapl_setup.par). Then the number of the sub-frame follows. The extension is ".db".

4 Description of the scripts

4.1 diapl_setup.bash

4.1.1 General description

This script sets several bash environment variables needed for the other scripts in the pipeline.

4.1.2 Input files

- diapl_setup.par
- instrument setup parameters file (default instrument.par)
- reference image (file name defined in diapl_setup.par)
- reference FWHM information file (file name defined in diapl_setup.par)

4.1.3 Compiled programs used in the script

The program fitshedit is used in this script.

4.2 fwhms.bash

4.2.1 General description

This script creates a separate image with a bad pixel map for each of the images in the input list. In the second step it creates a list of images for which mean FWHM and sky background level have been successfully calculated.
User can edit this script and modify the following parameter:

FWHM_LOG A name of the output file containing the information on the FWHM and background level values for all of the images in the list. Depending on the input parameters there may be some number of frames for which the program fail to calculate FWHM or background level.
This file is just for information and is not used in further steps.

4.2.2 Input files

An ASCII text file with a list of images to be processed. The name of this file is defined by the parameter `IMAGES` in `diapl_setup.par` (default `images.txt`).

4.2.3 Output files

1. An ASCII text file with a list of images with FWHM and sky background successfully calculated (possibly not all images from the input list). The name of this file is defined by the parameter `FWHMS` in `diapl_setup.par`. The file contains 5 columns with the following information:
   a) file name,
   b) mean FWHM,
   c) background level,
   d) median FWHM,
   e) number of stars used in average.
2. An ASCII text file with a list of all images from the input list and the results of the `fwhm` program for them – even the unsuccessful ones. It is left for the user inspection only and is not further used by DIAPL software. The name of this file is defined in the beginning of the script (default: `fwhm.log`).

4.2.4 Compiled programs used in the script

The programs: `bmask` and `fwhmm` are used in this script.
Relevant parameter files: `bmask.par` and `fwhmm.par`

NOTE: The script works properly only when the VERBOSE parameter in the `fwhmm.par` is set to 0.

4.3 mktpllist.bash

4.3.1 General description

This script prepares a preliminary list of the images with low sky background level and small FWHM from the list of all images. Since the images automatically selected may contain traces of the satellites or other unwanted features the resulting list should be treated as the input list for more detailed/visual inspection. The gain of this script is the reduction of number of images left for the inspection.
User can edit this script and change the following parameters:

BKG_PERCENT An integer number giving the percent of low background images selected from the total number of images.

FWHM_PERCENT An integer number giving the percent of small FWHM images selected from the total number of images.

NOTE: If FWHM_PERCENT is smaller than BKG_PERCENT then it has no effect.

4.3.2 Input file

An ASCII text file with a list of images with FWHM and sky background information. The name of this file is defined by the parameter `FWHMS` in `diapl_setup.par`. The the default is the output file from the `fwhms.bash`.

4.3.3 Output file

An ASCII text file with a preliminary list of template images. The name of this file is defined by the parameter `TPLIMAGES` in `diapl_setup.par`. This file is a subset of the input file.

4.4 shifts.bash

4.4.1 General description

This script is used to estimate linear shifts between the processed frames and the astrometric reference image.

4.4.2 Input file

An ASCII text file containing a list of images with FWHM and sky background information. The name of this file is defined by the parameter `FWHMS` in `diapl_setup.par`. This is the output file from the `fwhms.bash`, by default.

4.4.3 Output files

1. An ASCII text file containing a list of images with relative linear shifts and light flux ratios in respect to the astrometric reference together with information on FWHM and sky background. The name of this file is defined by the parameter `SHIFTS` in `diapl_setup.par` (default shifts.txt). The file contains 7 columns with the following information:
   a) image file name,
   b) shift in the X direction,
   c) shift in the Y direction,
   d) ratio of the total flux in a number of stars to the total flux of the same stars in the reference image,
   e) median FWHM,
   f) number of stars selected for the FWHM calculation.
2. An ASCII text file containing output from `xymatch` for all of the processed images. The name of this file is defined in the beginning of `shifts.bash` script (default: `xymatch_shifts.log`).

4.4.4 Compiled programs used in the script

The programs: `sfind, xymatch` are used in this script.
Relevant parameter files: `sfind.par`, `xymatch.par`

4.5 template.bash

4.5.1 General description

This script creates a template image. The template image is then scaled and subtracted from each of the processed images in the `subtract.bash` script.
User can edit this script and change the following parameters:

TRIMFILES	A name for the output text file containing the list of trimmed sub-frames.
STACKLIST	A name for the output text file containing the list of stacked sub-frames.
SHIFT_LOG	A name prefix for the output text file containing the information on shifts between sub-frames.

4.5.2 Input file

An ASCII text file with a list of the images to be stacked. The name of this file is defined by the parameter `SHIFTS` in

diapl_setup.par.

4.5.3 Output files

- A set of template sub-images.
- A template image. The name of the file is defined in the beginning of the script: parameter: TEMPLATE. Inspection of the image may shed some light on the quality of the template. This image is not further used by DIAPL software.

4.5.4 Temporary files

A set of ASCII text files with the names defined in the beginning of the script by the following parameters: TRIMFILES, STACKLIST, SHIFT_LOG.

4.5.5 Compiled programs used in the script

The following programs: mkshortone, fwhmm, cutfitsim, sfind, im2float, xymatch, xygrid, resample2, mstack, getpsf, template are used in this script.

Relevant parameter files: fwhm.par, sfind.par, xymatch.par, xygrid.par, resample2.par, mstack.par, getpsf.par

4.6 subtract.bash

4.6.1 General description

This script is used to subtract the template image from all images in the list created by the script shifts.bash.

4.6.2 Input file

An ASCII text file containing a list of images with relative linear shifts and light flux ratios in respect to the astrometric reference plus information on FWHM and sky background. The name of this file is defined by the parameter SHIFTS in diapl_setup.par.

4.6.3 Output files

A set of template-subtracted sub-images.

4.6.4 Temporary file

An ASCII text file with the name defined in the beginning of the script by the parameter CORR (default: corr.txt).

4.6.5 Compiled programs used in the script

The following programs: cutfitsim, sfind, im2float, xymatch, xygrid, resample2, aga are used in this script.
Relevant parameter files: sfind.par, xymatch.par, xygrid.par, resample2.par, aga.par

4.7 phot.bash

4.7.1 General description

This script is used to compute the photometry of the stars. The results are stored in the separate file for each sub-frame. The names of these files begin with the field name (parameter FIELD in diapl_setup.par). Then the number of the sub-frame follows. The extension is ".db".

4.7.2 Input file

An ASCII text file containing a list of images with relative linear shifts and light flux ratios in respect to the astrometric

reference plus information on FWHM and sky background. The name of this file is defined by the parameter `SHIFTS` in `diapl_setup.par`.

4.7.3 Output files

A set of photometry database files for each of the subsection of the input images.

4.7.4 Temporary file

An ASCII text file with the name defined in the beginning of the script by the parameter `PHOTIMAGES` (default: `photimages.txt`).

4.7.5 Compiled programs used in the script

The program: `phot` is used in this script.
Relevant parameter file: `phot.par`

5 Description of the compiled programs

5.1 aga

5.1.1 Command line arguments

```
aga parameter_file instrument_file mask_image template_image image_names_file
```

parameter_file:	name of the input text file containing parameters (default `aga.par`)
instrument_file:	name of the text file containing instrument related parameters (default `instrument.par`)
mask_image:	name of the FITS file containing bad pixels mask
template_image:	name of the FITS file containing the template image
image_names_file:	name of the text file containing the list of FITS file names with images to be processed

5.1.2 General description

This program performs subtraction of a template image from the image being processed for the photometry purposes.

5.1.3 Input files

Here is a short description of example content of the program parameters file (`aga.par`):

Keyword	Default value	Description
KER_HW	15	convolution kernel half width [pixels]
N_COMP	3	number of components of kernel convolution (Gaussian functions modified by polynomials)
DEG_1	4	first polynomial degree
SIG_GAUSS_1	0.78	sigma for first Gaussian
DEG_INC	-1	degree increment between subsequent polynomials
SIG_GAUSS_INC	1.73	sigma increment of subsequent Gaussian functions
BKG_DEG	1	degree of the polynomial that describes background dependence on (X,Y) (when sky has gradients set larger values)
BAD_VALUE	65000	value assigned to bad pixels
BAD_GROWRAD1	2	radius around bad pixel where BAD_VALUE is assigned (for the analyzed frame)

Keyword	Default value	Description
BAD_GROWRAD2	2	the same as above but for the subtracted frame
MIN_AREA	0.4	minimum area with good pixels required to perform subtraction
MAX_NITER	3	maximum number of iteration for cleaning pixel distribution inside a domain
N_SIG	3.0	sigma multiplicity for pixels distribution cleaning inside domain
MAX_CHI2	8.0	maximum χ^2 allowed for the correct subtraction
WDEG_SPATIAL	2	degree of the space dependence polynomial
DOM_HW	15	half-width for the star in the domain
NDOM_X	20	density of domain grid in X
NDOM_Y	20	density of domain grid in Y
DOM_THRESH	500.0	threshold above background for the stars used as domain centers (central pixel of the star)
N_SIG_DOM	2.0	sigma value for domains distribution cleaning
DOMAIN_MODE	1	mode of domain search: 0=uniformly distributed 1=centered on bright stars
MOHW	4	half-width for searching of domains around bright stars
N_ITER_DOM	2	number of iterations to find domain distribution
MIN_AREA_DOM	0.75	percentage of the domain to accept it as good
MIN_NKEEP	50	minimum number of domains left to calculate the final solution
VERBOSE	1	verbosity level (0=quiet, 1, 2, 3, ...)

The description of the instrument parameters file may be found in the section 3.2.2.

5.2 bmask

5.2.1 Command line arguments

```
bmask params instrument image output_image mask
```

params: input parameters file name

instrument: input instrument parameters file name

image: image FITS file name

output: output, modified image FITS file name

mask: output bad pixel mask image FITS file name

5.2.2 General description

This program reads the coordinates of bad pixels from its parameters file and creates a bad pixel mask image.

5.3 cutfitsim

5.3.1 Command line arguments

```
cutfitsim infile outfile n11 n12 n21 n22
```

infile: name of the FITS file with the input image
outfile: name of the output FITS file with the desired section of the input image
n11: starting X coordinate of the section to be cut (original image has 1)
n12: ending X coordinate of the section to be cut (original image has NAXIS1)
n21: starting Y coordinate of the section to be cut (original image has 1)
n22: ending Y coordinate of the section to be cut (original image has NAXIS2)

5.3.2 General description

This program cuts a sub-frame of an input image. The resulting image is created even if the coordinates are outside the input image. In such case the additional pixels are filled with zero values.

5.4 fitshedit

5.4.1 Command line arguments

```
fitshedit fits_file [keyword [value]]
```

If only the name of a FITS file is given then all headers (for all extensions) are printed to stdout. If a keyword is given then all header cards with this keyword are printed to stdout. If a value is given then the corresponding header card is modified in the FITS file.

5.4.2 General description

This program enables the user to view or modify the contents of the headers in the FITS files.

5.5 fwhmm

5.5.1 Command line arguments

```
fwhmm parameters_file image
```

image: name of the input FITS file with the image to analyzed

5.5.2 General description

This program calculates average FWHM and background level for the input image.

5.5.3 Input files

Here is a short description of the content of the parameters file (`fwhmm.par`):

Keyword	Default value	Description
SKY_MOD	mode	sky background level calculation algorithm (mode/median/mean)
APERTURE	8	initial aperture size in pixels
IN_SKY_RAD	2	sky annulus inner radius (times maxfwhm)
OUT_SKY_RAD	5	sky annulus outer radius (times maxfwhm)

Keyword	Default value	Description
MARGIN	5	limit of the star distance from the edge
MIN_FWHM	2.6	minimum FWHM of a good star
MAX_FWHM	10.0	maximum FWHM of a good star
MIN_PEAK	5000.0	minimum peak of a good star
MAX_PEAK	2.0e4	maximum peak of a good star
MIN_SKY	1.0	minimum sky level
MAX_SKY	5000.0	maximum sky level
VERBOSE	0	verbose level 0,1,2 (level 0 should be used for the scripts)

5.5.4 Output

The minimum output (VERBOSE=0) consists of:
the input file name, mean FWHM, background level, median FWHM, number of star taken for the statistics.

5.6 getpsf

5.6.1 Command line arguments

```
getpsf parameter_file instrument_file input_image mask coordinates output_file
```

parameters: name of the input text file containing parameters (default `getpsf.par`)
instrument: name of the text file containing instrument related parameters (default `instrument.par`)
input_image: name of the FITS file with the input image
input_mask: name of the FITS file with the bad pixel mask
coordinates: name of the list of star coordinates in the image
output_file: name of the output binary file containing parameters of the PSF model

5.6.2 General description

This program finds stars in the input image and then calculates a model of the PSF. This model is a sum of Gaussian functions multiplied by polynomials depending on the (X, Y) coordinates in the image.

5.6.3 Input files

Here is a short description of example content of the parameters file (`getpsf.par`):

Keyword	Default value	Description
NBOX_X	5	X-density of the BOXes
NBOX_Y	5	Y-density of the BOXes
NDEG_SPAT	2	degree of the polynomial describing dependence of the PSF shape on the position on a frame (X, Y)
NDEG_LOCAL	3	degree of the polynomial describing the PSF shape (U, V)
NGAUSS	2	number of Gaussian functions used in the PSF model
NPSF_MAX	100	maximum number of stars taken for the PSF modeling
MIN_NBOX	2	minimum number of stars in a BOX

Keyword	Default value	Description
MIN_FLUX	3000	minimum flux of a star
MAX_THRESH	500	maximum counts of the brightest pixel is brighter than the PSF model
RAT_THRESH	0.2	maximum ratio of the brightest pixel to the median of surrounding pixel (cosmic ray shield)
NSIG_DETECT	2.0	sigma threshold for the stars detection
CONTRAST	2.0	coefficient for the maxima selection
NSIG_RAT	3.0	
PSFHW	10	raster size for the PSF model
MAXHW	1	maximum radius of the circle around PSF peak within which the brightest pixel must be found
PEAKHW	5	radius of the circle within which the brightest pixel must be a local maximum
ISOHW	5	size of the region within which a star must be isolated
ISO_OFF	0.0	flux offset for the isolation test
ISO_SLO	0.15	slope of the offset dependence for the isolation test: neighbor_flux[%of_star_flux]<distance[pixels]*ISO_SLO+ISO_OFF (If ISO_OFF=0.0 and ISO_SLO=0.0 then star must not have any neighbors)
FITRAD	5.0	radius of the circle around centroid within which all pixels are taken to calculate the PSF model
APRAD	10.0	aperture radius
ANRAD1	20.0	inner radius of the background annulus
ANRAD2	25.0	outer radius of the background annulus
BKG_FRAC	0.3	moment for the background estimate within the background annulus
NSIG_CLIP	2.0	PSF sigma clipping factor
NITER_INIT	3	number of iteration steps with constant PSF
NITER	4	number of iteration steps with variable PSF
RECENTER	1	recenter the stars: 0=off 1=on (0.1 [pixels] step)
PSF_COS	1.0	starting value of the cosine coefficient for the PSF rotation angle
PSF_SIN	0.0	starting value of the sine coefficient for the PSF rotation angle
PSF_AX	-0.8	PSF X-width scale
PSF_AY	-0.8	PSF Y-width scale
SIGMA_INC	0.55	ratio of the widths of the subsequent Gaussian functions in the PSF model
SIGMA_MSCALE	1.58	coefficient for sigma scaling for the distribution moments estimation
VERBOSE	1	verbosity level (0=quiet, 1, 2, ...)

5.7 im2float

5.7.1 Command line arguments

```
im2float input_image output_image
```

input_image: name of the input FITS file conforming any format of the FITS standard (BITPIX=8, 16, 32, 32, -64)
output_image: name of the output FITS file with the image in FLOAT format (BITPIX = -32)

5.7.2 General description

This program converts an image from a FITS file in any format to a FITS file in FLOAT format.

5.8 jd_ccd

5.8.1 Command line arguments

```
jd_ccd FITS_file(s)
```

FITS_file(s) a number of FITS file names for which Julian Dates have to be calculated.

5.8.2 General description

This program calculates (barycenter corrected) Julan Dates for the time read from FITS header for a number of FITS frames.

5.8.3 Input files

A binary file `poshb.dat` should be present in the working directory. This file contains the information on the orbits of the planets in the Solar System.

5.9 lcs

5.9.1 Command line arguments

```
lcs parameters jd_log reference_photometry prefix
```

parameters	input parameters file name
jd_log	Julian Dates file name
reference_photometry	template image file name
photometry_db	photometry database file name
prefix	prefix for the output files

5.9.2 General description

This program extracts individual light curves for the stars in the photometry database.

5.9.3 Output

There is a separate ASCII text file created for each star's light curve.

5.10 mstack

5.10.1 Command line arguments

```
mstack parameter_file instrument_file stack_list suffix mask_mark output
```

parameter_file: name of the input text file containing parameters (default `mstack.par`)
instrument: name of the text file containing instrument related parameters (default `instrument.par`)
stack_list: name of the input text file containing the list of the names of FITS files to be stacked
suffix: output file name suffix
mask: a file name modifier for the mask
output: name of the output FITS file with the averaged image

5.10.2 General description

This program averages several images to create a template image.

5.10.3 Input files

Here is a short description of example content of the parameters file (`mstack.par`):

Keyword	Default value	Description
HIST_NBIN	2000	number of histogram bins (used for the background estimate)
HIST_LOW	1	minimum value in histogram
HIST_HIGH	2000	maximum value in histogram
NBIN_SMOOTH	6	histogram smoothing factor
BAD_VALUE	65000	value assigned to bad pixels
BKG_FRAC	0,3	moment for the background level estimate (0.5: median)
THRESHOLD	300	threshold for stars detection in counts
MIN_SCALE	0,5	minimum scaling factor between a frame and the reference frame
MAX_SCALE	2	maximum scaling factor between a frame and the reference frame
MIN_NGOOD	3	minimum number of frames with good counts to perform stacking at a given pixel
N_REJ_LOW	1	number of data points with lowest counts to reject
N_REJ_HIGH	1	number of data points with highest counts to reject
MEDIAN	0	0=use mean value for each pixel 1=use median for each pixel (WARNING! median well good only for frames with the same PSF)
BKG_ALG	mode	sky background level algorithm: mode, median or mean
VERBOSE	1	verbosity level (0=quiet, 1, 2, ...)

5.11 nmask

5.11.1 Command line arguments

```
nmask image_mask template_mask new_image_mask
```

5.11.2 General description

This program combines an image bad pixel mask with the template image bad pixel mask into a new bad pixel mask for the transformed image.

5.12 phot

5.12.1 Command line arguments

```
phot parameters instrument template psf list_of_images field
```

parameters:	name of the input text file containing parameters (default `phot.par`)
instrument:	name of the text file containing instrument related parameters (default `instrument.par`)
template:	name of the input FITS file with the template image
psf:	name of the input binary file with the parameters of the PSF model
list_of_images:	name of the input text file containing the list of the names of FITS files to be processed
field:	name of the observed field; input file: {field}`.coo`: ASCII table of coordinates of variable object candidates output file: {field}`.db`: ASCII/binary database of the photometry of variable objects

5.12.2 General description

This program calculates the photometry (AC signal) for each object from the input coordinate list. The aperture photometry is performed using slightly modified algorithm described in DAOphot source code (Stetson, P.B., 1987, PASP, 99, 191). The profile photometry …

5.12.3 Input files

Here is a short description of example content of the parameters file (`phot.par`):

Keyword	Default value	Description
APRAD	10.0	aperture radius
FITRAD	10.0	profile photometry radius
NORMRAD	15.0	PSF normalization factor
ANRAD1	20.0	inner annulus radius for background estimation
ANRAD2	25.0	outer annulus radius for background estimation
BKG_MODE	0	background estimate mode, when value is not 0 ANRAD values are used
NSIG_BKG	2.0	sigma clipping factor for pixels distribution
BAD_VALUE	-9999,99	value assigned when program is unable to compute photometry
ERR_CODE	65000.0	value assigned to bad pixels
DBFORM	A	Photometric database format:A= ASCII table; B= binary file
VERBOSE	1	verbosity level (0=quiet, 1, 2, ...)

5.12.4 Output database

The output photometry database may be saved in the ASCII table format or in a binary format.

Table columns (database records) are as follows:

1. number of a star
2. number of bad pixels inside the aperture
3. residual flux form profile photometry
4. error of the flux in column 3
5. residual flux from aperture photometry
6. error of the flux in column 5
7. background level in an annulus around the star
8. Chi_square (?)
9. corr (?)
10. Chi_square (PSF fit)
11. FWHM of the star PSF.

5.13 resamplem

5.13.1 Command line arguments

```
resamplem parameters instrument coefficients input_image output_image
```

parameters: name of the input text file containing parameters (default `resample2.par`)
instrument: name of the text file containing instrument related parameters (default `instrument.par`)
coefficients: name of the input binary file with the transformation coefficients
input_image: name of the input FITS file with the image to be transformed
output_image: name of the output FITS file with the transformed image

5.13.2 General description

This program geometrically transforms an input image to the pixels grid of the reference image. The bi-cubic spline method is used.

5.13.3 Input files

Here is a short description of example content of the parameters file (`resamplem.par`):

Keyword	Default value	Description
FIX_COSMICS	0	**0=strongly recommended** 1=remove cosmic rays: Rejects pixels with counts N_SIG_COSMICS above the median of neighbor pixels and the gradient is higher than MAG_GRAD **This procedure does not work properly.**
MAX_GRAD	2	gradient limit for FIX_COSMICS
N_SIG_COSMICS	15	sigma limit FIX_COSMICS
FIX_RINGS	0	1=remove bi-cubic spline by linear interpolation

		This procedure does not work properly.
N_SIG_RINGS	2	sigma threshold for FIX_RINGS
N_SIG_RM	2,5	sigma threshold for bad column removal (IS & KŻ)
GROW_RAD	0	growing radius for bad column removal
VERBOSE	1	verbosity level (0=quiet, 1, 2, ...)

5.14 sfind

5.14.1 Command line arguments

```
sfind parameter_file instrument_file input_image input_mask background fwhm output_file
```

parameter_file: name of the input text file containing program parameters (default `sfind.par`)
instrument_file: name of the input text file containing instrument parameters (default `instrument.par`)
input_image: name of the FITS file with the input image
input_mask: name of the FITS file with the bad pixel mask
background: background level in the input image
fwhm: average FWHM of the stellar PSFs in the input image
output_file: name of the output text file with the coordinates and rough estimates of brightness of the stars found

5.14.2 General description

This program performs a search for stars in the input image.

5.14.3 Input files

Here is a short description of the content of the program parameters file (`sfind.par`):

Keyword	Default value	Description
C_MIN	0.4	minimum correlation to accept a star
APRAD	1.2	photometry aperture radius in FWHM units
ANRAD1	20.0	inner radius of the background annulus in pixels
ANRAD2	25.0	outer radius of the background annulus in pixels
THRESH	3	sigma threshold above the background for star detection
BKG_ALG	mode	algorithm for background level calculation available algorithms: mode, median, mean
VERBOSE	1	verbosity level (0=quiet, 1, 2, ...)

5.14.4 Output

Output file consists of a header and 5 columns of data. The header consists of 2 lines with the information on the dimensions of the input image (in pixels) and the 3rd line with the keyword END. The data columns are as follows:

- column 1: X-coordinate,
- column 2: Y-coordinate,
- column 3: approximate flux (integral of Gaussian fitted to a PSF),

- column 4: local background level,
- column 5: number of saturated pixels in the aperture.

5.15 template

5.15.1 Command line arguments

```
template list_of_images output_image x_nim y_nim
```

list_of_images: name of the input text file containing a list of FITS files with the image sections to be glued
output_image: name of the output FITS file with the whole image
x_nim: number of section cuts along the X axis
y_nim: number of section cuts along the Y axis

5.15.2 General description

This program glues several sub-images into one big image.

5.16 vminmax

5.16.1 Command line arguments

```
vminmax parameters image_list output_image
```

parameters: input parameters file name

image_list: input list of the images file name

output_image output variability image file name

5.16.2 General description

This program calculates an amplitude of variability in the list of images for each pixel. A map of these amplitudes is saved into a FITS file.

5.17 xygrid

5.17.1 Command line arguments

```
xygrid parameters input_list coeff_file
```

parameters: name of the input text file containing parameters (default `xygrid.par`)
input_list: name of the input text file with the list of coordinates (as returned by program **xymatch**)
coeff_file: name of the output binary file containing the transformation coefficients

5.17.2 General description

This program calculates coefficients for the geometric transformation of an image to the pixels grid of the reference image.

5.17.3 Input files

Here is a short description of the content of the parameters file (`xygrid.par`):

Keyword	Default value	Description
NDEG	2	degree of the polynomial for the astrometric transformation

SIGMA_F	2	sigma clipping factor
MAX_NITER	3	maximum number of iteration steps
VERBOSE	1	verbosity level (0=quiet, 1, 2, ...)

5.18 xymatch

5.18.1 Command line arguments

```
xymatch parameters reference_list matched_list output_file
```

parameters: name of the input text file containing parameters (default `xymatch.par`)
reference_list: name of the input text file with the list of coordinates of stars in the reference image
matched_list: name of the input text file with the list of coordinates of stars in the analyzed image
output_file: name of the output text file with the list of matched coordinates in the format: X1, Y1, X2, Y2

5.18.2 General description

This program cross-identifies two lists of stellar positions using the triangles method. A list of corresponding coordinates in created as an output. Relative shift between the images is written to the standard output.

5.18.3 Input files

Here is a short description of the content of the parameters file (`xymatch.par`):

Keyword	Default value	Description
NSUB	20	number of brightest stars taken for the preliminary cross-identification
LLIM	5	minimum length of the longest side of a triangle [pixels]
RLIM	5	maximum ratio of the sides length in a triangle
FVNO	0.5	ratio of the number of cross-identified triangles to total number of the triangles
LTOL	1	maximum difference of the lengths of the longest sides of the triangles being compared [pixels]
RTOL	0.02	maximum error of the side lengths ratio of the triangles being compared
CTOL	0.02	maximum error of the cosines of the angles in the triangles being compared
PTOL	0.5	final tolerance of the (X,Y) coordinates of the same star [pixels]
VERBOSE	1	verbosity level (0=quiet, 1, 2, ...)

6 Acknowledgements

This work has been supported by the grant UMO-2012/05/B/ST9/03931.

We would like to thank Przemek Woźniak, the author of the DIA package, for sharing his code and for the introduction information in the first steps of the preparation of the DIAPL package. We also thank Janusz Kałużny for inspiring comments on this software. We thank Jean–Baptiste Marquette for his comments and for the introduction to the World Coordinate System software library.