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The CommandLog: A comprehensive method to extract precise stellar photometry from CCD exposures

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Abstract

The CommandLog contains a comprehensive method for extracting precise stellar photometry from CCD frames. It leads to swift analysis of photometry for several frames in a set. In this way the mean magnitudes can be calculated and flat field signature revealed. The method has been developed mainly for the Vatican Advanced Technology Telescope data frames. An IRAF package of tasks (CL and PERL scripts) is given and some easy-to-process data frames are included as an example. The use of text Tables allows organizing the frames and preparing them for automatic processing. The CommandLog contains an HTML document which facilitates the analysis by following carefully detailed instructions and also the examination of data frames. Pasting source CL code from an HTML window to the IRAF CL allows estimating and controlling all necessary IRAF parameters. The procedure also facilitates the preparation of specific IRAF scripts. Adaptation to other data sets should be easy enough provided one adheres to software conventions of IRAF, TTABLES, and PERL.

Keywords: CCD photometry, flat field error

1 Introduction

Processing CCD frames to extract precise stellar photometry is a complex task (Howell 1992, 2000). Besides many effects, it is difficult to estimate the flat field error and quality of calibration of a given object field. The CCD detector introduced a novel observational era in astronomy (see Buil 1991) but also creates new measurement problems related to systematic errors. This type of errors can be estimated by examing several frames in the same filter with different CCD world coordinates. Examination of easily and quickly accessible CCD frames force astronomers to develop automated methods able to take important decisions right at the telescope. Since 1999 we have collaborated on the the Vatican Advanced Technology Telescope[1] (VATT) CCD frames to solve the following basic problems:

- develop an automatic method for CCD frame reduction;
- reveal the flat field gradients;
- reveal the quality of calibration;
- minimize the errors of the flat fields/calibrations.

To achieve these goals we have created an HTML document and a set of customized tasks for use in IRAF[2]. We call the complete package *the CommandLog*.

The CommandLog is a guide to CCD frame reduction and photometry using IRAF[3]. With the mouse we paste the commands from the document into the IRAF CL. At the same time we control all important steps, parameters, etc. and create text databases. Thus we prepare the data for a more automatic elaboration[4].

We form a hierarchical folder data structure and use the "TTABLE" package as our "database" system. Some statistical analysis (the weighting of data, χ^2 test and Rosenfeld's error correction) can help in the evaluation of the data and get more precise information about the magnitude values and flat field

[1]Alice P. Lennon Telescope with its Thomas J. Bannan Astrophysics Facility; at Mount Graham, Arizona, U.S.A.; 32°42′N, 109°53′W, 3191 meters altitude, IAU Observatory Code number 290.

[2]IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

[3]We do not present here any scientifically relevant frames or Tables, and the sample data have only didactical purpose.

[4]It can be a particular script preparation. The CommandLog scripts allow us to construct completely automatic IRAF tasks for a complete reduction process.

signature. Learning the flat field gradients from an easy-to-observe star field (M 67) we may try to remove them analytically and then apply them to other fields (Janusz et al. 2004).

The installation of our new tasks is very easy: unpack the archive[5] in the $HOME folder and customize the IRAF environment. Our HTML document in color facilitates finding and adapting the IRAF source commands. The file `myiraf/ccdrj/index.htm` opened in a browser, e.g., Netscape, is the CommandLog.

2 Data structure

We construct a logical folder tree to elaborate a set of CCD frames within IRAF and to save the results. The folder structure is based on two data abstraction perspectives, namely, of filter and object (see Fig. 1).

2.1 Raw CCD frames

The dataset of our analysis is always a complete observing run which yields about 1000 CCD frames made on a telescope in several nights. The frames are written on CD-ROMs in “fits” format. We call them “raw frames”. On the VATT telescope we work with the Strömvil or occasionally with the Vilnius filter system (Straižys 1992) using the 2K-VATT CCD camera.

2.2 Logical data structure

Two kinds of data abstraction are made, i.e. there are two main viewpoints on all our data: that of filter and that of object, e.g. Strömvil y filter for M 67, etc. To satisfy this data abstraction we create a work folder for the complete run (e.g. “/home/S8” folder, it can be anywhere)[6] to hold instrument files (with trimming and bias information; bad column information), and subfolders for common object data (e. g. “A_M67”)[7] and for data in a filter (“FILTER1”, “FILTER2”, ...).

Executing the IRAF `mkiraf` command in the work folder, we prepare this folder for our reduction; this command:

[5] This is the `myiraf.gz` tar-zipped archive in the UNIX file system name convention. The “example” folder is actually a working folder with testing frames; other folders belong to the CommandLog structure; the “ccdrj” holds the HTML documentation.

[6] For instance the “example ” subfolder in the “myiraf.gz” archive is a work folder.

[7] We start the object data subfolders with “A_...” because this gives us the names at the beginning of any ordered file lists separated from other working files.

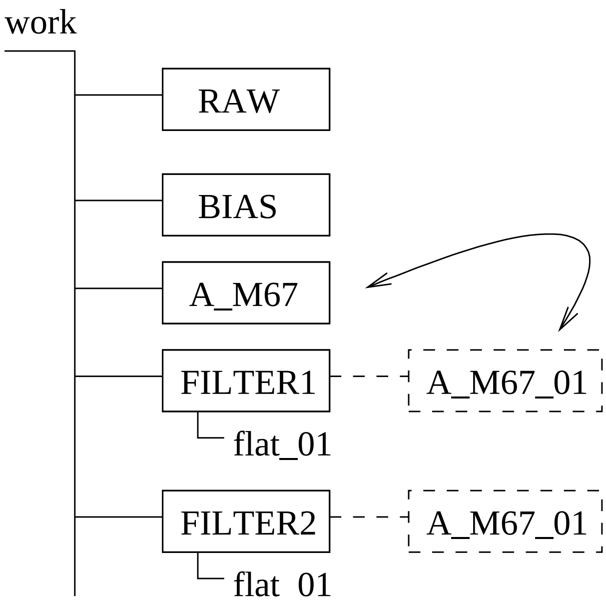

Figure 1: Folder structure.

1. makes this work folder to be the IRAF logical home$ folder,
2. creates there the "uparm" subfolder, and
3. creates the `login.cl` file.

The `myiraf$` points to the CommandLog directory, which is usually in the user's private folder as "/home/user/myiraf/". The classical IRAF "login-user.cl", copied or a link from `myiraf$` and edited, sets the IRAF environment variables. This approach allows us to start IRAF CL with local parameters set specifically for a run. We prepare here other useful files such as: the "subsets" file for filter convention names; files with transformations scheme, cursor files, etc. The "GAIN" subfolder is used for gain/readnoise check, "VAR" serves for other information not directly used to elaborate the frames.

We keep accessible the raw frames in order to be able to process them more than once for decreasing the errors. We copy "fits" files from raw CD-ROMs or make logical links to them (as "RAW1", ... subfolders). In the "BIAS" subfolder the averaged "zero" frame is to be prepared.

The subfolders "FILTER1", "FILTER2", ... contain information restricted to a given filter[8]. On this level all types of flat frames are created and object

[8]The subfolder "FILTER1" contains all data related to the "mag" catalog column ("visual" filter data), "FILTER2" – for "color" filter data, and so on. This denotes Strömgren y, b or Vilnius V, Y.

subsubfolders are made to elaborate object frames of a given filter using a given flat. In these subsubfolders we create a link to the common object subfolder in the work directory (e.g. "../../A_M67"), so we have a cross-reference for data exchange. The general graph of the work folder is shown in Figure 1; the directories are shown in boxes.

3 Algorithms

The main scope of going through the CommandLog is to generate the data structure, create the main database of all frames and other helping databases,[9] as well as prepare zero, flat and reference frames for all objects in question. Simple methods of CCD reductions with IRAF are described in Massey and Davis (1992) and Massey (1997). In our approach we extend and automate these methods to work with different sets of frames (normal frame set, shifted frame set, rotated frame set, big shift frame set). By means of this analysis, the flat field error can be estimated.

3.1 Main database creation

The "zero" step of the algorithmic process is to create a text data base ("qdb") of all raw frames and classify these frames with respect to their types (zero, flat, object), filter, etc. For each frame we give a valuation (negative value means that the frame is bad and can be deleted). On the VATT 2k-CCD camera much information is automatically recorded in the frame header, but some header fields might be incorrect. Some information written to the header is redundant on purpose to reveal these inconsistencies automatically. By editing the "qdb" fields we correct possible errors; by editing the separate "qdb" database we preserve the original frame headers. This small database along with one created for forming point-spread function (PSF) from selected candidate stars can be exchanged and corrected within our team.

Since the "qdb" with its compactness is rather dense for editing, in order to work on a subset of frames, we create "*.cor" subset database files holding needed fields selected from the "qdb". When the "*.cor" databases are fixed, we may update the "qdb" from the "*.cor" files.

By creating the "qdb" database we eliminate possible human errors, collect important information within its fields, make necessary sanity checks and classifications as well as "log" notes.

[9] The CommandLog has evolved through updates from testing, thanks to G. Coyne of the VORG sponsoring project. During this time we decided to give up the SQL database system and use the "ttables" text data bases. This solution is more natural for IRAF and the astronomical domain.

3.2 Zero frame

Using the general information database we automatically select frames to elaborate the averaged zero (bias) frame in the "BIAS" subfolder[10]. We move the zero frame ("qbias_") into the work folder to be in accord with the global abstraction scheme. Last, the raw bias frames can be deleted.

3.3 Flat frames

Having the "qbias_" frame we move to the next level of data abstraction into the "FILTER1" subfolder (the other filter data in their "Filter$_n$" subfolders are handled in the same way). In this subfolder we collect all type of flats for a given filter. In our raw data we have 3 types of flats: about 10 dome (DOM) flat frames, blank sky (BLA) frames and twilight (FLA) frames. We extract here some useful fields from the main "qdb" database and create a "qflat.cor" database. We insert all information about the raw flats in this database. Besides organizing the types of flats, we measure also the number of counts in the flats to choose the best method of calculating the mean (one bad dome flat can ruin the averaged flat frame). Blank sky frame(s) are actually object frames but we use them for illumination correction. Later we can test twilight flats, use other techniques to make a better "illumination correction" (differential photometry, photometry correction maps) or generate "synthetic flats" (surfaces that make the best fit for calibration, lower gradients).[11] The averaged frames, used to create a mean flat, can be deleted as well as their raw correspondences.

3.4 Object frames elaboration

The scope of this step is to get information about the object of interest frames, select the reference frame and fill in the fields in the "qobj.cor" database.

In a "FILTER_n" subfolder we have several object "A_..." subsubfolders. In the object subsubfolder (e. g. "A_M67_01") we collect all the data of the given star field (M 67) elaborated by given flat (01) in given filter (n). We select the fields for the "qobj.cor" database and collect information about the frames by their examination. The main database fields are: coordinates of

[10]We collect about 10 raw bias frames every night, so we have about 100 frames in the run. We watch for any bad bias for deletion; this is also informative for the CCD working conditions.

[11]This is our method to achieve more precise photometry. We do not describe it here because only the CommandLog is our subject, and we shall publish our results at another occasion.

a given, typical, single, reference star, sky parameters, estimated “psfrad”, “fwhm”, etc.

We select the best frame of the “FILTER1” set as a reference frame. We create also a link to the common folder (“../../A_M67”) and put this frame onto that level of data abstraction – it will be used by all frames in all filters as the coordinate reference frame. Knowing the position of the reference star and the rotation angle of any other frame, the transformation of coordinates can be done to have the positions of stars on one common reference frame. The reference frame can also be calibrated to the sky coordinates of RA and DEC. As a preparatory step for calibration, we create also a standards photometry catalog and standards name-position file (“qnxy”) to substitute star names in an OBS-file.

Now, we run classical IRAF tasks (“DAOFIND”, “PHOT” of the “NOAO” package) and obtain photometric data for 6–12 frames. We can eliminate bad-column stars, transform the coordinates to the reference frame and select “good” stars using a criterium (e.g. contamination). Thus we calculate photometry for a set of apertures [1]–[6] and examine local sky, contamination, etc. to set up well our criterium. In Figure 2 we can see the result of automatic star selection on the basis of the contamination criteria. On the axes are the magnitudes from the two extreme apertures. At the end of this process we have a “*_.mag.1” photometry file for each good object frame.

At this point the aperture photometry calibration to standard stars would be possible.[12] If we want to do this, we select one aperture index and create the “OBS-file” using a “virtual-filter” method, i. e. we treat the frames as if they were different filter frames (they are within the same filter, of course). Thus we comply with conventions in the IRAF task “MKOBSFILE” which creates one OBS-file with data from all frames.

Now, we calculate the magnitude shifts to put magnitudes on the same zero-point level in the instrumental system; and then, we calculate their various means (not weighted, weighted, σ, statistical χ^2 test, Rosenfeld's σ correction, if necessary) for various groups (normal, rotated, big shifts, etc.), as well as substitute the names of selected stars (mainly for calibration). Thus we finally obtain a single Table with the results. We make detailed analysis of this Table: the distributions of the means of the differential photometry for normal/rotated/shifted images give us information about gradients; statistical χ^2 surface distribution informs us about the statistical flat character. On the basis of this information we can figure out the correction of the flat. We use the aperture photometry of stars of good signal-to-noise ratio for calibration by standards of good photoelectric photometry distributed over the field-of-view.

[12] Two passbands are required for color calibration. We could also move directly to the PSF.

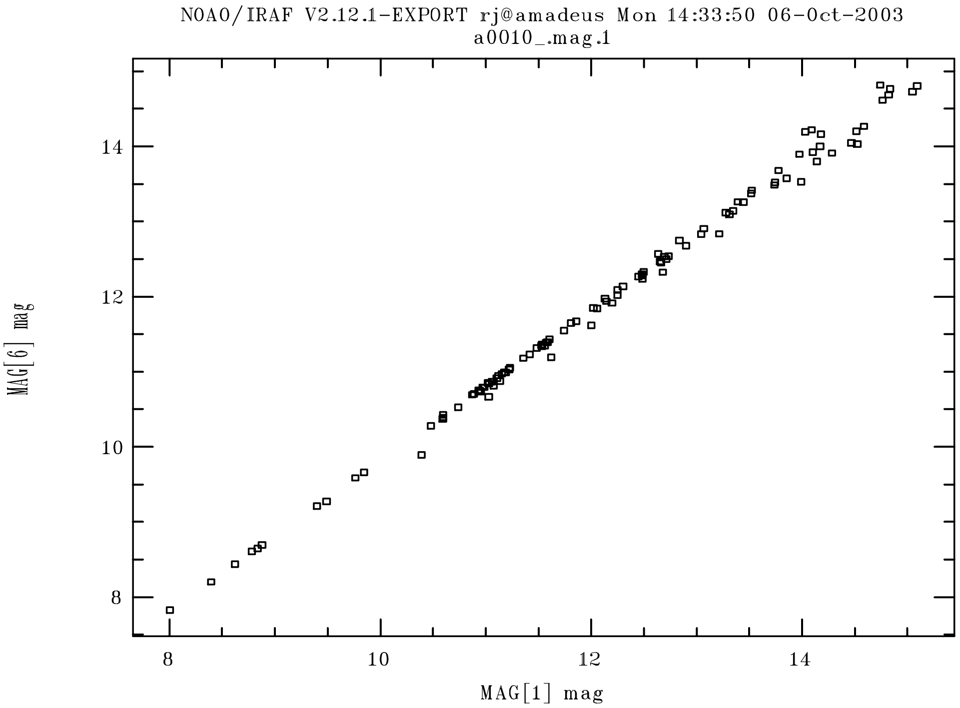

Figure 2: Selected, not contaminated stars. These are the unblended stars showing the same linear trend from the smallest and largest aperture.

For making a calibration by applying the PSF, the selection of clean candidate stars is necessary. We create a PSF candidates database and select "good" candidates. We estimate here also the best PSF model, and run the IRAF "ALLSTAR" task.

Analogously to the aperture photometry procedures, we receive "*_.als.1" files with coordinates on the reference frame and stars selected by a criterium (special attention is paid to ALLSTAR-chi, local sky, etc.); and, we finally obtain a single database with the means and statistical information.

The differential photometry along the x-axis of the CCD is plotted in Figure 3. The y-axis shows the difference between the mean magnitudes for all frames (rotated and normal CCD position) and the mean magnitude calculated only for normal frames. The x-axis indicates the x-direction of the CCD. Stars are selected by the magnitude cut off and magnitude error. We can clearly see a gradient across the CCD x-direction thus a flat field correction is necessary[13].

[13]We do not discuss it here, because we focus only on the CommandLog methods.

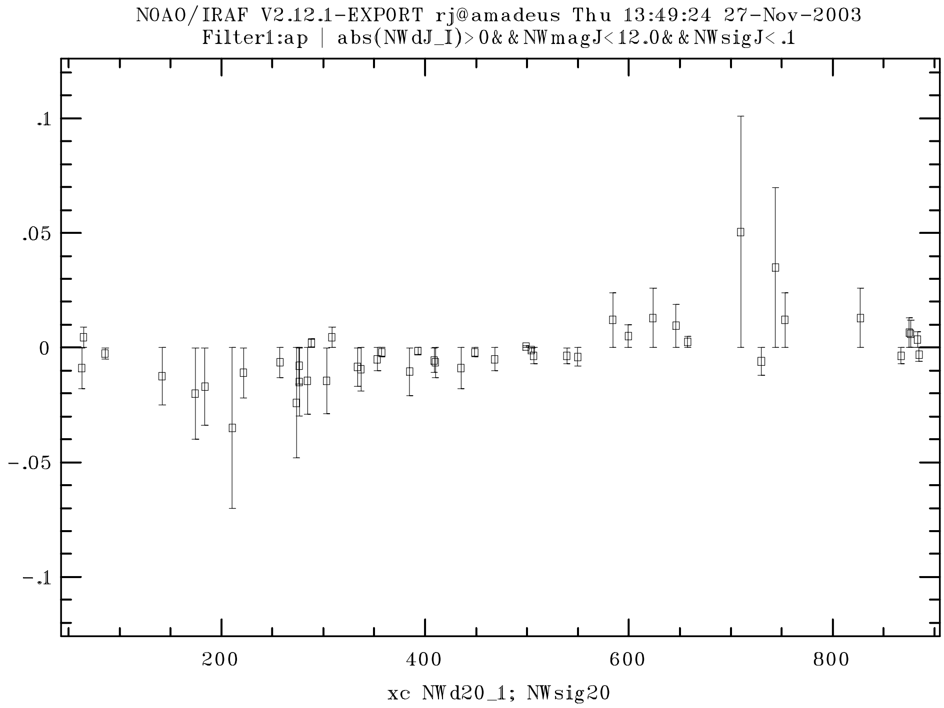

Figure 3: Differential photometry distribution across the CCD x-axis.

3.5 Calibration

We register this particular tested one filter-object-flat photometry Table in the common object folder database, so we are able to access its data for calibration.

We always check the calibration with two basic filters to see the residuals on the standards. We want to achieve two goals: minimize the flat field error (within the instrumental system) and minimalize the residuals (within the standard system). Achieving these goals might require some comparative compromise.

Having completed all the databases with correct data we are ready to repeat the calculations, after having improved some parameters. Many plots help us to reveal the quality of flat fielding and calibration.

4 Example data

We enclose some "didactical" data frames and a very approximate standard catalog. These frames do not have any scientific relevance, but should help a user to go through the CommandLog on realistic "fits" frames. In the "example" folder in the "myiraf.gz" UNIX tar archive we have prepared a two filter analysis, "RAW" "fits" frames and an "A_M67" 'calibration' folder. The structure of this "example" is generated going through the CommandLog.

To follow the CommandLog we recommend to open the "ccdrj/index.htm" in a HTML browser, select commands with the mouse and paste the block into the IRAF CL. The selected block should not contain any empty line; after pasting, we recommend pressing [Enter] to be sure that the last command is really executed. The same technique may help a user to write an IRAF script.

In our frame set, the small number of zero and flat frames creates, of course, larger noise, but for the purpose of example it is not so important. We rather want to show how the databases are used and the whole idea works[14].

In the "example" folder the processed fits frames and links are removed to save space. A user can easily regenerate them all.

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References

Buil, C. 1991, *CCD Astronomy. Construction and Use of an Astronomical CCD Camera*, Willmann-Bell Inc., Richmond, Virginia.

Howell, S. B. (ed.) 1992, *Astronomical CCD Observing and Reduction Techniques*, Astronomical Society of the Pacific Conference Series, Vol. 23.

Howell, S. B. 2000, *Handbook of CCD Astronomy*, Cambridge University Press.

Janusz R., Boyle, R. P. and Philip, A. G. D. 2004, *Baltic Astronomy*, in press

Massey, P. and Davis, L. E. 1992, *A User's Guide to Stellar CCD Photometry with IRAF*, IRAF.

Massey, P. 1997, *A User's Guide to CCD Reduction with IRAF*, IRAF.

Straižys, V. 1992, *Multicolor Stellar Photometry*, Pachart Publishing House, Tucson.

[14]The complete analysis with flat correction methods is in press in "Baltic Astronomy."