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Fast image processing method for PC: 6. Resampling of big frames

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Abstract. A method for resampling (or rebinning) of the pixel grid of one (input) frame according to the coordinate system of another (reference) frame within subpixel accuracy is presented. The respective algorithm, designed for block processing of big frames, is described. Each output pixel value is derived from the input pixel grid in the following way: (1) the coordinate transformations are obtained preliminary by the least squares method using 15 reference stellar images in both frames; (2) the computing process is applied to blocks of rows in the output (resampled) frame; (3) the current output pixel is projected onto the input pixel grid and its value is formed as the weighted sum of the values of the four nearby input pixels using the narrow gaussian distribution of the weights; (4) for increasing the speed as well as for processing of big frames, the image is read and processed in blocks; (5) the output pixel step may be decreased and after adding of a few such frames the result resolution may be increased up to 2 times. One example of resampling and addition of 4 frames, with the resolution increased 1.7 times, is presented.

Key words: methods: image processing — methods: numerical

1. Introduction

This paper is part of the description of several image processing methods of the Rozhen Image Processing System (RIPS) (Georgiev, 1991; 1996ab; 1998), realized on the basis of the PCVISTA software of Treffers & Richmond (1989, 1997). RIPS performs various space, amplitude and scale transformations, filtering, resampling, mapping, photometry and shape analysis of astronomical images. The methods and C-programs for median filtering, regression smoothing, partial restoration, iterative cleaning and simultaneous cleaning of two frames were described in the previous papers in this journal (Georgiev, 1996ab; 1998).

The resampling (or rebinning) procedure is a geometric transformation of the pixel grid of one (input) frame according to the coordinate system of another (reference) frame. The result is one (output) frame that may be added to the reference frame (for increasing the SNR of the observation), or subtracted from the reference frame (for revealing any variabilities). In the same manner, numerous slightly shifted (also called dithered) frames may be resampled to a common pixel grid and added. This method is widely used in ground-based infrared CCD observations, as well as in HST observations. Obviously, the resampled frames must keep the photometric and morphologic information content of the originals, therefore the resampling must be performed with subpixel accuracy.

The recent improvement of the resampling method was originally designed for combination of dithered (i.e. slightly shifted) HST frames (Hook & Adorf, 1995). This method is known as variable pixel linear reconstruction or, shortly, as drizzling. It does not require any information about the PSF of the frame and turns out to be very efficient in the case of the "big pixels" of HST. Instead of simply shifting the large input pixels into the correct position on the output frame and adding them, the drizzling method shrinks the input pixel before mapping onto the output and hence minimizes the effects of an additional convolution with the pixel response function. Practically the computer program projects the shrunk (about one-half) square of the big input pixels onto the small output pixels and computes the contributions of the input pixel to the output pixels occurred below the projection. So, the input pixel contributes or drizzles onto a few output pixels. The scheme of this process is illustrated in Fig.1a. More detailed information about the drizzling of dithered frames may be found in the papers of Adorf & Hook (1995), Fruchter et al. (1997), Lauer (1999), Hook (1999) and Fruchter and Hook (2002).

Two main problems must be solved in the practical realization of any resampling procedure. One of them is the choice of a method for deriving the pixel value in the output (resampled) frame from the pixel values of the input (original) frame. In the present work we give a method where the output pixel value

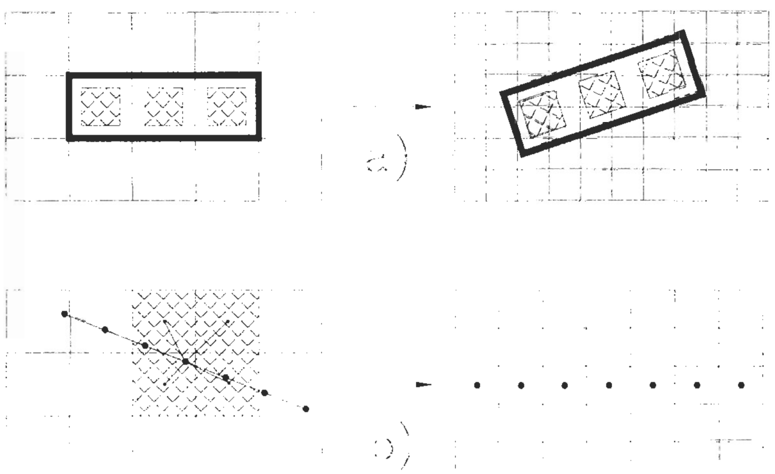

Figure 1: *Scheme of the two realizations of the resampling method: (a) drizzling distribution of the 3 big input pixels onto more fine output grid; the used shrank areas of the input pixels are presented by hatched inside squares (Fruchter and Hook, 2002); (b) retrieving the output pixel values from the input pixel system in the presented method; the centers of the output pixels are presented by dots and 4 input pixels that contribute to one middle output pixel are hatched.*

is a linear combination of four nearest input pixel values with gaussian distribution of the weighting coefficients. The second problem is the algorithm for block processing of big frames. Nowadays, the sizes of investigated digital frames grows up drastically and the algorithms for block processing are one approach to real-time processing. In the given solution we form and write a sequence of blocks of the output frame.

The principles of the resampling in the digital image processing are known so far (see Fine, 1970; Yanshin & Kalinin, 1994; Russ, 1995), but the descriptions of particular algorithms are rare in the literature. The present paper describes one solution of the problem, including support of drizzling procedure as an option of the resampling method.

2. Deriving the output pixel value

Let us assume the use of i and j, as well as I and J, as numbers of rows and columns of the input and output frames, respectively. We will also use (i',j') for designation of the projection of the output pixel position (I,J) onto the input pixel grid. Note that i' and j' are not integer numbers of rows and columns, but floating point numbers that play the role of x and y coordinates.

The most frequently used methods for calculation of the output pixel values in the resampling algorithms are (1) computation of the position of the current input pixel (i,j) (assuming it to be a point) onto the output pixel grid and transferring its pixel value z(i,j) to the nearest output pixel in the output frame Z(I,J) or (2) computations of projections of the current pixel (i,j) (assuming it is a square area) onto the system of square output pixels (I,J) and distributing the value z(i,j) onto a few output pixels Z(I,J). The first method is the most simple, however, it distorts the morphology of the images on small scales and for this reason it may be recommendable only for very rough work. The second method seems to be the most natural, but it is relatively complicated for realization as a general on-line procedure for big frames. For these reasons a different approach was chosen.

Either of the above-mentioned methods uses (1) stepping of the computing process through the rows and columns of the input frame and projecting the current input pixel onto the output pixel grid and (2) transferring the input pixel value onto the output pixels. Note, that finally each output pixel contains weighted contributions from the input pixels. Consequently, we can explore the opposite, straightforward and more simple approach: (1) stepping of the computing process through the rows and columns of the output frame and projecting the current output pixel onto the input pixel grid and (2) forming the current output pixel as the weighted sum of the nearby input pixels. Hence we retrieve the output pixel values directly by using the input pixel system. Moreover, the output grid may easily be made finer than the input one, i.e. the above-mentioned drizzling method (see Section 1) appears a particular case of the described resampling procedure.

The reasonable minimal numbers of the used input pixels are 4 or 5 — the neighbours of the projection (i',j') of the current output pixel onto the input grid. The scheme of the presented method for retrieving the output pixel values in the case of 4 neighbours is shown in Fig.1b. In the case of 5 neighbouring pixels we must use one central pixel (which is the nearest to (i',j') and its 4 neighbours. The most natural weights (or coefficients C) for the input pixel values z(i,j) seem to be proportional to the reciprocal value of the squares of the distances R between the projection (i',j') of the output pixel (I,J) onto the input grid and the nearest input pixels ($C \sim 1/(R \times R)$. However, because of the difficulties with the case R=0, we use coefficients that correspond to narrow gaussian distribution ($C \sim \exp(-(R \times R))$. The optional "sigma" width of the gaussian is usually 0.1 pix. Increasing the width of the gaussian, we can obtain a more smoothed output frame. We have also checked the use of 4 or 5 parametric two-dimensional polynomial fit of the 4 or 5 nearest pixels in the input pixel grid. However, this approach causes significant smoothing of the output frame and it rests as an additional option of the method. The proposed method of resampling is a linear procedure. It is a union of the resampling and drizzling methods and has some practical advantages: (1) easy management of the weight coefficients of the input pixels and (2) easy forming of the output frame in sequential blocks (or, in the case of very big frames — sequential single rows). The disadvantage is that the additional convolution with the pixel response function slightly smoothes the output frame. Therefore extension of the output scale more than 2 times is not efficient. However, in many applications the slight smoothing effect is an advantage of the method.

3. Implementation of the algorithm

Let us describe the resampling algorithm implemented in a particular C-program, called REBIN. It transforms the pixels system z(i,j) of the input frame FINP in accordance with the pixel grid of the reference frame FREF and produces the pixels Z(I,J) of the output frame FOUT. The pixel grid of FOUT may correspond exactly to the pixel grid of FREF, or, accounting the axes extending coefficients Ci and Cj ($0.5 < Ci < 2.0$ and $0.5 < Cj < 2.0$) — to a rougher or finer pixel grid.

The coordinate transformation in the linear case accounts for shifting, scaling and rotation of FINP pixel grid vs FREF pixel grid. Two files of the lists of the coordinates of about 15 respective stars in FINP and FREF must be formed previously. Using them, REBIN derives the linear transformation equations by the least squares method. In the case of drizzling, REBIN changes reasonably the parameters of the transformation equations and introduces the corresponding larger output frame.

The main frame processing loop is executed n times where n is the number of the output frame blocks. Each such block contains numerous output rows (f.e. 50) that are stored temporarily in a 2D memory array MOUT. REBIN fills each such output block and writes them on the disk. The use of output blocks rather than single rows increases the processing speed a few times. Though, in the case of very big frames the block may be a single output row.

The first internal loop is the most complicated. It reads consequently numerous input rows (i) of the part of the FINP that comprehends the projection of the current output block (n) onto the input pixel grid. The positions of the corners of the output block on the input pixel grid define the current limiting rows i1, i2 and limiting columns j1, j2 in FINP. However, REBIN uses 4 input pixels for deriving each output one, and for this reason, in some cases it needs the rows (i) and (i–1), but in other cases — the rows (i) and (i+1). Therefore, for each (i) REBIN must keep in an input memory MINP 3 sequentially placed input rows. Thus the limits of the used part of the input frame become i1–1, i2+1 and j1–1, j1+1. Moreover, if one of the numbers i1, i2, j1 and j2 is an edge number, REBIN supplements the used part of the input frame with rows or columns numbered i1-1, i2+1, j1-1 or j1+1 using the respective row or column from the opposite edge of the frame. In the case where a part of the projection of the output block onto FINP occurs outside FINP, a suitable pixel value (e.g. the mean background of the input frame) is used to supplement the input working area.

The second internal loop steps through the rows (I) in the current output block. Each row is assumed to be as a line which is projected onto the area of the current 3 rows of the input frame MINP. The crossing points of the projection with the lines corresponding to the bounds i+0.5 and i–0.5 of the current input pixel row (assumed as band of squares) are derived. They are used for deriving limiting pixel numbers J1 and J2 in the current output row.

Then the third loop steps on the numbers J between J1 and J2 for filling the output pixel values Z(I,J). Now the projection (i',j') of each current output pixel (I,J) onto FINP occurs in the currently accessible part of FINP (a part of the input row (i) and its 2 neighbours).

The last operation is a computation of the weighted sum of 4 input pixel values z(i,j) whose centers are the nearest to (i',j').

4. One example of resampling and adding of frames

The proposed method applied to 4 frames of the bright galaxy M 51 with exposure times 5 min each is described below. The observations are made with the 50/70/172 cm Schmidt telescope of the Rozhen NAO in R band. The telescope is equipped with SBIG CCD

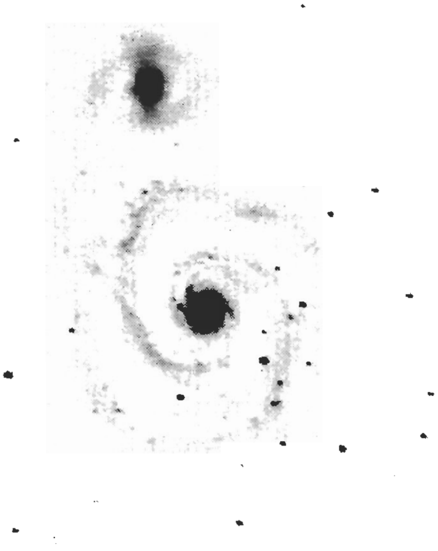

Figure 2: *Isophote maps of 4 cleaned and simply added frames of the galaxy M 51 with relative shifts* < 0.8 *pix. The original scale is* $1.82''$ *per pixel and the FWHM is about* $5''$.

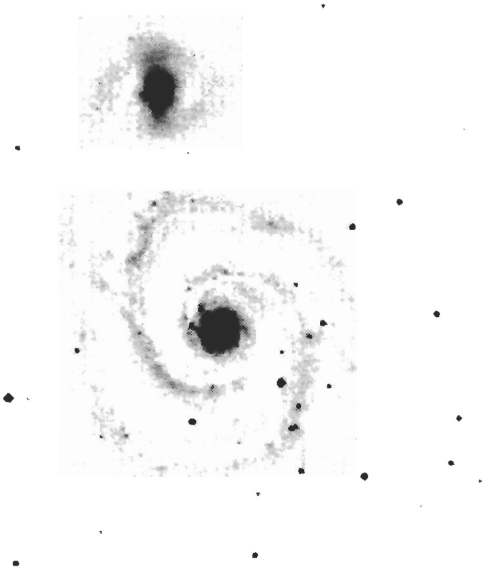

Figure 3: *Isophote maps of the same 4 frames, used in Fig.2, after resampling of each frame with 1.82 times expanding and adding of the results. The scale is* $1''$ *per pixel and the FWHM is about* $3''$.

camera ST6, as well as with a Barlow lens, used as 1.48 times focal expander. The scale is $1.82''$/pix and the field is $11.3' \times 8.6'$ (375×284 pixels). The relative frame shifts caused by the guiding errors are < 0.8 pix. The natural full width at half the maximum (FWHM) of the stellar images of the observation is about $3''$, therefore in the present example we have the "big pixel" case.

The frames are processed preliminarily with RIPS. Special procedures for making dark and flat masters from 5 source frames, as well as for simultaneous dark subtraction, flat fielding and scaling are created for the observations with a ST6 CCD. After preliminary processing we removed the smoothed background "continuum" from the frames applying median filtering with the window diameter W=51 pixels ($1.5'$). The obtained residual frames, which represent the spiral structure of M 51 better than the original ones, were assumed as source frames for further processing. The impulse noise (cosmics, warm and cold pixels) of each frame were cleaned by special kind of "hard" and "soft" median filtering, preserving the peaks of the stellar images (Georgiev, 2000).

Preliminarily, the 4 cleaned source frames were simply added for obtaining the reference frame FREF for the resampling. The result (not shown) is very similar to each original frame and to the one presented in Fig. 2. The seeing or the FWHM of the stellar images in FREF, as well as in the original frames, is about 3 pix or $5.4''$.

Two resampling procedures were applied further. First, the 4 frames were resampled separately according to the FREF with conserving the scale ($1.82''$ per pixel) and then added. The FWHM of the result, which is shown in Fig.2, occurs at about 2.8 pix or $5''$. There are no significant differences between the simple added frames and resampled and then added frames, however the noise in the second case is somewhat suppressed.

Second, the 4 frames were resampled separately according to the FREF with expanding the scale 1.82 times and then added. The result is shown in Fig.3. Now the scale is $1''$ per pixel and the FWHM is about 3 pix or $3''$. Therefore, the resolution is about 1.7 times better than in the original frames. The noise is again slightly suppressed. The last frame is obviously more informative than the previous. It shows better the stellar complexes in M 51, as well as the bar-like formations in the bulges of M 51 and its satellite.

5. Conclusions

The described method proved to be a very useful tool in the preliminary processing and combination of CCD frames. It may strongly be recommended, especially for the cases of big pixels, where increasing of the resolution up to 2 times can be done by expanding the output pixel grid and adding a few frames. The method is also suitable for combination of frames from different telescopes.

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References

Adorf H.-M., Hook R.N., 1995, ESO/ECF Workshop on Calibrating and Understanding HST and ESO Instruments, ESO, Garching, 251

Fine V.S., 1970, Image recognition, Moscow, Nauka, (in Russian)

Fruchter A.S., Hook R.M., Busko I.C., Mutchkler M., 1997, HST Calibration Workshop, STSCI, Baltimore, 518

Fruchter A.S., Hook R.M., 2002, Publ. Astr. Soc. Pacific, **114**, 144

Georgiev T.B., 1991, Astrofiz.Issled. (Izv.SAO) **33**, 127

Georgiev T.B., 1996a, Bull. Spec. Astrophys. Obs., **39**, 124; 131; 140

Georgiev T.B., 1996b, Bull. Spec. Astrophys. Obs., **41**, 132

Georgiev T.B., 1998, Bull. Spec. Astrophys. Obs., **43**, 164

Georgiev T.B., 2000, IAU Commission 9, WGSS Newsletter, **12**, 10

Hook R.N., 1999, ST-ECF Newsletter, **25**, 3

Hook R.N., Adorf H.-M., 1995, Calibrating HST, STSI, Baltimore, 341

Lauer T.R., 1999, Publ. Astr. Soc. Pacific, **111**, 227

Russ J.C., 1995, The image processing handbook, CRS Press, 199

Treffers R.R., Richmond M.W., 1989, Publ. Astr. Soc. Pacific, **101**, 725

Treffers R.R., Richmond M.W., 1997, private communication

Yanshin V., Kalinin G., 1994, Processing of images using C-language, Moscow, Mir, (in Russian)