

IMAGE PROCESSING IN PHOTOGRAMMETRY : THE DIRECT APPROACH

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ABSTRACT

The DIgital RECTifier approach uses image processing and analysis techniques in photogrammetric procedures. The whole process includes image enhancement by digital filtering and image rectification by analytic means. The input data are scanned metric or non-metric photographs and the output is either a rectified raster image or optionally a vector image in standard formats. The required hardware is a scanner, a laser printer and a PC/80386 compatible with a standard graphics card. The system configuration, performance and applications are presented.

KEY WORDS: Image processing, Digital image, Rectification, Soft-copy Photogrammetry

1. INTRODUCTION

Recent technological advances allowed the development of techniques and instrumentation, which otherwise would require extensive computer power and resources (Gruen, 1989, R  ther and Parkyn, 1990). This event actually suggested the replacement of the costly conventional photogrammetric instruments by equipment covering a range of capabilities and prices. The direct benefit for Architectural Photogrammetric applications is the chance to use portable, stable and user friendly equipment, without having to compromise in accuracy requirements or pay the price of the over-killing, highly accurate but very expensive, multi-purpose photogrammetric instruments.

Over the last few years we have witnessed a line of research and production aiming to the development of small, cost-effective systems for stereo-photogrammetry (eg. Gagnon et.al., 1990), remote sensing applications (eg. Welch, 1989), etc.. The first such systems to appear were suggesting using a regular digitizer (eg. Faig et.al., 1990), instead of a comparator, to make measurements of photo-coordinates. Although such systems are quite easy to use and require very little experience and training, they are characterized by disadvantages like:

- The digitizer's low pointing precision
- No completeness checking
- The picture is not treated as a digital means but the user can only collect and process isolated points and convert them to graphic vectors to be plotted.

Trying to overcome these disadvantages, other systems (like the one suggested by Nolette et.al., 1992) follow another approach and use scanned photographs and basic procedures of Digital Photogrammetry. However, both kind of systems suffer from shortcomings like: they provide no image processing and photometric enhancement, they only output vector data.

This paper is concerned with the description of the recently developed Digital Rectifier (DIRECT) system (Patias, 1991a). This system can be considered as a hybrid image processing - photogrammetric system, which is based on off-the-self low-cost hardware, powerful software and user friendly interfaces. It can be used very easily and requires only marginal knowledge on computers and photogrammetry (Patias, 1991b). While the system is still being enhanced, preliminary tests indicate results over-passing the accuracy requirements for Architectural Photogrammetry projects.

2. THE DIRECT SYSTEM

2.1 Hardware aspects

The hardware components of DIRECT were kept off-the-self and low-cost. More specifically, for proper performance, the Digital Rectifier suggests :

- A standard IBM-compatible PC with Intel 80286 or 80386 microprocessor (math-coprocessors are used when present but not required) with 640Mb of RAM (cache memory can be taken advantage of, although not required), at least 40Mb Hard disk and a pointing device (mouse, digipad or digitizer).
- A standard 640x480 by 8-bit (256 colors) VGA card and display monitor (either monochrome or color).
- A standard A4 8-bit scanner with resolution at least 300dpi (dots/inch).
- A standard laser printer (with compatible resolution) and optionally a standard vector plotter.

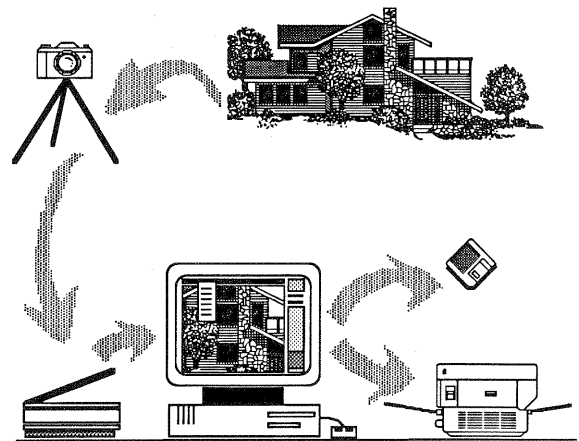


Figure 1. The DIRECT system concept

2.2 Operational aspects

The DIRECT's basic concept of work-flow is pictured in Fig. 1 and contains the next phases :

- The data are captured using either metric or non-metric camera.
- Enlarged paper print is produced through an enlarger.
- The produced paper print is scanned and stored into the computer.
- The data processing deals with :
 - Enhancement of the photometric characteristics of the image so that measurements can be obtained easily and accurately.

- Correction of errors due to lenses, film, enlarger, scanner.
- Digital rectification of the image using ground control. Then the user has the alternative to either apply the transformation parameters to collected vector data only or apply them on a pixel-by-pixel and thus rectify the whole picture.
- Translation of vector data to standard formats for further editing and plotting.
- Raster reconstruction, resampling and enhancement of the rectified photos, production of digital mosaics, laser printing.

In order to achieve these tasks, the Digital Rectifier is accompanied by the Digital Rectifier - Utilities (DIRECT-U), an image processing module.

The functions of DIRECT are schematically given in the next figure (Fig. 2).

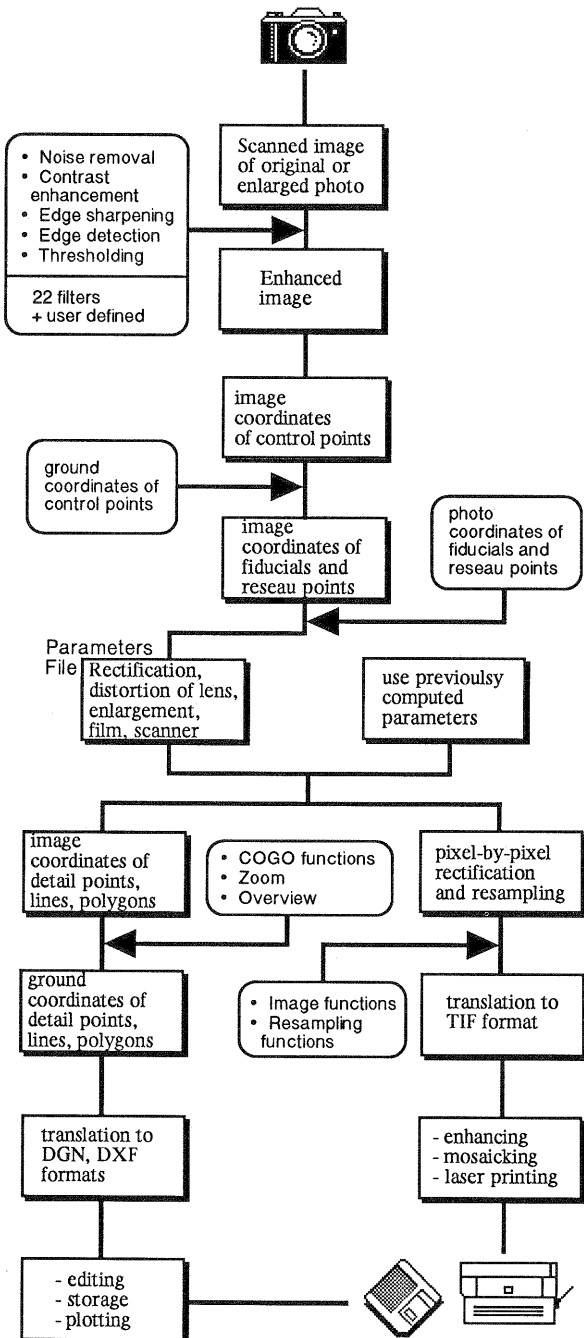


Figure 2. The series of DIRECT's functions

Data acquisition - Photo enlargement The digital data are captured by scanning the enlarged print. Normally (it depends on the format of the camera) enlargements of 3x-5x suffice (Needham and Smith, 1984), given an A4-size scanner. The purpose of the enlargement is to compensate for the low resolution of the scanners. Photo-enlargements have been used in many applications before (eg. Welch and Jordan, 1983, Faig et.al., 1990) with success.

DIRECT system can read raster files in most of the standard formats, like TIF, PCX, GIF, or regular ASCII files. The scanning procedure can use any scanner.

The cumulative histogram of the grey values and other relative information regarding the picture (i.e. size of file, number of pixels, etc.) are computed and stored in a file for future reference. If the image have been rectified before, the rectification parameters are stored in the Parameters File and they can be used any time for on-line rectification of the collected points (Konecny, 1979, Novak, 1992).

Data collection The whole image is displayed into a small window at the right of the screen from where the user can pick a portion to work with. The chosen portion fills the screen and the collection of the data starts. Using the COLLECT menu the user has the option of collecting control points, feature points, or other features using the line and polygon options. The collected data are superimposed in different colors, for completion checking.

The user can follow the cursor movement since its both pixel (I,J) and ground coordinates (X,Y) are continuously refreshed and displayed on the screen. By moving the cursor and pressing the left key the point is registered, while the right key is used to mark the end of a line or polygon.

For better pointing DIRECT provides four features: First, the user has additional opportunities to further enhance the image by filtering. Second, he can choose to zoom (as many times as he wants) the displayed image by selecting the area he is interested in. Third, a small zooming window gives him the possibility of having another area displayed with a different zoom factor (other than that of the whole screen). Zooming can be performed with three different algorithms, i.e. using nearest neighbor, bilinear, or bicubic resampling. These algorithms differ from each other in quality, accuracy and speed and the user has the option of using either one by checking the appropriate selection into the UTILITY menu. Four, the cursor can move in two speeds: free-hand, and pixel-by-pixel (using the up-down-right-left arrows).

The collected data are automatically stored into the desired output file in a generic format. The coordinates of these points are either pixel coordinates (in the case of no previous rectification of the image) or ground coordinates (if a rectification parameters file exist). Correction of affine errors as well as those of lens distortion can be applied to the collected data.

Then the user can move to another portion and so on until he finishes the data collection. A final completion check is offered with the "OverView" option. Using this option all the collected data are superimposed on the image and displayed in any portion or the whole image.

Vector rectification Once the image and the ground coordinates of the control points (more than 4) are known the standard analytical rectification procedure takes place. The output is a rectification parameters file which establishes the relationship between the image and the ground reference frames. By using these parameters in an on-line mode all the collected points, line and polygons are automatically transferred to ground. Subsequently, the user can choose to translate the generic file format to some standard graphic formats like Intergraph MicroStation's .DGN, or Autodesk AutoCad's .DXF for further editing, plotting and connection

to databases. It should be pointed out that the translated features remain also as points, lines or polygons into the new files leaving thus only minor editing and touching-up to be done by the user.

Raster rectification and reconstruction The other option is to rectify the whole image off-line. This is done on a pixel-by-pixel basis using the known rectification parameters. The rectification of an input image $f(k,l)$ produces an image whose grey-level values are functions of non-integer raster coordinates $g(x,y)$. Thus $f(k,l)$ may map between the pixels of $g(x,y)$ or, in other words, many pixels of the output image may have a grey value of zero. Some form of grey-level interpolation or resampling is then needed in order to obtain output values at integer positions (eg. Hood et.al., 1989).

The DIRECT-U resamples the image using the pixel filling technique and gives the user the choice of the interpolation scheme (nearest neighbor, bilinear, or bicubic).

3. GEOMETRIC CORRECTIONS

3.1 Affine Correction

DIRECT allows for correction of affine errors (eq.1). These errors can be introduced due to film distortion, during the process of enlargement of the original or due to scanning of the printed copy (see eg. Warner et.al., 1991, 1992). The user can use control such as reseau crosses in semi-metric cameras, fiducial marks, a calibration grid printed on photo during the enlargement or a calibration grid scanned together with the photograph, etc.

$$\begin{aligned} x' &= a_1x + b_1y + c_1 \\ y' &= a_2x + b_2y + c_2 \end{aligned} \quad (1)$$

3.2 Lens Distortion

In case calibration report of a metric camera is available, radial lens distortion coefficients (eq.3) can be introduced in DIRECT and correct for such errors (eq.2). If calibration report is not available, such coefficients can be computed from DIRECT using appropriate control points.

$$\begin{aligned} x'' &= x' + \frac{\delta r}{r} x \\ y'' &= y' + \frac{\delta r}{r} y \end{aligned} \quad (2)$$

Where

$$\delta r = k_1r + k_2r^3 \quad r^2 = x'^2 + y'^2 \quad (3)$$

and the parameters k_1 and k_2 are either known from the calibration report or they may be computed from control points.

The same applies for non-metric cameras as well. Even in this case the first coefficient (or may be the second one also) is judged to be enough.

3.3 Digital Rectification

DIRECT can perform the rectification either of the collected data only, or of the whole image, according to the usual rectification formulas (eq.4).

$$\begin{aligned} X &= \frac{a_1x'' + b_1y'' + c_1}{a_3x'' + b_3y'' + 1} \\ Y &= \frac{a_2x'' + b_2y'' + c_2}{a_3x'' + b_3y'' + 1} \end{aligned} \quad (4)$$

4. PHOTOMETRIC CORRECTIONS

4.1 Enhancement of the original image

The image enhancement processes are provided by the DIRECT-U module. The purpose of image enhancement is to change the photometric qualities of the image (eg. Dawson, 1989, Mertsios et.al., 1989, Moik, 1980), to alternate irrelevant features and emphasize features of interest, so that the collection of the data to be performed with greater ease and accuracy.

During image enhancement the user selects a window of the whole image to experiment with. The original image is displayed and next to that the enhanced counterpart is also displayed, for comparison together with their respective histograms. During this phase the following tasks can be performed by DIRECT-U:

Noise removal Low pass filtering using convolution of 3x3 kernels is used. The purpose is to eliminate any high-frequency noise present in the image. The user has the option to either use any of the three masks/kernels, which are provided, or design and use its own 3x3 masks. The latter can be entered by any editor and stored in a file. Any number of such ASCII files can be created and be used later on by their name.

Contrast enhancement Images of poor contrast characteristics usually result in poor recognition of terrain characteristics and thus to low pointing accuracy. The purpose of the contrast enhancement option is to modify the structure of the original histogram, changing this way the percentage contribution of each (or groups of) grey value to the cumulative histogram. Since the original histogram is already stored, the user is given the alternatives of modifying it in a uniform, linear or exponential form (or of course use its own procedure).

Edge enhancement Sharpening of the edges is a feature that permits the better recognition of the points (pixels) lying on a line. Therefore more accurate measurements can be obtained. This is done by the edge enhancement option using any of the 4 masks provided by the module.

Edge detection For even sharper edges the edge detection algorithms (6 options) can be used.

Thresholding The purpose of the thresholding is to mask small variations in grey values. It is normally used after edge enhancement/detection in order to further enhance the image and mask everything but the enhanced line features. The user can interactively choose the threshold value by picking the corresponding grey value from the grey values chart at the right of the screen.

The user has the option of passing more than one filter over the original image. That is he can keep the filtered image and perform another filtering on top. The currently used filter, the filter kept and other relevant information are displayed in the status area at the bottom of the screen. After this initial experimentation and once the user has decided the sequence of the filters to be applied, the whole image is filtered and stored for subsequent use by DIRECT.

4.2 Enhancement of the rectified images

In order to improve the appearance of the digital rectified images, filtering and contrast enhancement can be applied to the images (Kidwell and McSweeney, 1985). This is accomplished by using convolution with an edge enhancement kernel, increasing therefore the high-frequency component and thus sharpening the images. The next step is the cumulative histogram stretch by using the contrast enhancement option.

4.3 Digital mosaicking

One major drawback in analog rectification and mosaicking is the existence of brightness discontinuities along the mosaic seams. In digital mosaicking such problem can be easily overcome. DIRECT's basic concept involves the use of the histogram equalization technique between the adjacent rectified images or the use of Wallis filters. Once the rectification of the whole image or the mosaic has been performed and the rectified image's quality has been enhanced, the output can be routed to the laser printer.

5. SYSTEM PERFORMANCE AND APPLICATIONS

5.1 Enlargement and scanning errors

In order to evaluate the accuracy of the enlargement-scanner system the following test have been conducted: A precise (1 μ m accuracy) Jena grid (grid size of 2 cm) has been printed on paper through the enlarger and scanned at 200dpi (pixel size=127 μ m). An affine transformation has been used with 30 control points and 69 check points. From the computed affine transformation parameters (eq.1), we can compute the physical parameters S_h (horizontal spacing of pixels), S_v (vertical spacing of pixels) and Φ (angle of non-perpendicularity) and the results were:

$$S_h = \sqrt{a_1^2 + a_2^2} = 128\mu\text{m}$$

$$S_v = \sqrt{b_1^2 + b_2^2} = 127\mu\text{m}$$

$$\Phi = \tan^{-1}(-a_2/a_1) - \tan^{-1}(b_1/b_2) = 0^\circ.01$$

Besides, for the 69 check points the average and the rms of the computed discrepancies v_i ($v_i = \sqrt{v_x^2 + v_y^2}$) are:

Affine correction of enlarger-scanner errors	
average v_i	= 87 μ m = 0.68 pixels
rms v_i	= 46 μ m = 0.36 pixels

Therefore it seems that the enlargement-scanning process does not introduce significant errors. The errors are below the pixel size. However depending on the scanner used, the enlargement factor of the original and the accuracy required it may be appropriate to additionally correct for such affine errors.

5.2 Pointing precision

In order to assess the pointing precision of the DIRECT system multiple measurements of targeted points have been performed. The photograph was of original scale 1 : 140, while the paper print was a 4x enlargement. The photograph has been scanned at 600dpi (pixel size=42 μ m). From 50 such measurements, made by unexperienced people, the rms discrepancy of the repeatedly determined point positions is

$\sigma_{v_i} = 4.2\mu\text{m}$ (0.1 pixels), with maximum difference between two determinations of the same point not exceeding 13.5 μ m (0.32 pixels). Three similar sets of measurements have been obtained using 2x and 4x zooming on the original image and using an image sharpening filter. The computed statistics are shown below:

Measurement mode (n=50)	σ_{xy} μm (pixels)	max.difference μm (pixels)
Original image 1x	4.2 (0.10)	13.5 (0.32)
Original image 2x	3.1 (0.07)	5.2 (0.12)
Original image 4x	1.0 (0.02)	2.1 (0.05)
Sharpened image 1x	3.1 (0.07)	10.5 (0.25)

5.3 Rectification accuracy

In order to evaluate the system performance, we have conducted the following tests.

A photograph of Saint Dimitrios, one of the oldest byzantine churches in Thessaloniki has been chosen. The original photograph has been taken by our Wild P-32 camera, $c=64.11\text{mm}$ and format 80x60mm. The scale of the original photo was approximately 1 : 220. The paper print was a 3x enlargement (approximate scale 1:80) and was scanned by the HP Scan-Jet scanner (nominal resolution 300dpi, interpolated 600dpi) at a resolution of 600dpi (42 μ m) and 256 grey levels. Two sets of measurements of the photo coordinates of 19 targeted points were obtained. The first set consists of the measurements made on our Wild STK-1 stereo-comparator, with a resolution of 1 μ m, on the original negative. The second set consists of the measurements made by the DIRECT system on the scanned paper print enlargement. For both data sets the same 4 (minimum) control points at the edges have been used in the rectification process, while the rest 15 points were used as check points. The planimetric error vectors v_i between STK and DIRECT rectification were computed and the statistics obtained are shown in the next table. No lens distortion or enlarger-scanner errors have been corrected.

A second test involved the photography of a building to-be-restored. The camera used is a Hasselblad 500C ($c=80\text{mm}$) without reseau and the printed copy enlarged 3x and scanned at 300dpi. From the 13 targeted control points, the 4 of them have been used as control and the rest as check points. The ground coordinates of the points have been determined by surveying measurements. Without correcting either for lens and film distortion or enlarger-scanner errors we have obtained the following statistics for the discrepancies:

STK-DIRECT Wild P-32/1:220/3x	Ground-DIRECT Hassel./1:350/3x
mean $v_i = 7\text{ mm} = 0.76\text{ pixels}$	23 mm = 0.77 pixels
rms $v_i = 6\text{ mm} = 0.64\text{ pixels}$	19 mm = 0.63 pixels

The obtained results show that the achieved accuracies are well below the thresholds required for plotting at scales used in Architectural Photogrammetry.

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