

Architectural Photogrammetry goes to the digital darkroom

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Abstract

Architectural Photogrammetry can and should benefit from the recent advances in Digital Photogrammetry and Image Processing. The purpose of this research is to suggest the replacement of the conventional darkroom lab by a "digital darkroom", which is composed by a computer, a graphics screen, a scanner and a laser printer.

The whole process includes image enhancement by digital filtering and a photo-grammetric image rectification with 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 proposed procedure, which is based on the digital darkroom concept, does not require extensive photogrammetric knowledge and experience and is judged to be very useful for single image restitution for Architectural Photogrammetry.

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INTRODUCTION

Recent technological advances allowed the development of techniques and instrumentation, which otherwise would require extensive computer power and resources (Gruen, 1989, Rüther 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 (acceptable rmse about 127 μ m).
- Problematic stereoscopic viewing.
- No completeness checking is provided to the user.
- They are based on analytical photogrammetry concepts, that is 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 Gagnon et.al., 1990) 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 (DR) 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, 1989). While the system is being still enhanced, preliminary tests indicate results over-passing the accuracy requirements for Architectural Photogrammetry projects.

HARDWARE CONSIDERATIONS

The hardware components of the DR-system 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 4-bit (16 colors) VGA card and display monitor (either monochrome or color).
- A standard A4 scanner with resolution at least 300dpi (dots/inch).
- A standard laser printer (with compatible resolution) and optionally a standard vector plotter.

OPERATIONAL ASPECTS

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

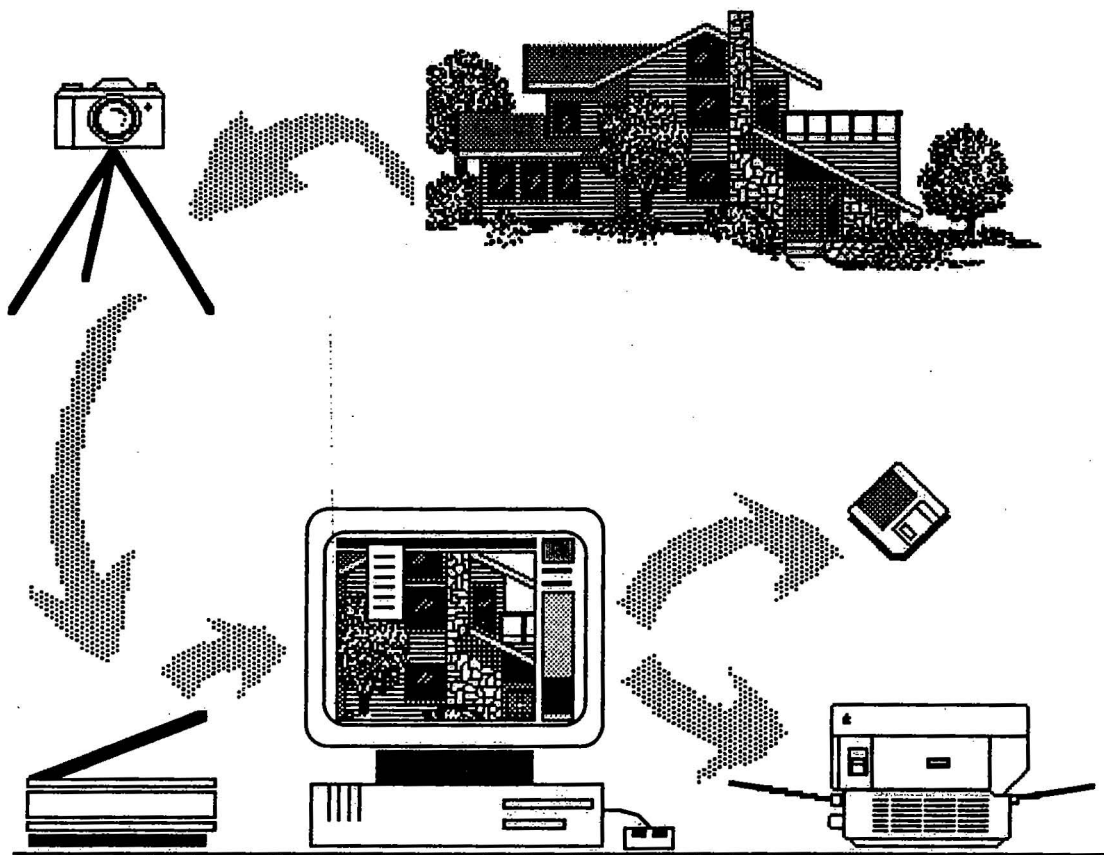


Figure 1. The Digital Rectifier (DR) system concept

1. The data are captured using either metric or non-metric camera.
2. Enlarged paper print is produced through an enlarger.
3. The produced paper print is scanned and stored into the computer.
4. The data processing deals with :
 - a. Enhancement of the photometric characteristics of the image so that measurements can be obtained easily and accurately.
 - b. 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.
5. Translation of vector data to standard formats for further editing and plotting.
 6. 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 (DR-U), an image processing module. In Figures 2 and 3 the functions of the DR system and the DR-U are shown :

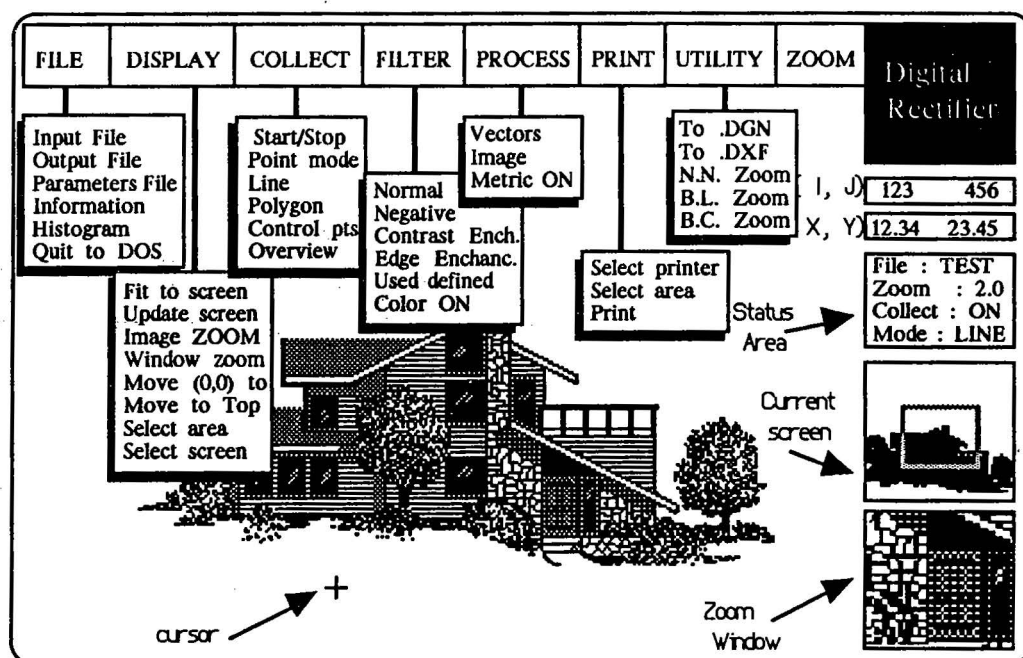


Figure 2. The Digital Rectifier (DR) system functions

1. 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 x3-x5 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.

The DR system can read raster files in most of the standard formats, like TIFF, PCX, GIFF, or regular ASCII files. The scanning procedure can use any scanner, but for better results resolution of 600dpi (pixel size 42 μ m) is recommended.

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, Patias, 1991b).

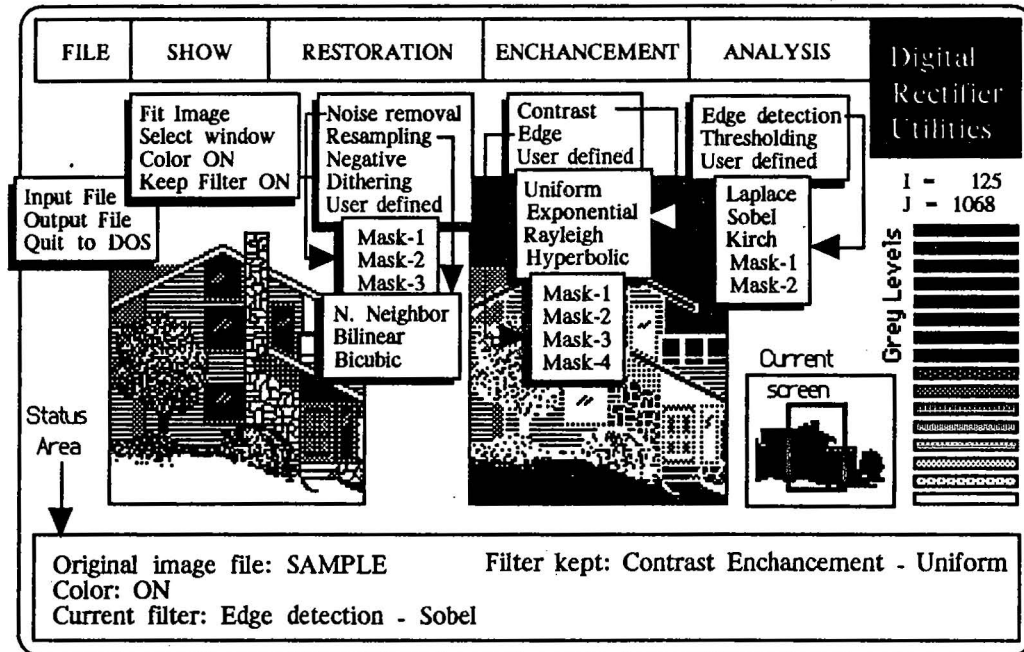


Figure 3. The Digital Rectifier - Utilities (DR-U) functions

2. IMAGE ENHANCEMENT

The image enhancement processes are provided by the DR-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), 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. During this phase the following tasks can be performed by DR-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 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 in 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, exponential, Rayleigh 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 (5 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 chart at the right (see Fig. 3).

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 the DR system.

3. DIGITAL RECTIFICATION

The DR system can perform the rectification either of the collected data only, or of the whole image.

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 displayed 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 the DR system provides three 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.

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).

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

ENHANCEMENT OF THE DIGITAL RECTIFIED IMAGES

In order to improve the appearance of the digital rectified photographs, 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.

DIGITAL MOSAICKING OF THE RECTIFIED IMAGES

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. DR's basic concept involves the use of the histogram equalization technique between the adjacent rectified images. 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.

SYSTEM PERFORMANCE

In order to assess the pointing precision of the DR system multiple measurements of targeted points have been performed. The photograph was of original scale 1 : 140, while the paper print was a x4 enlargement (therefore a pixel has size $42/4=10.5\mu\text{m}$). From 50 such measurements, made by unexperienced people, the standard deviation of the repeatedly determined point positions $\sigma_{xy}= 0.4$ pixels ($4.2\mu\text{m}$), with maximum difference between two determinations of the same point not exceeding 1.3 pixels ($13.5\mu\text{m}$). Three similar sets of measurements have been obtained using 2x and 4x zooming on the original image and using an image enhancement filter. The computed statistics are shown below:

Table 1. Pointing precision of targeted points using different measurement modes

Measurement mode (n=50)	σ_{xy} pixels (μm)	max.difference pixels (μm)
Original 1x	0.4 (4.2)	1.3 (13.5)
Original 2x	0.3 (3.1)	0.5 (5.2)
Original 4x	0.1 (1.0)	0.2 (2.1)
Enhanced 1x	0.3 (3.1)	1.0 (10.5)

In order to evaluate the system performance, we have conducted the following test. 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 $80\times 60\text{mm}$. The scale of the original photo was approximately $1 : 220$. 19 signalized control points have been used on the church's wall and their ground coordinates were determined through an adjustment of the topographical measurements.

The paper print was a x3 enlargement (approximate scale $1 : 80$) and was scanned by the HP Scan-Jet scanner at a resolution of 600dpi ($42\mu\text{m}$) and 16 grey levels. Two sets of measurements of the photo coordinates of the 19 control points were obtained. The first set consists of the measurements made on our Wild STK-1 stereo-comparator, with a resolution of $1\mu\text{m}$, on the original negative. The second set consists of the measurements made by the DR 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 results obtained are shown in Table 2. The planimetric error vectors v_i between ground and rectified DR measurements and between STK and DR rectification were calculated and the following statistics were obtained :

	Ground - DR	STK-DR
mean v_i =	0.026m	0.007m
rmse v_i =	0.020m	0.006m
max v_i =	0.038m	0.015m

Table 2. X, Y coordinates (m) obtained by topography and rectification using STK-1 or DR measurements.

Point #	Topography		STK rectification		DR rectification	
	X (m)	Y (m)	X (m)	Y (m)	X (m)	Y (m)
1	12.007	25.602	12.010	25.602	12.011	25.602
2	13.939	25.532	13.940	25.536	13.940	25.534
3	15.935	25.545	15.939	25.548	15.944	25.547
4	17.929	25.500	17.934	25.504	17.939	25.500
5	19.951	25.532	19.957	25.536	19.958	25.529
6	19.949	23.659	19.937	23.641	19.936	23.639
7	17.944	23.647	17.946	23.622	17.951	23.618
8	15.937	23.658	15.950	23.641	15.963	23.626
9	13.940	23.647	13.972	23.619	13.990	23.607
10	11.934	23.667	11.967	23.646	11.966	23.643
11	9.942	23.664	10.003	23.632	9.998	23.637
12	13.301	21.564	13.291	21.564	13.285	21.567
13	15.137	21.083	15.113	21.088	15.111	21.089
14	17.301	21.630	17.281	21.633	17.286	21.633
15	17.249	20.022	17.213	20.034	17.213	20.035

These results are not the best that could be obtained since the contrast of the photographs was not good. Actually the inability to precisely point the

target is reflected to the STK measurements as well. However they are actual work results and this is the reason why we present them here.

GROWTH POTENTIAL

The Digital Rectifier system is still being enhanced and tested. However, the preliminary tests show that its growth potential is high. At present we are working towards three main objectives. The first is the enhancement of the algorithms using non-metric cameras, so that even better results can be obtained. The second, is the enhancement of the mosaicking algorithms in order to get mosaics of better visually quality (better than the original images), while occupying less computer storage memory. The third, is the ability to make stereoscopic measurements, together with automatically performing interior orientation and stereo-image correlation.

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