# MATLAB and photogrammetric applications

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## Abstract

**Many automated processes in digital photogrammetry such as relative orientation of a stereopair of aerial images or a derivation of a digital terrain model (DTM) are based on image matching. Several approaches to image matching have been developed. In this paper, attention is paid to area based matching. Using of MATLAB in procedures of finding parameters of exterior orientation of an aerial image based on an existing orthoimage and checking of DTM using two overlapping orthoimages is described.**

## 1  Introduction

Finding conjugate points in two or more overlapping images automatically is one of the fundamental tasks in digital photogrammetry. The process is usually referred as image matching. Depending on the matching entity (intensity values, edges, regions, or their symbolic description) several approaches have been developed. Area based matching (ABM) that compares intensity values between two image patches is a simple, effective and relatively successful method. Therefore it is widely implemented into most commercial software packages. Cross-correlation and least squares matching represent two basic approaches to ABM [9].

Knowing parameters of exterior orientation is essential for photogrammetric applications as mapping, DTM or orthoimage generation. Usually, ground control points are measured for this purpose. In 1999 a report of the European Organization for Experimental Photogrammetric Research (OEEPE, now EuroSDR) project 'Automatic Orientation of Aerial Images on Database Information' was published [2]. The main idea of this project was to use existing orthoimages, DTMs, and digital maps as control information. Several methods were developed and tested. The one from Aalborg University based on an existing orthoimage and DTM was developed further including a comparison of the existing and newly derived orthoimages.

Geometric quality of orthoimages depends both on accuracy of orientation parameters and DTM. Finding outliers, systematic errors, and improvements of DTMs are the main goals of the running EuroSDR project 'Automated DTM Checking'. One of the methods that can be used for this purpose is based on finding corresponding points in two overlapping orthoimages that were derived from the same DTM.

In both mentioned projects, MATLAB scripts were created to solve following tasks:

- deriving image patches of a defined size and at defined positions

- finding position of the best fit between two image patches by cross-correlation

- applying least squares matching with a chosen number of radiometric and geometric parameters

- solving spatial resection (orientation task) or calculating height corrections (DTM task)

## 2  Area based matching

Intensity or gray values assigned to each pixel in the image are the matching entities in ABM. An image patch with odd number of rows and columns (a template) is cut from one image. It is compared with image patches of the same size from the second image. A comparison is only done within a search area i.e. an area which position and size is restricted by e.g. geometric conditions given by approximations of orientation parameters, expected errors in DTM, etc. A value of normalized cross-correlation coefficient is calculated at each position of the template within a search area. A position where the coefficient reaches its maximum is assumed as a position of the best fit. The position of the best fit is referred to the center of the template. In order to avoid mismatches, image patches of appropriate size covering areas of good contrast, texture, or structure should be chosen. This can be checked by calculating a standard deviation of the intensity values (contrast) or entropy. Moreover, repetitive patterns within a search area should be avoided.

### 2.1 Correlation

Normalized cross-correlation coefficient r quantifies a relation between two image patches $\mathbf{g}_T$ and $\mathbf{g}_S$ according to the formula 1.

$$r = \frac{\sigma_{TS}}{\sigma_T \sigma_S} = \frac{\sum_{i=1}^{R}\sum_{j=1}^{C}\left(g_T(i,j)-\bar{g}_T\right)\left(g_S(i,j)-\bar{g}_S\right)}{\left(\sum_{i=1}^{R}\sum_{j=1}^{C}\left(g_T(i,j)-\bar{g}_T\right)^2 \sum_{i=1}^{R}\sum_{j=1}^{C}\left(g_S(i,j)-\bar{g}_S\right)^2\right)^{1/2}} \qquad (1)$$

$r$ .................. *normalised cross - correlation coefficient*

$\sigma_T, \sigma_S$ ...... *standard deviations of grey values in the template and search image patches*

$\sigma_{TS}$ ............ *covariance of grey values in the image patches*

$g_T, g_S$ ...... *grey values in the template and search image patches*

$\bar{g}_T, \bar{g}_S$ ...... *mean grey values*

$R, C$ .......... *number of rows and columns of image patches*

The normalised correlation coefficient has values within the range $-1 \leq r \leq 1$. In the image matching process positive values close to 1 are demanded. A template moves pixel by pixel over the search window and a correlation coefficient is calculated in each position. The position where the correlation coefficient reaches its highest value is selected as a position of the best fit. If the position of the best fit should be determined with a subpixel accuracy, the values of correlation coefficient around its maximum are approximated by a continuous function, e.g. polynomial which coefficients are solved in least squares adjustment. The position of the maximum of the polynomial corresponds to the position of the best fit in the subpixel range. Based on standard deviations of polynomial's coefficients derived in least squares adjustment, a standard deviation of the improved position of the best fit can be calculated.

Uniqueness of the template within a search area can be checked by autocorrelation. In this case both a template and a search area are taken from the same image. By evaluating of correlation surface (given by values of correlation coefficient over the whole search area), it is possible to decide about suitability of the chosen template for matching. An example is shown in the figure 1. In the same way a proper size of a template can be tested and found.

| | single object | | low contrast | | repetitive pattern | |
|---|---|---|---|---|---|---|
| | SA | T | SA | T | SA | T |

| Correlation surface |
|---|



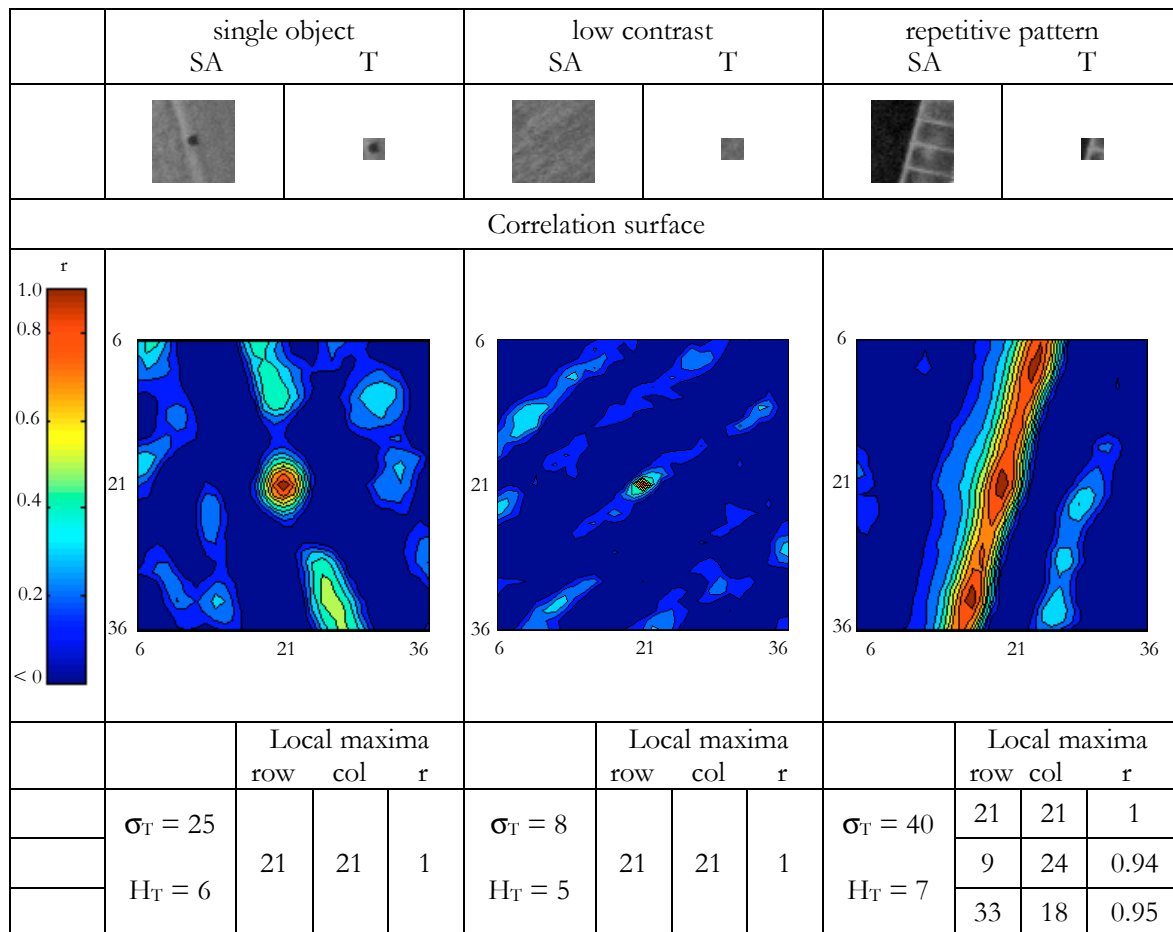| | | Local maxima | | | | Local maxima | | | | Local maxima | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | row | col | r | | row | col | r | | row | col | r |
| | $\sigma_T = 25$ | | | | $\sigma_T = 8$ | | | | $\sigma_T = 40$ | 21 | 21 | 1 |
| | | 21 | 21 | 1 | | 21 | 21 | 1 | | 9 | 24 | 0.94 |
| | $H_T = 6$ | | | | $H_T = 5$ | | | | $H_T = 7$ | 33 | 18 | 0.95 |

Figure 1: The use of autocorrelation for evaluating suitability of an image patch for matching. The figures in the middle show the distribution of the correlation coefficient. All negative values were changed to 0. The size of the templates (T) is 11 x 11 pel$^2$ and the size of the search area (SA) 41 x 41 pel$^2$, 1pel≈21µm. The standard deviation of gray values $\sigma_T$ and entropy $H_T$ give an overview about contrast and an amount of radiometric information in the template.

In practice, autocorrelation would mean increasing of the processing time of image matching. It is the reason why it has not been applied in available commercial software packages so far. In automated photogrammetric processes like tie point measurements or DTM derivation, the position of templates is chosen by means of interest or edge operators [9] that search for points suitable for matching.

Setting a threshold (a minimum value) for the correlation coefficient is a common method of eliminating mismatches in photogrammetry. A threshold value of 0.7 or 0.5 is usually applied [5]. Setting a threshold does not mean that all the mismatches are eliminated. Some of correct measurements are excluded at the same time. Using a lot of measurements (the redundancy principle) and applying statistical and adjustment techniques for outlier elimination is a possibility for solving this problem.

## 2.2 Least squares matching

Correlation coefficient is not an ideal measure of similarity between two image patches in case of their geometric and radiometric differences. An idea of least squares matching (LSM) is in minimising differences in intensity values between the template and search image patches in an adjustment process where geometric and radiometric corrections of one of matching windows are determined [9].

The relation between intensity values of two image patches $\mathbf{g}_T$ and $\mathbf{g}_S$ is expressed by the formula 2:

$$\mathbf{g}_T + \mathbf{e} = \mathbf{g}_S \qquad\qquad (2)$$

$\mathbf{e}$ is a noise vector caused by different radiometric and geometric effects in both images. In an ideal case of a perfect match $\mathbf{e}=0$. The goal is to find such geometric and radiometric transformation parameters of one of the windows, that the vector $\mathbf{e}$ is minimized. The details about a linearization of the formula 2 and the iterative process of calculation can be found in [1] or [7]. Two radiometric parameters, namely shift in brightness and contrast stretching are usually considered in the adjustment. The number of geometric parameters corresponds to the type of transformation that fits to the geometric relation between a template and a search window. With respect to the size of image patches an affine transformation (six parameters) is usually used. In some cases, such as matching two orthoimages, translation (two parameters) is sufficient. An important condition for successful LSM is to find an approximate position of the search area relatively accurate, e.g. within a few pixels. Cross-correlation can be used for this purpose. Quality of LSM is usually evaluated by standard deviation of derived transformation parameters, especially shifts.

## 2.3 MATLAB solutions

Several functions solving ABS in MATLAB has been developed for the purpose of research work and education. The overview of functions is given in Tab.1. Headers of functions can be found in the appendix.

Table 1: Overview of developed functions for area based matching

| m-file | Description |
|---|---|
| correl_coef.m | Finding a position of the best fit between a template ($r_t$ x $c_t$ pel$^2$) and a search area ($r_S$ x $c_S$ pel$^2$, $r_S \geq r_t$, $c_S \geq c_t$). |
| c_subpixel.m | Correlation in subpixel range by approximation of a correlation surface by the $2^{nd}$ order polynomial in the neighborhood of the position of the best fit |
| least_sq6_0.m * | Least squares matching with six geometric parameters (affine transformation). Functions 'LSM6_0', 'resampling6_0', and 'lin_rad_ad' are called by this function. |
| LSM6_0.m | Calculation of corrections of six geometric parameters in least squares adjustment. |
| resampling6_0.m | Resampling of an original search window according to the calculated geometric parameters. |
| lin_rad_ad.m | Calculation of a radiometric shift and scale between a template and a search window in least squares adjustment. |

* Functions solving least squares matching with four and two geometric parameters are also available

# 3  Applications of area based matching

The following text reports about application of ABS on two photogrammetric applications, namely a determination of parameters of exterior orientation of an aerial image and quality control of DTM. In both cases, all calculations except of standard procedures such as a derivation of an orthoimage were done by means of self-developed MATLAB scripts and functions. Details about both projects can be found in [2], [7], [8].

## 3.1 Orientation of a single aerial image based on existing orthoimage and DTM

Parameters of exterior orientation of an aerial image (position of a perspective center $X_0$, $Y_0$, $Z_0$ and rotations of an image $\omega$, $\varphi$, $\kappa$) can be determined indirectly by means of measurement of control points. If the position of at least three control points is known both in the image and in the ground reference coordinate system, the parameters of exterior orientation can be calculated using collinearity equations [5]. Measuring of control points in the field can be a time consuming process. Therefore several methods based on using existing data sets such as digital topographic maps or orthoimages and DTMs were tested within an OEEPE project 'Automatic Orientation of Aerial Images on Database Information' [2]. The idea was to carry out the whole procedure of finding control information, measurement of control points in the images, and calculating orientation parameters fully automatically.

The method presented in [3] is based on matching image patches derived from an orthoimage and a new aerial image by means of cross-correlation. A DTM must be also available. Ground coordinates of the orthoimage patch are known (the orthoimage is georeferenced), a height can be interpolated from the DTM. Image coordinates of a corresponding point in an aerial image are determined by image matching. Approximations of parameters of exterior orientation must be known for this purpose. If both ground and image coordinates of sufficient number of points that are well distributed over the whole aerial image are then known, final parameters of exterior orientation can be calculated. Due to the time interval between taking the images, only the image patches containing time stable and well-defined objects are chosen. In order to eliminate erroneous matches, a threshold for the correlation coefficient is applied. After finding corresponding patches between the orthoimage and an aerial image, orientation parameters are calculated by means of spatial resection with robust adjustment. Further investigation of the method with respect to replacing of a manual selection of control points in the images by an automated procedure, an application of LSM and increasing a degree of automation are presented in detail in [7].

A workflow of the suggested and tested procedure is shown in figure 2. The last step 'quality control' corresponds to a comparison of an existing orthoimage and a new orthoimage derived using orientation parameters calculated in the previous step. Except of derivation of a new orthoimage and extracting coordinates of control points from a topographic database, all calculations were done by means of self-developed MATLAB scripts.

```
┌────────────────────────────────────────────────────────────────────────────┐
│        Extracting co-ordinates of control points from topographic data sets  │
└────────────────────────────────────────────────────────────────────────────┘
                                    │
┌────────────────────────────────────────────────────────────────────────────┐
│                                 ┌───────────────────────────────────────────┐│
│                                 │ Measuring fiducial marks. Parameters       ││
│                                 │ of affine transformation between pixel     ││
│                                 │ and image co-ordinate systems              ││
│                                 └───────────────────────────────────────────┘│
│  ┌──────────────────────────┐   ┌───────────────────────────────────────────┐│
│  │ Extracting patches from  │   │ Collinearity equation for calculation of   ││
│  │ an existing              │   │ approximate image co-ordinates of          ││
│  │ orthoimage (templates)   │   │ control points in a new aerial image       ││
│  └──────────────────────────┘   └───────────────────────────────────────────┘│
│                                 ┌───────────────────────────────────────────┐│
│                                 │ Extracting patches from a new aerial       ││
│                                 │ image (searching area)                     ││
│                                 └───────────────────────────────────────────┘│
└────────────────────────────────────────────────────────────────────────────┘
```

Area based matching (cross-correlation, LSM)

Detection and elimination of outliers

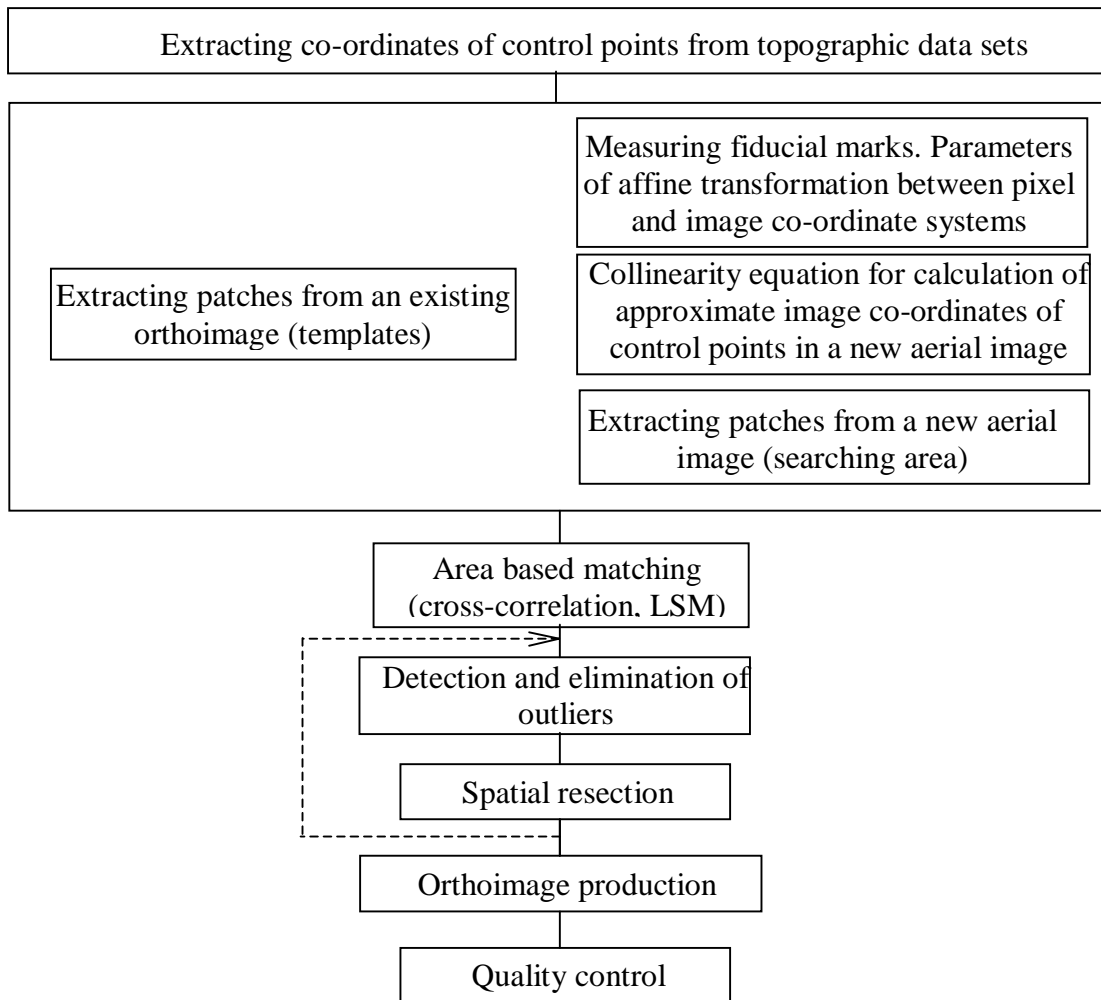Spatial resection

Orthoimage production

Quality control

Figure 2: Workflow of a tested method for automatic orientation of aerial images including orthoimage derivation and quality control. X, Y, Z coordinates of suitable objects are derived from a topographic database. Image patches are extracted from an existing orthophoto (templates) and a new aerial image (searching areas) and matched. Parameters of exterior orientation (EO) are calculated by means of spatial resection. It is carried out in an iterative process together with detection and elimination of outliers. A new orthoimage is derived and compared with the existing topographic orthoimage or map in order to evaluate its accuracy with regard to the existing data sets.

**3.2 Checking of DTM based on two overlapping orthoimages**

A geometric accuracy of DTMs is an important parameter for orthoimage production and other applications in hydrology, planning etc. Therefore the goal of a running EuroSDR project 'Automated DTM checking' is to develop methods for finding systematic errors and outliers in existing DTMs. One of possible methods is based on finding corresponding points in two overlapping orthoimages [4], [6], [7]. Provided the orientation parameters of images are correct, the corresponding points should have the same coordinates in both orthoimages. A difference in coordinates signalizes an error in a DTM. A DTM correction can be calculated by means of formula 3. Because the orthoimages are georeferenced, the coordinates of corresponding points are given directly in the reference coordinate system (e.g UTM).

$$dh \approx dX\,h/b + (dX\,h/b)^2/b \qquad\qquad\qquad\qquad (3)$$

*dh.........height correction*
*dX ........measured parallax*
*h...........flying height*
*b          length of base*

The calculation consists of following steps:
- Derivation of image patches in DTM posts. A size of templates and search areas is chosen according to the texture in the image and expected height errors.
- Area based matching including cross correlation and LSM.
- Calculation of DTM corrections according to the formula 3.

MATLAB scripts covering all three steps were created. The last step also includes setting thresholds for correlation coefficient and accuracy of LSM. Further investigations showed up, that it was more sufficient to match several points in the neighborhood of DTM posts and to calculate a final DTM correction as a mean of all neighboring corrections after excluding outliers that corresponded to mismatches.

The tests were carried out with images at the scale of 1:25 000 and a DTM given as a 10 m square mesh grid (derived from digitized contour lines, expected accuracy of 1.5 - 2 m). Only points on the terrain were matched. After applying corrections the DTM improved considerably. A comparison with manual measurement in large-scale images (accuracy of 9 cm) revealed a standard deviation of 0.4 m and only 1% of outliers (compare to accuracy of 1.5 to 2 m). The achieved accuracy corresponds to height measurement in stereomodels at the scale of 1:25 000.

## 4   Conclusion

Several MATLAB scripts and functions were developed for the purpose of carrying out tests connected to research projects dealing with automated orientation of aerial images using existing data sets and checking of DTMs. Both applications are based on area based matching. MATLAB proved to be a suitable developing environment for fulfilling both tasks. The only problem was processing time when large data sets (several thousands of points) had had to be matched. Created functions will be used in other research projects and in education of photogrammetry both for demonstration and practical exercises.

## Acknowledgement

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## Appendix – area based matching, overview of developed m-files

### correl_coef.m

function [r_max, pos, r, search, p_bf]=correl_coef(t, S)

% cross correlation of two image patches t, S
% t ... template
% S ... search area
% r_max ... maximal value of the correlation coefficient calculated within the search area
% pos ... position of the best fit, center of the template
% r ... correlation surface
% search ... a section of S corresponding to the template at the position of the best fit
% p_bf ... position of the best fit, upper left corner of the template


### c_subpixel.m

function [r_s, s_r_s]=c_subpixel(r_c);

% correlation in subpixel range by means of correlation coefficient
% r_c ... correlation surface
% r_s = [row, col] ... position of the best fit
% s_r_s = [Srow, Scol] ... standard deviation of the position of the best fit

**least_sq6_0.m**

function [par, s0, s_u, j]=least_sq6_0(t, S, search, p_bf)

% Least squares adjustment (LSM) with six geometric parameters.
% Radiometric adjustment is calculated prior to LSM by means of function lin_rad_adj.m
% t ... template
% S ... search area
% search ... a section of S corresponding to the template at the position of the best fit
% found by means of correlation coefficient (function correl_coef.m)
% p_bf ... position of upper left corner of the 'search' within S
% par = [tr, a1, a2, tc, b1, b2] ... geometric parameters
% s0 ... standard deviation of unit weight calculated from least squares adjustment
% s_u ... standard deviations of the shift parameters
% j ... number of iterations


**LSM6_0.m**

function [dx, s0, Q]=LSM6_0(t, search);

% Least squares matching with six geometric parameters
% Adjustment process for calculation of the corrections of the geometric parameters
% t ... template
% search ... a section of S corresponding to the template at the position of the best fit
% dx ... corrections to the geometric parameters
% s0 ... standard deviation of the unit weight
% Q ... cofactor matrix


**resampling6_0.m**

function rIm=resampling6_0(par, p_bf, S, sz);

% Resampling of the search area by means of bilinear interpolation
% Six geometric parameters were obtained in 'least_sq6_0.m'
% rIm ... resampled image
% par = [tr, a1, a2, tc, b1, b2] ... transformation parameters
% p_bf ... position of upper left corner of the position of the best fit within Y
% S ... search area
% sz ... size of the template


**lin_rad_ad.m**

function [r0, r1]=lin_rad_adj(t, search);

% Calculation of linear radiometric parameters r0, r1 between a template and a search area by
% means of least squares adjustment
% r0 ... shift parameter
% r1 ... scale parameter
% t ... template
% search ... a section of a search area
% observation equation: t+v=r1*s+r0