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A New Approach for Extraction of Information from Unoverlapped Photographed Area of a Stereo-pair

Ayman F. Ragab

Surveying and Photogrammetry, Department of Public Works,
Faculty of Engineering, Ain Shams University

Abstract: Most of conventional photogrammetric tasks in reconstructing the 3D object space have been mainly relying on distinct discrete points, to be totally associated with all underlying operations, just only in the overlapping region between photos. Nowadays, with the advent of digital photogrammetry, the used digital imagery has facilitated the opportunity to implement linear features, in addition to points, in various photogrammetric activities. The discriptive power of lines for 3D object reconstruction has been motivated by the major advantages of dealing with these straight lines (directions), especially with its great ability of automatically and reliably extracting these linear features from the input imagery. Also, linear features can be used to increase redundancy and improve the geometric strength of photogrammetric applications. This paper makes use of the benefits of these straight linear features or directions in determining the 3D ground coordinates of some object points, which are not presented in the overlap area of a certain stereo-pair. The developed approach deals with the image of the interest point in the first photo only, along with a specified direction, on which this point lies in the second photo. This approach gives a comparable results in 3D positionong, with the traditional concept of overlapping points, but with the possibility of decreasing the required overlap between photos, in order to cover a great extent of a certain area in less time and effort.

Key words: New approach for extraction · Stereo-pair · Egypt

INTRODUCTION

The majority of photogrammetric applications, including map compilation processes, are based heavily on the use of distinct point-based features. These points are well determined in two-dimensional imagery and they are suitable for manual operations. However, points do not usually possess both significant geometric and semantic information [1]. In addition, points do not exist in real environment and they must be signalized, normally with reflective targets and measured with field surveying techniques [2]. After the introduction of softcopy workstation and digital image compilation and analysis, the majority of recent research activities have been focusing on the automation of various point-based procedures in photogrammetry.

Recently, more attention has been focused on using higher-level features rather than point features. The use of digital image and well-developed image processing tools motivated the concept of this research, due to the ease of automatically extracting linear features than for point features [3], since linear features of an object are often well visible and better recognizable than corner points. The relibility of extracing linear features comes from the relationships among the set of the connected points that constitute that linear features. Moreover, higher-level features possess more semantics regarding the object space, as an important factor that can help in subsequent processes such as object recognition. In addition, linear features can be easily derived from existing maps, GIS databases, or terrestrial mpbile mapping systems (MMS), for example. Finally, linear features can be used as a dual representation of aerial features through the use of their boundaries. Accordingly, the course of digital photogrammetry towards automation has aroused a sincere interest in line-based approaches, in which linear features are introduced as the primitives in most fundamental photogrammetric tasks [4].

Corresponding Author: Dr. Ayman F. Ragab, Associate Professor of Surveying and Photogrammetry, Department of Public Works, Faculty of Engineering, Ain Shams University

The main objective of the present paper is to extract information for 3D object reconstruction within the limits of the unoverlapped region. This new approach depends on the accomodation of straight lines (directions) on the second photo of the stereo-pair, instead of dealing with the corresponding associated discrete points. In other words, to get the 3D ground coordinates of any object point in the unoverlapped area, the image of this point of interest should appear only on the first photo and to be lying on a specified direction in the second photo, without the need to be presented in this photo. Of course, this approach will give the ability to photogrammitically cover a great area, without increasing the number of taken photos. In addition, it helps in saving time for image coordinates measurements, since the interest point in this case is not necessary to be shown in the overlapped area.

In this context, the conventional photogrammetric procedures for 3D object positioning will be briefly illustrated first, followed by the motivation behind applying the new approach. Then, the developed approach, of using straight lines (directions) instead of discrete overlapped points, will be throughly investigated and presented. In addition, a quick overview of practically how this developed approach can be easily implemented, according to the tremendous advantages of softcopy photogrammetry workstations and digital image processing. Also, a practical evaluation of this developed approach, concerning the 3D ground coordinates computation of some object points, will be tested compared with the conventional methods. Finally, the main conclusions along with some appropriate recommendations will be given.

THE CONVENTIONAL MATHEMATICAL MODEL

As it is quite well-known, in order to photogrammetrically reconstruct a 3D object space from imagery, each interest point should be appeared in each two consecutive photos. In other words, it should be lie in the overlapped area between any stereo-pair. Then, the relationship between any point visible in the image space and its corresponding object space point is usually modelled by the well-known collinearity condition equations. In this involved mathematical model, the prespective center, the image point and its associated object point should lie on a straight line [e.g. 5]. In addition, incorporating only the first element of the lens distortion parameters (k_1), which make the significant effect in this model [6], the final expression will be:

$$\bar{x} + \bar{x}k_1 r^2 = (-f).\left[\frac{m_{11}(X - X_L) + m_{12}(Y - Y_L) + m_{13}(Z - Z_L)}{m_{31}(X - X_L) + m_{32}(Y - Y_L) + m_{33}(Z - Z_L)}\right] \quad (1)$$

$$\bar{y} + \bar{y}k_1 r^2 = (-f).\left[\frac{m_{21}(X - X_L) + m_{22}(Y - Y_L) + m_{23}(Z - Z_L)}{m_{31}(X - X_L) + m_{32}(Y - Y_L) + m_{33}(Z - Z_L)}\right] \quad (2)$$

in which:

$$\bar{x} = x - x_o \qquad \bar{y} = y - y_o, \qquad r = (\bar{x}^2 + \bar{y}^2)^{1/2}$$

- *x,y* are the image coordinates of any object point;
- x_0, y_0 are the coordinates of the principal point, expressed in the image coordinate system;
- X,Y,Z are the object-space coordinates of the point;
- *f* is the focal length of the camera;
- X_L, Y_L, Z_L are the object-space coordinates of the perspective center.
- *ms* are the elements of the (3x3) product transformation matrix (*R*), which are the functions of rotation angles (omega, phi, kappa) and given by:

$$R(\omega,\phi,\kappa) = \begin{bmatrix} \cos\phi\cos\kappa & \sin\omega\sin\phi\cos\kappa + \cos\omega\sin\kappa & -\cos\omega\sin\phi\cos\kappa + \sin\omega\sin\kappa \\ -\cos\phi\sin\kappa & -\sin\omega\sin\phi\sin\kappa + \cos\omega\cos\kappa & \cos\omega\sin\phi\sin\kappa + \sin\omega\cos\kappa \\ \sin\phi & -\sin\omega\cos\phi & \cos\omega\cos\phi \end{bmatrix}$$

Hence, each associated objec point in the available ground coordinate system provides two collinearity condition equations, similar to those given by equations (1) and (2), in each taken photo. Accordingly, there are two different approaches for solving this algorithm, which are two-steps solution and one-step solution. In this two-steps solution, the numerical values of the image coordinates and the correponding 3D ground coordinates of the used control points are utilized only first, to obtain both intrinsic and extrinsic camera orientation parameters. Then, such nuisance parameters, as determined from the above first step, are kept fixed and used in a second step to obtain the 3D ground coordinates of any object point of interest, through its corresponding image coordinates. However, in the one-step solution, the solution is performed simultaneously to obtain both nuisance parameters and primary parameters of unknown ground coordinates of object points. The one-step solution will usually yield to more precise results, according to the increase in the number of degrees of freedom of the least squares adjustment and the interchangeable indirect effect of both sets of unknown parameters [7].

PRELIMINARY CONSIDERATIONS

On the other hand, the 3D ground coordinates of any interset object point in the overlap area of a certain stereo-pair can be computed by an alternative sequence, instead of applying the pure collinearity mathematical model, as discussed in the previous section. This involved sequence takes only the two collinearity condition equations, in the form of equations (1) and (2), for any interest point in the first photo only. Then, the line segment connecting the conjugate image point and any visible control point will be taken into account in the second photo of the stereo-pair. Accordingly, the corresponding perspective center and the object space line segment constitute an *object plane*, whose equation can be considered the required third one, to be added to the previous original two collinearity condition equations, of solving for the unknown 3D ground coordinates (X,Y,Z) of that interest object point.

Accordingly, the underlying principle of this corresponding plane equation, as shown in Fig. 1, states that the three vectors which are involved in the second photo should be coplanar. These vector are defined by [1]:

V_1: Is the vector connecting the chosen control point and the interest unknown object point in the object space.

V_2: Is the vector connecting the perspective center of the second photo and the chosen control point in the object space.

V_3: Is the vector connecting the perspective center of the second photo and the image point of the interest unknown object point in the image space. Of course, this vector coincides with the main vector connecting the perspective center and the interest unknown object point. Then, both vectors have the same components ratio.

It should be noted that, these three vectors must be expressed with respect to the same reference frame, which can be the object ground coordinate system. This is basically done for the vector (V_3), in which the original measured image coordinates have been transformed to another image coordinate system, that is parallel to the object ground coordinate system. Accordingly, the coplanarity condition can be mathematically expressed through a triple product as:

$$(V_1 x V_2).V_3 = 0 \tag{3}$$

so that,

$$\begin{vmatrix} (X_{L2}-X_1) & (Y_{L2}-Y_1) & (Z_{L2}-Z_1) \\ (X_1-X) & (Y_1-Y) & (Z_1-Z) \\ Nx & Ny & Nz \end{vmatrix} = 0$$

where:

$$Nx = m_{11}\left(\overline{x}+\overline{x}k_1r^2\right)+m_{21}\left(\overline{x}+\overline{x}k_1r^2\right)+m_{31}\left(-f\right).$$

$$Ny = m_{12}\left(\overline{x}+\overline{x}k_1r^2\right)+m_{22}\left(\overline{x}+\overline{x}k_1r^2\right)+m_{32}\left(-f\right).$$

$$Nz = m_{13}\left(\overline{x}+\overline{x}k_1r^2\right)+m_{23}\left(\overline{x}+\overline{x}k_1r^2\right)+m_{33}\left(-f\right).$$

in which, the ratio of the three components (Nx,Ny,Nz) corresponds to the line connecting the perspective center and the image point of the unknown interest object point, in the rotated image coordinate system, is the same ratio of the three original componenets [(X_{L2}-X), (Y_{L2}-Y), (Z_{L2}-Z)] corresponds to the vector (V_3) in the object ground coordinate system.

Finally, this coplanarity condition equation can be simply rewritten as:

$$J_1.X + J_2.Y + J_3.Z + J_4 = 0 \tag{4}$$

whose, (J_1,J_2,J_3,J_4) are known computed constants. Consequently, this equation incorporates the unknown 3D ground coordinates [X,Y,Z] of a certain object point, as a function of the image coordinates of the interest point in the second photo, intrinsic and extrinsic camera orientation parameters, as well as the known ground coordinates of the chosen control point. So, this equation does not introduce any new parameters.

It is worthwhile to mention here that, only two independent plane condition equations, in the form of equation (4), can be derived and added to the original two collinearity condition equations deduced from the first photo, in order to be solved simultaneously by least squares adjustment procedures. Of course, these two independent equations will be related to any selected two control points. In other words, any additional plane condition equation will be dependent and no solution can be reached. In addition, the same results, concerning the 3D ground coordinates of any number of object points, can be obtained by using any pair of the involved ground control points. Also, it should be noted that, this sequence can be applied not only for a stereo-pair, but can be extended to be included in a photogrammetric analysis with any number of taken photos. Finally, this trend is compared with the original conventional collinearity condition equation for a two definite stereo-pairs, whose their corresponding intrinsic and extrinsic camera orientation parameters are adjusted and completely known. The first stereo-pair is formed from close range photogrammetric data, while the other one is formed from aerial photogrammetric data.

In this context, the obtained 3D ground coordinates of all selected check object points in both tested stereo-pairs, using both sets of condition equations, which are the pure collinearity condition equations and the adopted previously mentioned sequence, are typically identical in all directions. Accordingly, this associated trend in reconstructing the 3D object space, which can be simply considered as a mix between collinearity and coplanarity condition equations, has been motivated the implementation of the new approach, developed in this paper, in extracting information within the overlapped and/or unoverlapped area between taken photos, as it will be discussed in the next section.

THE DEVELOPED APPROACH

As stated before, instead of dealing with one object point defined by its image coordinates in the two overlapped photos, the developed approach will take the image coordinates of that interest object point visible in one photo only, besides a specified line (direction) in the second photo, on which this interest point lies. This specified direction has its start point to be any one of the involved ground control points. In this terminology, an intermediate image point in the overlapped segment of the line connecting the chosen control point and the visible image point in the first photo will be selected, along with its corresponding conjugate image point in the second photo. This practical step is easily done by the principle of digital photogrammetry applications and image matching. Consequently, the 3D ground coordinates of this intermediate point will be determined, through the use of known intrinsic and extrinsic orientation parameters of the associated stereo-pair. Then, this intermediate point will constitute the plane condition equation, as presented in the previous section, on which the interest object point lie. It should be noted that, all or some intermediate points along that direction could be virtual points, which any digital photogrammetric workstation has the ability to locate them, of course, with the skill and experience of the operator.

Of course, this approach is easily implemented and applied using linear features, since any required intermediate point on that linear features could be precisely determined and selected. In this case, this linear feature does not matter to be totally visible in the stereo-pair, since any selected image point along this linear feature will lie on the object plane, formed by this linear feature and the perspective center. Accordingly, any vector containing the persepective center and any point along the image space linear feature should be coplanar with the formed object plane, as depicted in Fig. 2. Hence, it is convenient to add the plane condition equation, similar to equation (4), corresponds to this intermediate point along the linear feature, to the original two collinearity condition equations related to the interest object point visible in the first photo only. Therefore, these three equations are the minimum required ones to be solved together, in order to get the 3D ground coordinates (X,Y,Z) of any interest point along this linear feature, even if it was not visible in the second photo of that stereo-pair.

So, the number of object plane condition equations is equal to the number of the measured intermediate points along the imaged linear feature or direction. Therefore, the great ability in the increase of the number and/or precision of selecting the intermediate image point along any specified direction, the more the acuuracy in determining the 3D ground coordinates of any unknown object point. Of course, the number of the intermediate image points to be selected is governed by the extent of the linear feature or the specified direction in the overlapped area of the stereo-pair.

PRACTICAL IMPLEMENTATION OF THE DEVELOPED APPROACH

This section is devoted to a quick overview of the practical steps, that can be performed on any digital photogrammetric software, in order to implement the developed approach. These steps are briefly summarized as follows:

- Adjust normally the stereo-pair to be modeled in 3D-space.
- Get the image coordinates (x,y) of the unknown interest object point, which appears only in the first photo of the stereo-pair.
- View the stereo-pair separately on the digital photogrammetric workstation.
- In the first photo, draw a line connecting any selected control point and the interest unknown object point. In this case, a segment of the corresponding line in the second photo will be introduced, automatically by the concept of image matching technique, just in the overlapped area between the two photos of the stereo-pair. This step is schematically shown in Fig. 3.

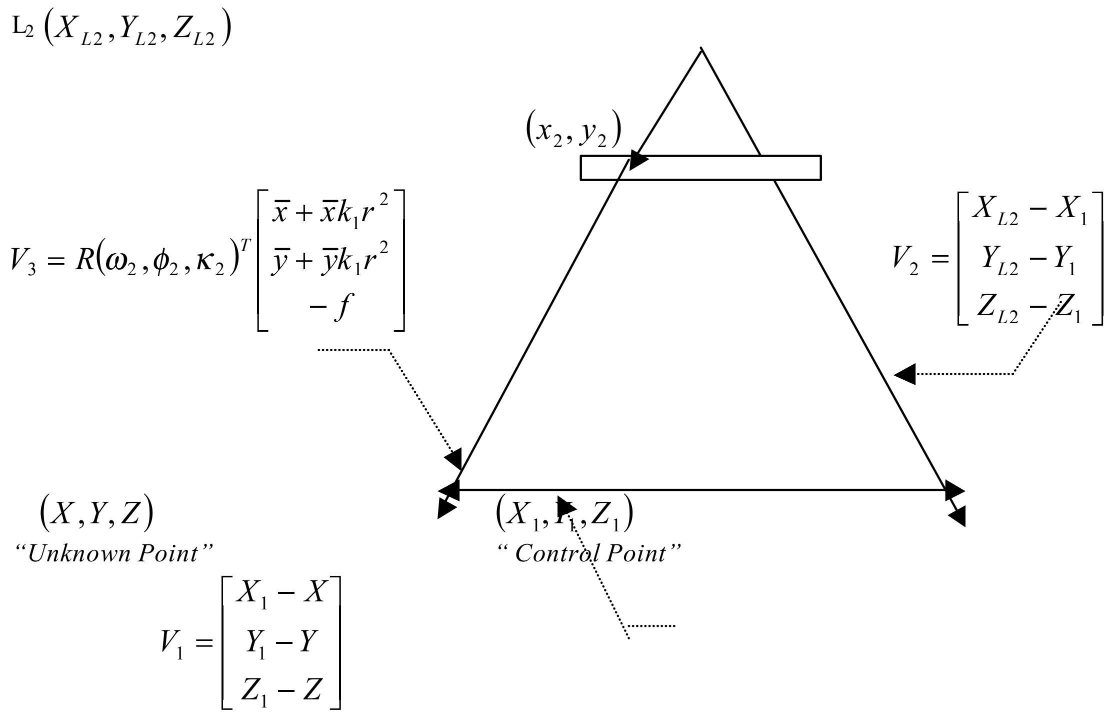

Fig. 1: Mathematical model of an image straight line segment

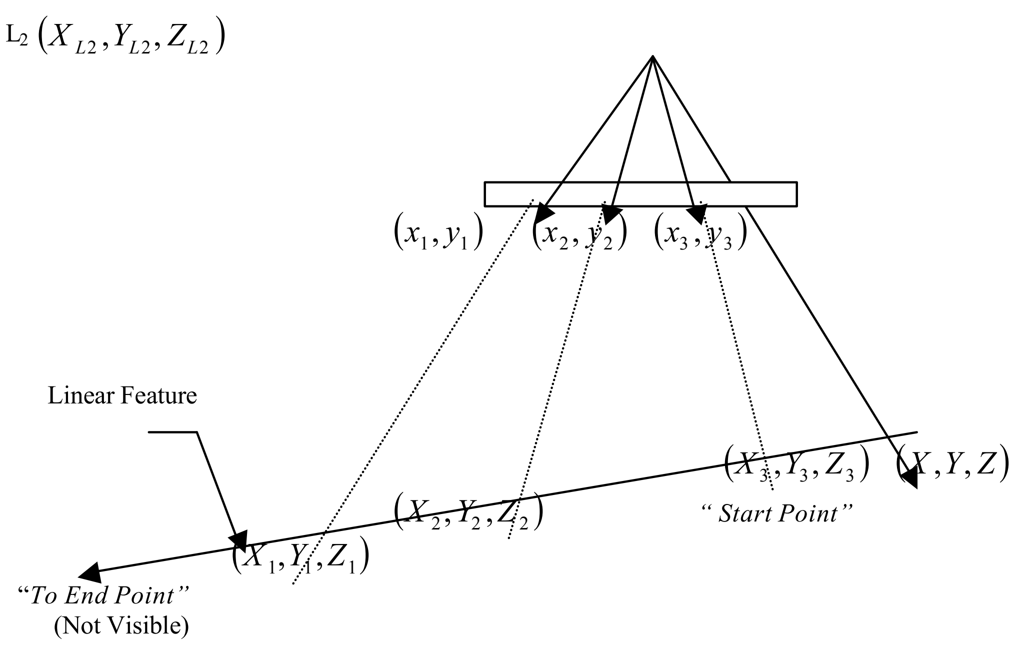

Fig. 2: Mathematical model of linear feature

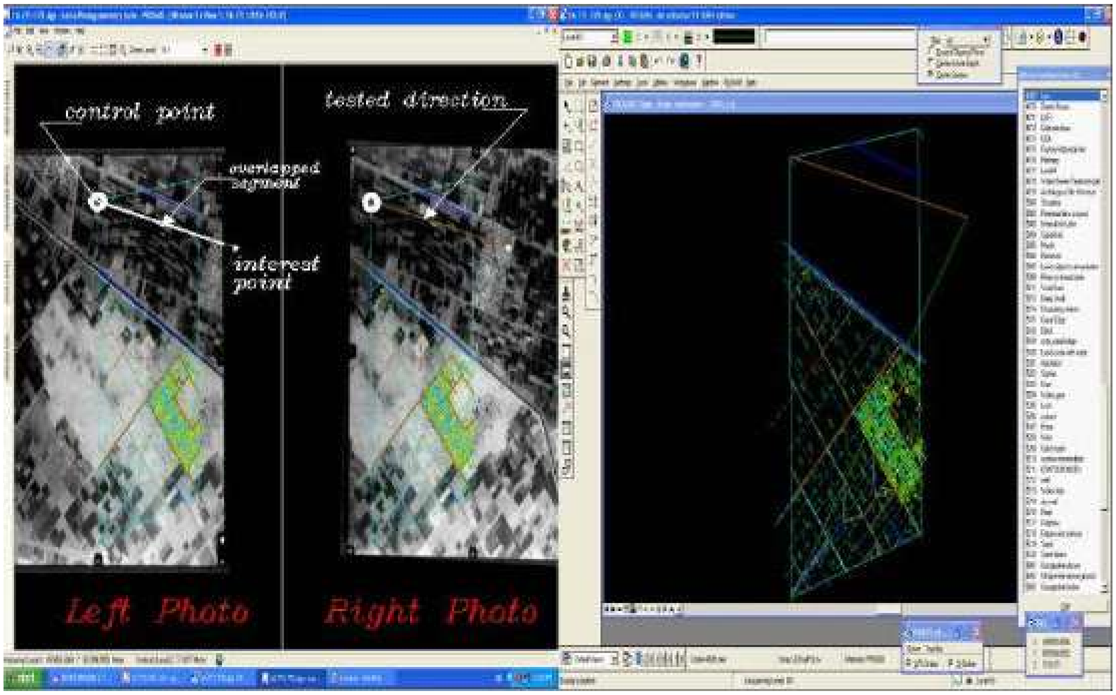

Fig. 3: Matched created line segment

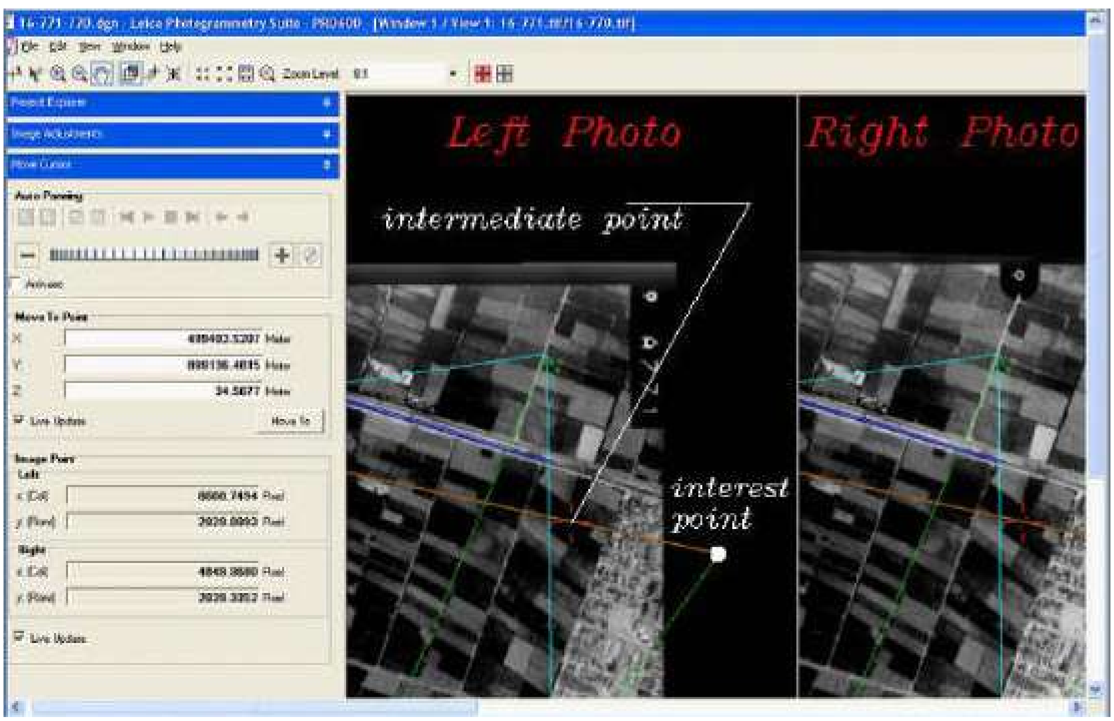

Fig. 4: Identifying intermediate points locations

- View this segment of the line stereoscopically and get directly the 3D ground coordinates (*X,Y,Z*) of some locations on that line, or the corresponding matched image coordinates in both photos. Of course, these coordinates can be used as intermediate points that lie on the created direction and hence, forming the required object plane. Also, this step is illustrated in Fig. 4.
- Apply analytically, by a developed MATLAB program, the solution of the formed equations associated with the new developed approach.

EXPERIMENTAL RESULTS

The developed approach is applied on an aerial stereo-pair, captured by a frame camera, whose focal length is 153.90 mm and with a flight height equals approximately 2000 m. This stereo-pair, which is shown in Fig. 5, is processed on a Leica Photogammetry Suite-PRO 6000 "LSP" digital photogrammetric software. This approach is tested twice, the first one is for an interest point lies on the overlap area, while the second one is for another point lies outside the overlap area. In both cases, a line (direction) was drawn from a ground control point to the unknown interest object point and a number of intermediate points was precisely selected on that direction, within the overlapped segment, with their corresponding 3D ground coordinates (*X,Y,Z*) and/or their image coordinates (*x,y*) in both photos. In the first case, three intermediate points were selected on the direction, while in the second case, also a certain number of intermediate points were selected on each direction.

It is worthwhile to mention here that, in the first case, the output ground coordinates of the unknown interest object point is compared with its corresponding values, derived directly from the digital photogrammetric software. In the second case, in which the unknown interest object point is outside the overlap area and hence, its 3D ground coordinates derived from the software is not precise, especially concerning its height, two different directions from two different control points are considered. The output ground coordinates of this unknown object point from each direction is computed and checked together, to ensure the reliability of the developed approach. Moreover, the final adjusted ground coordinates is compared with the corresponding coordinates derived digitally from the next stereo-pair, that having the unknown point to lie in the overlap area. The obtained results for both study cases are listed in Table 1.

From this table, it is quite clear that, the developed approach is considered efficient and powerful to be applied, since the output 3D ground coordinates computed from each tested direction are nearly the same, besides the resulted discrepancies between that computed 3D ground coordinates and the corresponding original values computed directly from the digital software are small in magnitude and usually in order of few centimeters. Of course, these discrepancies could be accepted, according to the scale and height of photography. It should be noted here that, these discrepancies could be in order of sub-centimeter in case of close-range stereo-pair, since usually the variation in depths in the perpendicular direction of the photographed facades is not so significant. In addition, these discrepancies tend to be zeros in case of linear features, since it is easily to choose precisely any intermediate points along these linear features.

Table 1: Ground Coordinates Discrepancies between the Results of Both the Developed Approach and the Commercial Digital Photogrammetric Software

Case (1) "Overlapped Area"

No. of Intermediate Points	Resulted output 3D ground discrepancies (m) ΔX	ΔY	ΔZ	ΔP
1	0.296	-0.235	0.540	0.659
2	0.249	-0.198	0.454	0.554
3	0.218	-0.137	0.397	0.473

Case (2) "Unoverlapped Area"

Selected Image direction Discrepancies (m)	No. of Intermediate Points	Resulted output 3D ground ÄX	ÄY	ÄZ	ÄP
1	1	0.173	-0.403	0.909	1.009
	2	0.118	-0.275	0.620	0.668
	3	0.103	-0.239	0.539	0.598
2	1	0.112	-0.261	0.587	0.652
1 & 2	4	0.097	-0.227	0.512	0.568

CONCLUSIONS

In the current paper, a new developed approach for reconstructing a 3D object space inside and/or outside the overlapped area of a stereo-pair, using straight lines or directions, has been presented. Using straight lines for 3D positioning of any object point is based on the principle that straight lines in the object space will be imaged by a frame camera as image straight lines, in the absence of distortion. Deviation from straightness in the image space will be accommodated and modeled by dealing with a number of points that should lie on this line or direction, to be finally governed to best fit that direction. This final created direction with the perspective center of the photo, which does not contain the interest object point in its overlap area, will constitute the required object plane, that include the interest unknown object point.

The proposed algorithm of this approach proved to be efficient and powerful, since its corresponding results for the 3D ground coordinates are nearly the same compared with the conventional collinearity condition equations, that depend on conjugate points on the overlapped area. Of course, this will overcome the problems due to the existence of shadows, illuminations,... etc., which lead to a great difficulties in identifying some object points in one photo of a stereo-pair and hence, their corresponding image coordinates in that photo will not be well-determined. Accordingly, applying this developed approach will be a vital issue. Also, as a great privilege of this developed approach, it can be also extended, with some precautions and operator skill, to be applied for extracting information in the unoverlapped area. Accordingly, such methodology is valuable for decreasing the percentage of the overlap between any stereo-pair.

It should be noted that, this approach is promosing and applicable to images containing a group of straight lines. In this case, to get the whole extent of any linear feature, it will not be necessary to be totally visible in the stereo-pair. This can be easily achieved for close range imagery, since man-made scenes in those images are rich of straight lines. In addition, the precision of identifying and selecting any intermediate point along the specified direction does not greatly affect the final corresponding computed 3D ground coordinates of the unknown object point. For aerial imagery, special attention should be paid to ensuring the straightness of linear features prior to their use and also for measuring the image coordinates and/or selecting the intermediate points along the tested direction.

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