Normalization of Linear Array Scanner Scenes Using the Modified Parallel Projection Model

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Key words: Linear Array Scanners, Rigorous Model, Modified Parallel Projection, Epipolar Resampling

SUMMARY

Epipolar resampling aims at generating normalized images where conjugate points are located along the same row. Such a characteristic makes normalized imagery important for many applications such as automatic image matching, DEM and ortho-photo generation, and stereo-viewing. Traditionally, the input media for the normalization process are digital images captured by frame cameras. These images could be either derived by scanning analog photographs or directly captured by digital cameras. Current digital frame cameras are incapable of providing imagery with ground resolution and coverage comparable with those of analog ones. Linear array scanners are emerging as a viable substitute to two-dimensional digital frame cameras. However, linear array scanners have more complex imaging geometry than that of frame cameras. In general, the imaging geometry of linear array scanners produces non-straight epipolar lines. Moreover, epipolar resampling of captured scenes according to the rigorous model, which faithfully describes the imaging process, requires the knowledge of the internal and external sensor characteristics as well as a Digital Elevation Model (DEM) of the object space. Recently, parallel projection has emerged as an alternative model approximating the imaging geometry of high altitude scanners with narrow angular field of view. In contrast to the rigorous model, the parallel projection model does not require the internal or the external characteristics of the imaging system and produces straight epipolar lines. In this paper, the parallel projection equations are modified for better modeling of linear array scanners. The modified parallel projection model is then used to resample linear array scanner scenes according to epipolar geometry. The proposed methodology requires a minimum of five ground control points and does not require the availability of DEM. Experimental results using IKONOS data demonstrate the feasibility of the proposed methodology.

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1. INTRODUCTION

Resampled images according to epipolar geometry have the prime characteristic of having conjugate points along the same row. This characteristic is valuable for automated image matching as the search space for conjugate points becomes one-dimensional, thus reducing matching ambiguities. Resampled images according to epipolar geometry are utilized in many photogrammetric applications such as automatic image matching, DEM and ortho-photo generation, and stereo-viewing.

The normalization procedure as well as deriving object space information from imagery require mathematical modeling of the incorporated sensor. Rigorous and approximate sensor models are the two main categories describing the mathematics of the involved imaging geometry. The former is based on the actual geometry of the image formation process involving the internal (Interior Orientation Parameters – IOP) and the external (Exterior Orientation/geo-referencing Parameters – EOP) characteristics of the implemented sensor. Since rigorous modeling is the most accurate model, it has been the focus of a large body of photogrammetric literature (Lee and Habib, 2002; Habib et al., 2001; Lee et al., 2000; Wang, 1999; McGlone and Mikhail, 1981). The EOP/geo-referencing parameters can be indirectly estimated using Ground Control Points (GCP) or directly obtained using GPS/INS units. The indirect estimation of the EOP requires an excessive number of ground control points. Moreover, for space-borne scanners with narrow Angular Field Of View (AFOV), the estimation process is unstable (Wang, 1999). On the other hand, direct geo-referencing, using GPS/INS units, is negatively affected by bias values in the available IOP and/or EOP (Fraser and Hanley, 2003; Habib and Schenk, 2001). Furthermore, the direct geo-referencing parameters might be concealed by the scene provider. For example, Space Imaging does not provide the EOP for commercially available IKONOS scenes.

Reently, many approximate models such as Rational Function Model (RFM), Direct Linear Transformation (DLT), Self-calibrating Direct Linear Transformation (SDLT), and parallel projection (Tao and Hu, 2001; Wang, 1999; Okamoto et al., 1992) have been developped. Among these alternative models, the parallel projection is the simplest one, which could be utilized for epipolar resampling since it accurately describes the imaging geometry of scanners with narrow AFOV moving with constant velocity and attitude.

This paper starts with a brief discussion of epipolar resampling of frame and linear array scanner imagery. This introduction is followed by the rationale behind the choice of the parallel projection model and its mathematical formulas. Then, the proposed approach for epipolar resampling of linear array scanner scenes is introduced. The experimental results section outlines the performance of the new approach in resampling IKONOS scenes according to epipolar geometry. Finally, the paper highlights the research conclusions and recommendations for future work.

2. EPIPOLAR RESAMPLING OF FRAME AND LINEAR ARRAY SCANNER IMAGERY: BACKGROUND

Epipolar resampling aims at generating normalized images where corresponding points are located along the same row. Moreover, the *x*-parallax between conjugate points in the normalized imagery is linearly proportional to the depth of the corresponding object point across the air base connecting the involved perspective centers. Prior to investigating linear array scanner scenes, one has to closely analyze the normalization process for frame images. Such an analysis is essential since it provides the conceptual bases, which are common to frame cameras and linear array scanners. Figure 1 depicts the relative relationship among the original and normalized frame images. For a given image point (p), the epipolar plane is defined as the plane through the air base and the point in question. The intersection of the epipolar plane with the image planes produces conjugate and straight epipolar lines ($I_{p'}$, I'_p). The normalization process creates new imagery where conjugate epipolar lines are aligned along the same row (Cho et al., 1992).

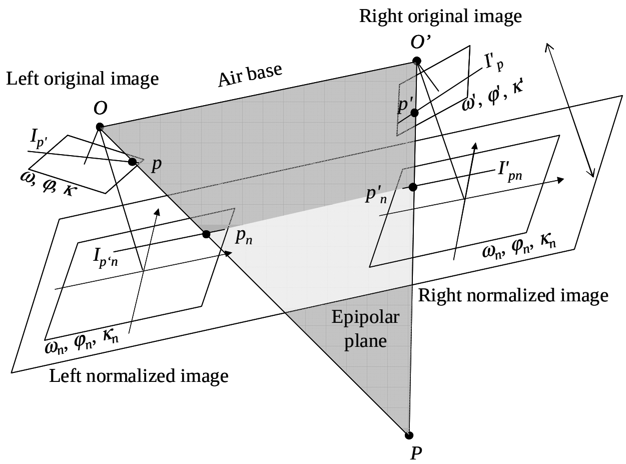


Figure 1: Epipolar resampling of frame images

Habib et al., 2004, discussed the difficulties associated with rigorous resampling of linear array scanner scenes according to epipolar geometry. These difficulties can be summarized as follows:

- In general, the resulting epipolar lines in linear array scanner scenes are not straight even for the simplest flight trajectory; namely a scanner moving with constant velocity and attitude.
- Using the rigorous sensor model, there is no simple transformation function that maps non-straight epipolar lines in the original scenes onto straight ones in the normalized scenes.

Moreover, the resampling procedure requires the availability of a DEM together with the internal and external sensor characteristics. The object space requirement is impractical since the normalization process is mainly carried out to facilitate DEM generation. In addition, the internal and external sensor characteristics might not be available due to lack of the necessary control and/or intentional concealment by the scene provider, which is the case for IKONOS imagery.

Due to the above difficulties, approximate models, which do not involve the internal and external characteristics of the implemented sensor, are emerging as potential alternatives leading to a simpler normalization procedure for linear array scanner scenes. Among these models, the parallel projection seems to be the most promising as it yields straight epipolar lines (Habib et al., 2004). Thus, the following sections deal with this model with regard to its suitability as an approximate sensor model and how it influences the normalization procedure.

3. PARALLEL PROJECTION

This section starts by discussing the rationale behind the selection of the parallel projection as an approximate sensor model and its mathematics. This discussion will be followed by a necessary modification to bring the actual imaging geometry of linear array scanners closer to the parallel projection.

3.1 Rationale

The parallel projection assumes that the projection rays from the object space to the scene plane are parallel to each other. Therefore, for such an imaging geometry, there is no projection/perspective center. This would be the case if the principal distance associated with perspective projection approaches infinity; that is the sensor's AFOV approaches zero. The suitability of the parallel projection model in approximating the imaging geometry associated with linear array scanner scenes can be attributed to the following remarks (Okamoto et al., 1992):

- Many space born scanners have narrow AFOV. For example, the AFOV for an IKONOS scene is less than 1º. In such a case, the perspective light rays along the scanning direction are very close to being parallel.
- Space imagery is usually acquired within a short time period – e.g., it is about one second for an IKONOS scene. Therefore, the scanner can be assumed to have the same attitude while capturing the scene. Consequently, the perspective/planar bundles defined by consecutive scans are parallel to each other.
- For scenes captured within a very short time period, the scanner can be assumed to move with constant velocity (i.e., the scanner travels equal distances in equal time intervals).

The first observation leads to an *almost* parallel projection along the scan lines, while the remaining remarks yield parallel projection across the scan lines. In summary, one might assume that scenes captured by space borne scanners with narrow AFOV in a short time period conform to parallel projection geometry. The mathematics of the parallel projection will be discussed in the next subsection.

3.2 Mathematical Formulation of the Parallel Projection Model

The objective of this section is to introduce the mathematical relationship between the coordinates of corresponding object and scene points in imagery captured according to parallel projection. Before going into the details of the mathematical relationship, let us start by analyzing the involved parameters in such a transformation. As it was mentioned earlier, the parallel projection assumes that the projection rays from the object space to the scene plane are parallel to each other. Therefore, the first group of parameters should define the direction of the projection vector relative to the object space coordinate system. This group could be represented by a unit projection vector $(L, M, N)^T$. A unit projection vector can be described by two independent parameters (e.g., L, M). The second group of parameters should deal with the orientation and the location of the scene plane relative to the ground coordinate system. The orientation of the scene plane can be defined by the rotation angles (ω, φ, κ) relating the scene and object coordinate systems. On the other hand, the location of the scene plane relative to the ground coordinate system can be described by the spatial offset between the origins of the involved coordinate systems (Δx, Δy, Δz). However, due to the nature of the parallel projection, the z-component of the offset vector (Δz) is irrelevant as the same scene will be generated regardless of the numerical value of Δz. Therefore, only the planimetric components of the offset vector (Δx, Δy) are necessary. Finally, a scale factor (s) should be adopted to reduce the spatial extent of the derived scene. In summary, the parallel projection formulation involves eight parameters ($L, M, \omega, \varphi, \kappa; \Delta x, \Delta y,$ *and* s).

Having discussed the involved parameters, let us proceed by considering Figure 2, where O is chosen to be the origin of the object and scene coordinate systems. An object point P – $(X, Y, Z)^T$ – in the object space is mapped to $(u', v', 0)^T$ in the scene coordinate system. The mathematical relationship between corresponding scene and object coordinates can be derived using the vector summation in Equations 1.

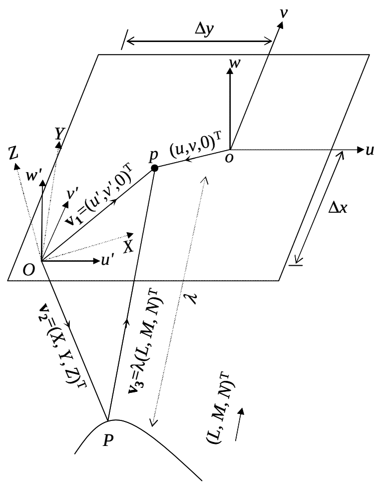


Figure 2: The parallel projection model

$$\begin{bmatrix} u' \\ v' \\ 0 \end{bmatrix} = R^T_{(\omega,\varphi,\kappa)} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} + \lambda R^T_{(\omega,\varphi,\kappa)} \begin{bmatrix} L \\ M \\ N \end{bmatrix} \qquad (1)$$

where:

λ is the distance between the object point P and the corresponding scene point p; and

$R_{(\omega,\varphi,\kappa)}$ is the rotation matrix between the scene and object coordinate systems.

The u' and v' axes of the scene coordinate system can be relocated and rescaled using Δx, Δy, and s to obtain another coordinate system whose axes are defined by u and v, Figure 2. Applying the scale and the two shift values to the scene coordinates (u', v', 0) in Equations 1 leads to Equations 2.

$$\begin{bmatrix} u \\ v \\ 0 \end{bmatrix} = s.\lambda.R^T_{(\omega,\varphi,\kappa)} \begin{bmatrix} L \\ M \\ N \end{bmatrix} + s.R^T_{(\omega,\varphi,\kappa)} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} + \begin{bmatrix} \Delta x \\ \Delta y \\ 0 \end{bmatrix} \qquad (2)$$

Equations 2 can be re-parameterized, after eliminating λ, to produce the linear form of the parallel projection in Equations 3.

$$\begin{aligned} u &= A_1 X + A_2 Y + A_3 Z + A_4 \\ v &= A_5 X + A_6 Y + A_7 Z + A_8 \end{aligned} \qquad (3)$$

The coefficients $A_1 - A_8$ in Equations 3 represent the linear parallel projection parameters corresponding to (L, M, ω, φ, κ; Δx, Δy, *and* s). Forward and backward transformations between these sets of parameters could be developed. It should be noted that Equations 2 and 3 describe the mathematical relationship between a three-dimensional object space and a two-dimensional scene. An extension of this model deals with a planar object space. In this case, the Z component of the object coordinates can be expressed as a linear combination of the planimetric coordinates (X and Y) leading to a standard 6-parameter Affine transformation, Equations 4. Thus, the parallel projection between two planes is represented by a 6-parameter Affine transformation.

$$\begin{aligned} u &= A'_1 X + A'_2 Y + A'_3 \\ v &= A'_4 X + A'_5 Y + A'_6 \end{aligned} \qquad (4)$$

3.3 Perspective to Parallel (PTP) Transformation

The imaging geometry of scenes captured by a scanner moving along its trajectory with constant velocity and attitude can be described by a parallel projection along the flight trajectory and perspective geometry along the scanner direction. The perspective projection along the scanner direction can be approximated by a parallel projection for systems with narrow AFOV. However, the scene coordinates along the scan line direction can be modified to bring the perspective projection along the scan line closer to being a parallel one. This modification can be established through Perspective to Parallel (PTP) transformation (Okamoto et al., 1992), as expressed by the first equation in (5). The second equation in (5) indicates that no modification is required across the scan lines since the system is assumed to travel with constant velocity and attitude.

$$v = y \frac{1}{1 - \frac{y}{c}\tan(\psi)} \qquad (5)$$
$$u = x$$

where:

c is the scanner's principal distance;

ψ is the scanner roll angle; and

x, y are the original scene coordinates across and along the scan line, respectively.

It should be noted that the PTP in Equations 5 assumes a *flat terrain* (Okamoto et al., 1992). Combining the linear form of the parallel projection and the PTP transformation yields the modified parallel projection in Equations 6.

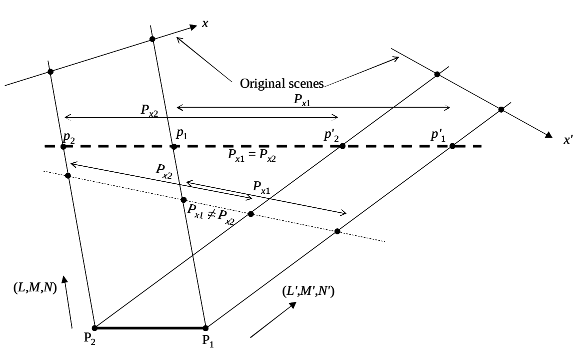
$$x = A_1X + A_2Y + A_3Z + A_4$$
$$y = \frac{A_5X + A_6Y + A_7Z + A_8}{1 + \frac{\tan(\psi)}{c}\left(A_5X + A_6Y + A_7Z + A_8\right)} \qquad (6)$$

The nine parameters in Equations 6 ($A_1 - A_8$ and ψ) can be estimated using a minimum of five GCP. The next section deals with the utilization of the parallel projection parameters for epipolar resampling of linear array scanner scenes.

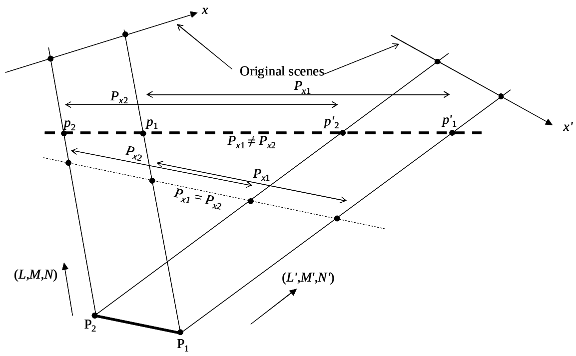
4. NORMALIZATION PLANE SELECTION

Ono et al. (1999) proved that using the parllel projection model, epipolar lines become straight lines. In addition, Morgan et al. (2004) proved that epipolar lines of different points are parallel to each other within a scene captured accoring to the parallel projection. Furthermore, the authors derived a methodology for rotating, scaling, and shifting the scenes in order to eliminate *y*-parallax between the scenes. However, this methodology is incapable of providing a linear relationship between *x*-parallax and depth values.

Recall that in the case of frame cameras, a nomalizaion plane was chosen on which the images are projected during the normalization procedure. Similarly, in the case of linear array scanners, we would like to choose a plane to project the scenes. The selection criterion is to maintain a linear relationship between *x*-parallax and depth values. Figure 3-a depicts a profile along the epipolar plane containing the two object points P_1 and P_2 at the same elevation. The figure also shows the epipolar line pairs for non-coplanar and coplanar stereo-scenes. A closer investigation of this figure reveals that the same *x*-parallax value for these points could be only achieved when dealing with stereo-scenes contained within a common horizontal plane (as represented by the bold dashed line in Figure 3-a). Therefore, scenes contained in a *common* and *horizontal* plane will exhibit *x*-parallax values that are linearly proportional to the *elevation*. To be more general, any common plane (as represented by the dotted line in Figure 3-b) would yield *x*-parallax values that are proportional to the depths along the normal to that plane. This common plane will be denoted hereafter as the normalization plane. For visualization purposes, it is preferred to obtain equal *x*-parallax values for points at the same elevation. Thus, a horizontal normalization plane should be selected as shown in Figure 3a. In summary, to ensure a meaningful x-parallax in the normalized scenes, the original stereo-scenes should be projected onto a common normalization plane.



(a)



(b)

Figure 3: A horizontal normalization plane results in equal x-parallax values for points at the same elevation (a), and a non-horizontal normalization plane results in equal x-parallax values for points at same the depth from that plane (b)

The question now is how can we project the original scenes onto the normalization plane? Since the parallel projection between two planes is modeled by a 6-parameter Affine transformation, the projection of the original scene onto the normalization plane can be realized through the transformation in Equations 4. Following this transformation, the projected scenes should be rotated, scaled, and shifted to produce the final normalized scenes. It should be noted that a transformation involving planar rotation, scaling, and shifting is a subset of Affine transformation. Due to the transitive property of the Affine transformation, the projection onto the normalization plane and the in-plane rotation, scale, and shift can be combined into one Affine transformation. Therefore, the normalization procedure hinges on the determination of the Affine transformation parameters between the original and normalized scenes. The determination of these parameters will be the focus of the next subsection.

5. NORMALIZATION PROCEDURE

So far, we have established the following facts for captured scenes according to parallel projection:

- The epipolar lines are straight.
- Within the same scene, the epipolar lines are parallel to each other.
- The *y*-parallax between conjugate points/epipolar lines can be eliminated by in-plane transformation involving rotation, scale, and shift.
- To ensure a meaningful relationship between the *x*-parallax and depth information, the original scenes should be projected onto a common plane (normalization plane).
- The transformation from the original scenes to the normalized ones can be established by a 6-parameter Affine transformation.

The question to be addressed in this section is how can we estimate the Affine transformation parameters, which directly project the original scenes onto the normalized ones? Before answering this question, let us discuss the situation where the captured scenes according to parallel projection are normalized ones. To directly acquire normalized scenes, the left and right scene planes should have the same orientation in space (i.e., they are contained within a common plane). This can be mathematically described by Equations 7.

$$\begin{aligned} \omega &= \omega' = \omega_n \\ \varphi &= \varphi' = \varphi_n \end{aligned} \quad (7)$$

where:

(ω, φ) is the orientation of the left scene plane;

(ω', φ') is the orientation of the right scene plane; and

(ω_n, φ_n) is the orientation of the normalization plane.

As it was mentioned earlier, to have the *x*-parallax linearly proportional to the elevation, the normalization plane should be a horizontal one (i.e., $\omega_n = \varphi_n = 0$). Besides the orientation of the normalization plane, the x-axis of the scene coordinate system should be parallel to the direction of the epipolar lines. This is essential for having the epipolar lines aligned along the scene rows. The direction of the *x*-axis within the scene is defined by the rotation angle (κ_n). So, the (κ_n) value should be determined in such a way that the *x*-axis coincides with the epipolar lines. The direction of the epipolar lines can be determined by intersecting the epipolar plane – the plane containing the projection vectors (L, M, N) and (L', M', N') – with the normalization plane. Selecting a horizontal normalization plane, one can determine the orientation of the epipolar lines (1, tan(κ_n), 0) by solving Equation 8, which dictates the coplanarity of the projection vectors (L, M, N) and (L', M', N') and the epipolar line, refer to Figure 4.

$$\begin{vmatrix} L & M & N \\ L' & M' & N' \\ 1 & \tan(\kappa_n) & 0 \end{vmatrix} = 0 \quad (8)$$

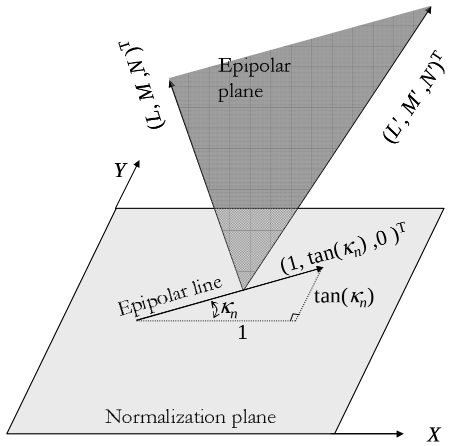


Figure 4: The direction of the epipolar lines along a horizontal normalization plane

Thus, the numerical value for (κ_n) can be determined according to Equation 9.

$$\kappa_n = \arctan\left(\frac{N.M' - M.N'}{N.L' - L.N'}\right) \quad (9)$$

To ensure that conjugate epipolar lines are aligned along the same rows, the left and right scenes should have the same scale (s_n) and the same shift along the y-axis (Δy_n). The shift value along the x-axis is irrelevant but it could be chosen to be the same for both scenes (Δx_n). In summary, selecting (L, M, ω_n, φ_n, κ_n, Δx_n, Δy_n, s_n) and (L', M', ω_n, φ_n, κ_n, Δx_n, Δy_n, s_n) as the parallel projection parameters from the object space to the left and right scenes, respectively, would ensure the generation of normalized scenes. This entails projecting the scenes between two planes along the parallel projection direction, which is nothing but 6-parameter Affine transformation, Equations10.

$$\begin{aligned} u_n &= a_1\ u + a_2\ v + a_3 \\ v_n &= a_4\ u + a_5\ v + a_6 \end{aligned} \tag{10}$$

where:

(u_n, v_n) are the normalized scene coordinates; and

a_1 to a_6 are the affine transformation parameters.

In summary, the normalization process could proceed as follows (refer to Figure 5 for a conceptual flow chart):

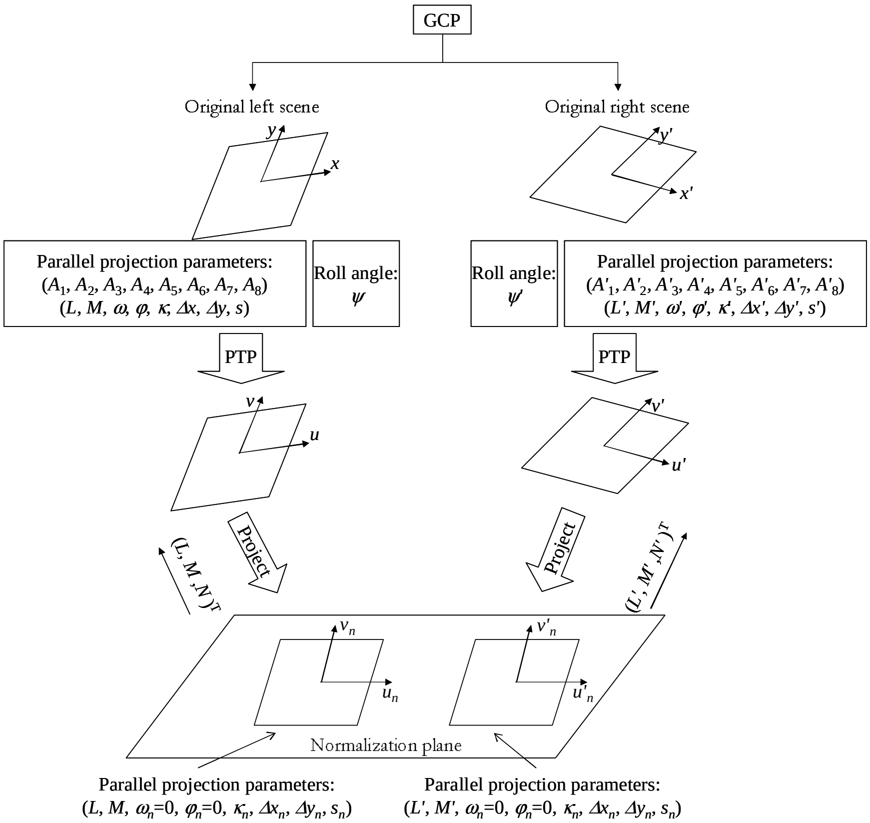


Figure 5: An overview of the proposed epipolar resampling procedure

1. Use a minimum of five ground control points to estimate the nine parameters of the modified parallel projection (A_1 – A_8 and ψ in Equations 6) for the left and right scenes in question.

2. Use the estimated parameters in step 1 to derive the corresponding non-linear parameters of the parallel projection for the left and right scenes ($L, M, \omega, \varphi, \kappa, \Delta x, \Delta y, s$) and ($L', M', \omega', \varphi', \kappa', \Delta x', \Delta y', s'$), respectively.
3. Use the estimated roll angles in step 1 to perform the PTP transformation for the left and right scenes.
4. Select the parallel projection parameters for the left and right normalized scenes ($L, M, \omega_n, \varphi_n, \kappa_n, \Delta x_n, \Delta y_n, s_n$) and ($L', M', \omega_n, \varphi_n, \kappa_n, \Delta x_n, \Delta y_n, s_n$), respectively. To ensure an x-parallax that is linearly proportional to the elevation, we should select a horizontal normalization plane (i.e., $\omega_n = \varphi_n = 0$). The (κ_n) value should be derived according to Equation 9. The shift and scale values ($\Delta x_n, \Delta y_n, s_n$) can be selected to be the average scale and shift values for the original left and right scenes.
5. Use the original and the normalized parallel projection parameters to derive the Affine transformation parameters (Equations 10), which are used for directly projecting the original scenes after PTP transformation onto the normalized ones.

It should be noted that the requirement for the GCP is to ensure the alignment of the normalized scenes along a common plane. This alignment leads to x-parallax values that are linearly proportional to the depth across the normalization plane. In addition, GCP are needed to estimate the roll angles. Such angles are used to perform the PTP transformation, which is a pre-requisite for utilizing the parallel projection.

6. EXPERIMENTAL RESULTS AND DISCUSSION

The main objectives of the conducted experiments revolve around proving the feasibility of the suggested approach and evaluating the accuracy of the resampling process as it is impacted by the number of utilized GCP. To achieve such objectives, we acquired a panchromatic stereo-pair of IKONOS scenes over Daejeon, South Korea. The geographical coordinates of the covered area range from 36.26° to 36.36° North Latitude and from 127.31° to 127.45° East Longitude. For these scenes, we do not have any information regarding the roll angles or any GCP. Instead, the rational function coefficients for both scenes are provided. The rational function coefficients are used in an intersection procedure to derive the ground coordinates of 162 points. It should be noted that the accuracy of the estimated ground coordinates for these points depends on:

- The measurement accuracy of the scene coordinates;
- The accuracy of the rational functions' coefficients (not provided); and
- The validity of the rational functions as an approximate sensor model.

The developed approach for epipolar resampling is then applied to generate normalized stereo-scenes. Three sets of experiments are conducted using different numbers of GCP and checkpoints as shown in Table I. The square root of the estimated variance component resulting from the least squares adjustment adopting Equations 6, and the average absolute values of the resulting y-parallax in the resampled scenes for the 162 tie points are listed in Table 1. The table also shows the square root of the estimated variance component from straight-line fitting through the pairs defined by the resulting x-parallax in the normalized scenes and the corresponding depth values. One has to note that these numerical values reflect the quality of the used GCP, the accuracy of scenes coordinate measurements, and the validity of the modified parallel projection model (including the assumption of a flat terrain). Close investigation of these numbers reveals that increasing the number of GCP improves the results as indicated by smaller variance component and absolute *y*-parallax values. However, one can argue that there is an insignificant improvement between Experiments 2 and 3. Thus, it can be concluded that few GCP are sufficient to carry out the proposed epipolar resampling methodology. The quality of the line fitting between the *x*-parallax and corresponding depth, as represented by the last row in Table 1, is acceptable considering the inaccuracies introduced by various errors throughout the normalization process (e.g., errors in the object and scene coordinates as well as those arising from the deviation from a planar object space assumption in the PTP transformation). Finally, the resampled scenes are overlaid to generate a stereo anaglyph, Figure 6, which can be stereo-viewed using anaglyph glasses.

Table 1: Experimental results of the normalization process

Experiment	1	2	3
# of GCP	9	25	162
# of Checkpoints	153	137	0
$\hat{\sigma}_0$, pixels	3.6	2.8	2.2
Mean $\lvert P_y \rvert$, pixels	2.1	1.7	1.5
$\hat{\sigma}_0$ (line fitting of P_x and Z), m	6.0	5.6	5.4

7. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

This paper outlines a new approach for epipolar resampling of linear array scanners scenes. The resampling process is based on parallel projection, which is suitable for modeling imaging scanners with narrow AFOV moving with constant velocity and attitude. The original scenes should undergo a Perspective to Parallel (PTP) transformation to bring the perspective geometry along the scanner direction closer to being parallel. The parallel projection and PTP transformation have been combined into a modified parallel projection model. The involved parameters in the combined model can be estimated using a minimum of five GCP.

It has been established that the epipolar lines in scenes captured according to parallel projection are straight lines and parallel to each other. The generation of new scenes, where there is no *y*-parallax between conjugate points, can be carried out through an in-plane transformation involving rotation, scaling, and shift. Such a transformation can be carried out using a minimum of four tie points. On the other hand, the generation of normalized scenes with a meaningful *x*-parallax value that is linearly proportional to the depth requires projecting the original scenes onto a common plane followed by an in-plane transformation. The transformation from the original scenes into normalized ones can be directly established through a 6-parameter Affine transformation using a minimum of five GCP. Experimental results with IKONOS imagery verified the feasibility and success of the proposed resampling procedure.

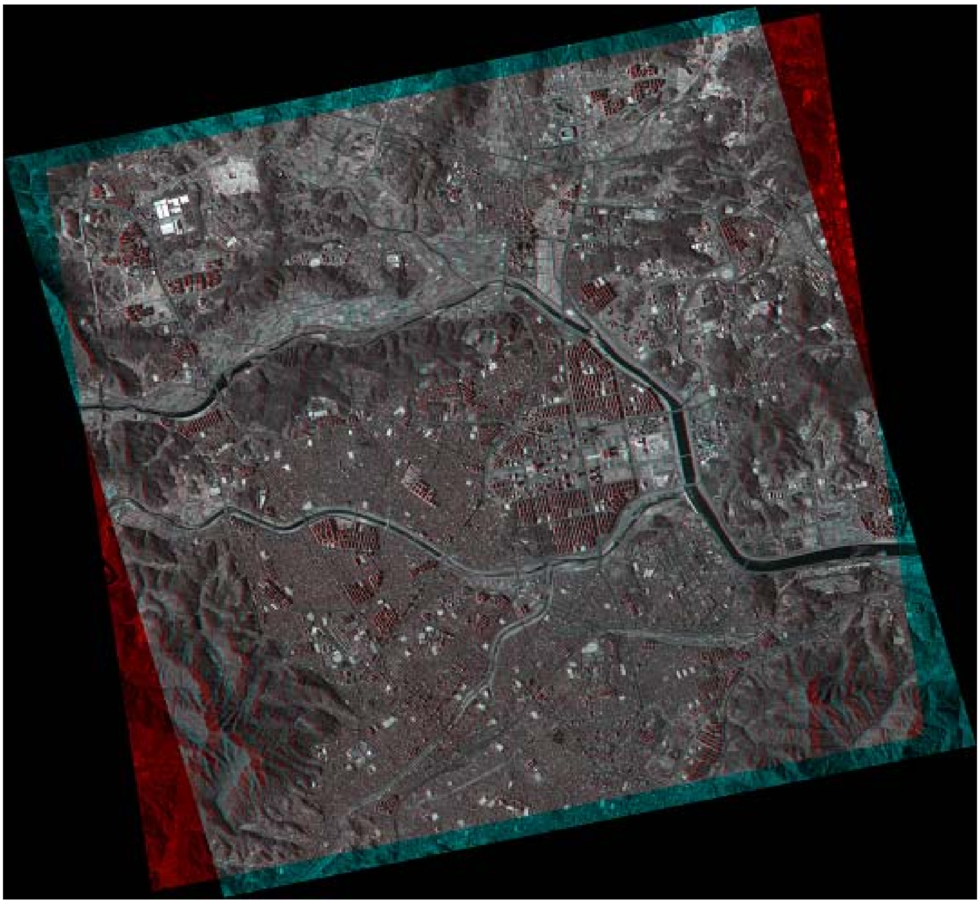


Figure 6: Generated stereo anaglyph from the normalized IKONOS scenes

Future work will focus on DEM and ortho-photo generation based on the normalized scenes. Inclusion of higher order primitives (such as linear and areal features) and object space constraints within the parallel projection model will also be investigated. Moreover, we will investigate the effect of the deviations from the assumptions in the PTP transformation (especially, the flat terrain).

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