PRINCIPLE OF SEAMLESS STEREO ORTHOIMAGE DATABASE AND ITS MEASUREMENT ACCURACY ANALYSIS

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Commission III, PCV'02

KEY WORDS: Seamless Stereo Orthoimage Database, Digital Orthophoto Quadrangles (DOQ), Digital Stereo-orthophoto Partner (DSP), Stereo Measurement

ABSTRACT:

The idea and concept of Seamless Stereo orthoimage Database is firstly put forward around the world. The meanings and basic principle of Seamless Stereo Orthoimage Database are deeply analyzed in this paper. Based on stereovision of human's eyes, the main idea of Seamless Stereo Orthoimage Database is to generate a seamless Digital Orthophoto Quadrangles (DOQ) database from DEM and odd photos and generate additionally a Digital Stereo Orthophoto Partner (DSP) from DEM and even photos, and then a large area 3D virtual landscape environment can be formed without y-parallax. The database is called Seamless Stereo Orthoimage Database formed by DOQ and DSP together. In such environment, the 3D measurement and analysis can be done under the interface of normal GIS or CAD systems without complex DPW. The 3D objects, such as houses, trees, cloverleaf junctions, geologic ruptures, and so on, which are not acquired during data acquisition at DPW, can be measured by end user himself. The principle, algorithm and excellent measurement accuracy analysis are presented in detail in this paper.

1. Introduction

The rapid development of aerial, space and computer technologies, the maturity and application popularization of digital difference rectification technology, has opened a broad prospect for orthoimage. Orthoimage has become the major carrier of spatial data and product. Digital orthoimage not only has abundant geographical information, but also can meet with the geometry accuracy requirement of relief map. However, the 3D information doesn't be contained in the orthoimage, which brings many inconveniences for the application of orthoimage.

Stereovision model based on human's physiological parallax is the foundation of photogrammetry. The means of rendering real terrain and ground features at the moment of photography with stereoscopic equipment is also a style of terrain visualization. The advantages of stereo model based on images are only to restore the parallax at the moment of photograph without the complex course of constructing models. But as the images from original photograph have vertical parallax, the stereo model after a serial of complex orientation operations is only set up by photogrammetric operators who are specially well trained and the stereoscopic range is only limited to the small overlap range of one stereo pair. The neighbor stereo models are separate and cannot mosaic seamless stereo image database over a large area. The stereo model based epipolar line images is free from vertical parallax, it cannot also be mosaic together because of their different epipolar line directions, the stereoscopic range is also limited a pair of images. T.Blachut and S.Collins put forward the concept of stereo orthophoto pair in 1968 (Blachut T.J.,1968,1976;Kraus,1984;Collins S.H ,1968,1969,1972;Deren Li, 1988; Deren Li and Zhaobao Zheng, 1992). The main idea is to construct stereo model using orthophoto and a specially made photo called the "stereo-partner". Orthoimage has seamless characteristic and can generate a seamless orthoimage database. If we generate a DSP database, the stereo model across stereo pairs can be formed with DOQ database and DSP database by special algorithm. So it is called Seamless Stereo Orthoimage Database.

2. The Basic Principle of Seamless Stereo Orthoimage Database

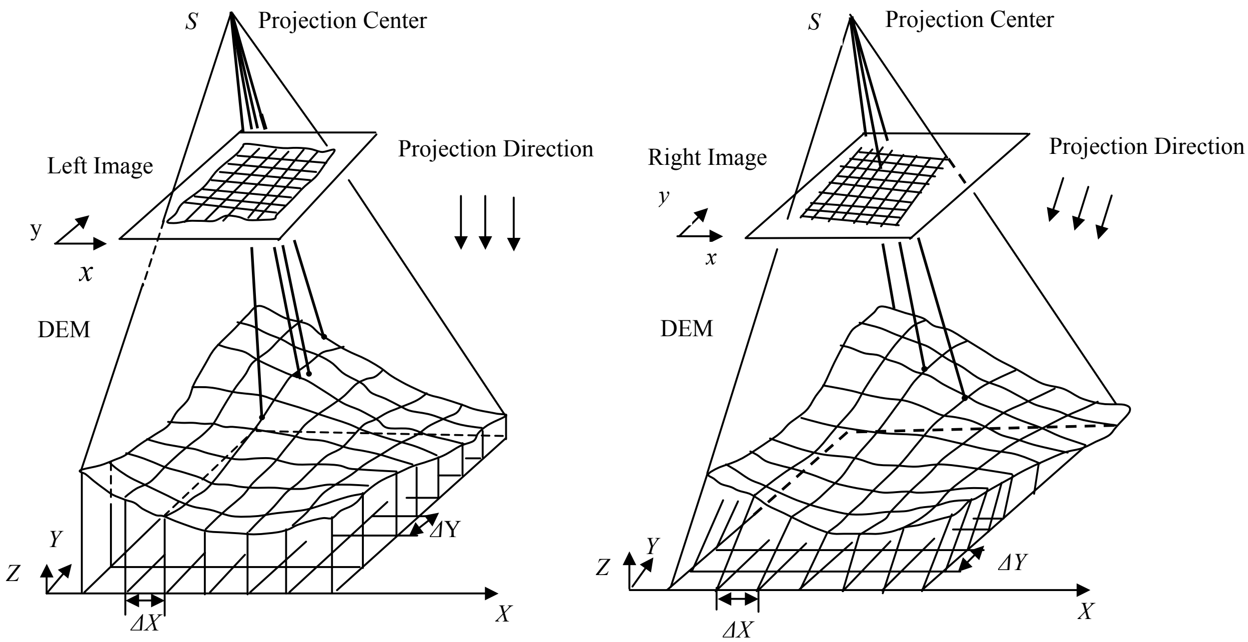
In the field of photogrammetry and RS, digital differential rectification is a very mature technology at present, which mainly is used for the production of orthoimage. Digital orthoimage not only has correct planar position, but also hold abundant image information. However, it is only two-dimension, not including three-dimension information. Though overlaying contour on the orthoimage can partly meet the fault, it is impossible to substitute for stereoscopic view to obtain stereo sense. Therefore, we can artificially produce a so-called Digital Stereo-orthophoto Partner (DSP) vs. Digital Orthophoto Quadrangles (DOQ). DOQ and DSP are all together called Stereo Orthophoto Pair (Blachut, 1968,1976). The basic principle of Seamless Stereo-orthoimage Database is based on stereo orthophoto pair. Figure 1 summarily shows the basic principle of Seamless Stereo Orthoimage Database (Kraus, 1984).

As shown in figure 1, the coordinate Z of the grid XY points forms digital elevation model (DEM). Figure 1a shows the diagram of making orthoimage, directly transforming the elevation of grid point to original photo according to collinearity equation to obtain image data for orthoimage.

In order to obtain stereo landscape model, the x-parallaxes are artificially introduced according to DEM and right image. The simplest method for parallax introduction is to use parallel ray with a certain angle between Z-axis (Figure 2b. The artificial parallaxes reflect the feature of terrain and form an auxiliary image, which can construct a stereo model with orthoimage.

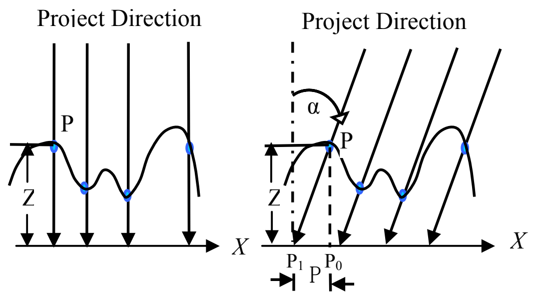
Figure 2 is a vertical plane diagram of projection; take the ground point P as an example, the height difference relative to the plane of projection is Z, p_0 is the ortho projection point of P and p_1 is the slope parallel projection point of P. Orthophoto is obtained by ortho projection and Stereo Ortho-photo Partner is obtained by slope parallel projection. The parallax P is obtained by stereo measurement, so it is obvious that

$$P = \tan\alpha \bullet Z = k \bullet Z \qquad (1)$$



a. Ortho Projection b. Slope Parallel Projection

Figure 1 The Basic Principle of Stereo Orthoimage Database



a. Orthophoto b. Stereo Orthophoto Partner

Fig.2 The Parallel Projection Method

As the direction of slope parallel projection parallel with XZ plane, there are only x-parallaxes between orthophoto and stereo orthophoto partner. Because they are generated from left and right photos of a stereo pair separately, it meets the prerequisite condition of stereo measurement and can provide not only planimetric correct position but also the height of ground point.

In order to make measurement, the angle α had better agree with the parallaxes of original stereo model, generally it is taken $\tan\alpha = \frac{B}{H}$, B is the base line of stereo model, H is the flight height. The height difference relative to the reference plane can be calculated by the x-parallaxes measured from the stereo orthophoto pair divided by coefficient k and multiplied the denominator of photo scale. At last, the height is get after the height of starting point is added. The formula is as follows,

$$Z_i = \frac{P_i}{k} \mathrm{M} + Z_0 \qquad (2)$$

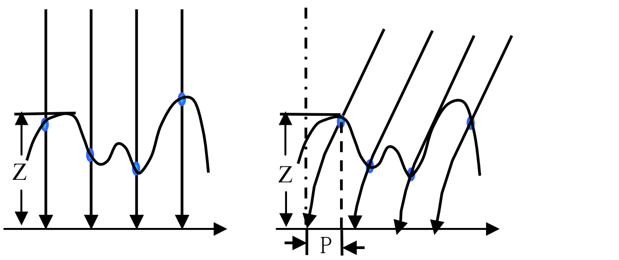
3. The Several Methods for Introduction of Artificial Parallax

An advantage of Seamless Stereo orthoimage Database is the measurement of height information; therefore the correct artificial parallax introduction should be a very important issue. Slope parallel projection above discussed is the simplest but not the best method; the other two more rigorous methods will be discussed in the following.

(1) Logarithm Projection Method

The parallax introduced by slope parallel projection is linear function of height difference, which is not in accord with the parallaxes of original stereo model and can cause measurement problems (Collins S.H, 1968; Kraus, 1984). In order to overcome the measurement problems, logarithm projection is used to parallax introduction. The principle of logarithm projection is as shown in figure 3.

Project Direction　　　　Project Direction



a. Orthophoto　　　　b. Stereo Orthophoto Partner

Fig.3 The Logarithm Projection Method

The parallax function of logarithm projection is:

$$P = B \bullet \ln\left(\frac{H}{H - Z}\right) \qquad (3)$$

Where: B is base line of photograph
H is flight height
Z is the height of ground point
P is the parallax corresponding with the height of Z

In logarithm projection method, the height of ground point can be calculated by the following formula,

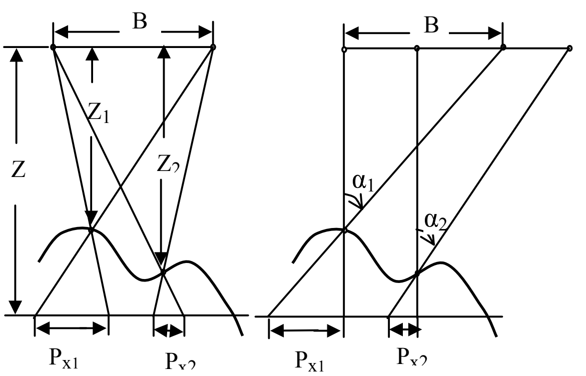
$$Z_i = H\left(1 - \exp\left(-\frac{P_i}{B}\right)\right) + Z_0 \qquad (4)$$

(2) Non-Parallel Projection Method

Though logarithm projection method can introduce the parallax in accord with the original parallax, the point of intersection between logarithm function and DEM must be solved by successive approximation. So it is considered that using other method to replace logarithm projection.

As shown in figure 4, figure 4a shows the parallaxes produced by the different height difference of ground point relative to reference plane during photography. Figure 4b shows two projection rays with the angle α_1 and α_2 for producing the same parallax with the parallax of original photograph. From the geometry relation in figure 4, we can obtain,

$$tg\alpha_1 = \frac{B}{Z_1} \qquad tg\alpha_2 = \frac{B}{Z_2} \qquad (5)$$

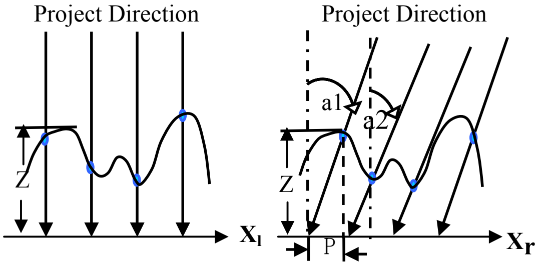


a The Original Parallaxes　　　　b The Introduced Parallax Identical with Original Parallaxes

Fig.4 The Original Parallaxes and Introduced Parallaxes

Therefore, in order to accord with the original parallaxes during photography, Non-Parallel Projection Method is put forward for introducing parallaxes. Figure 5 shows the basic principle of this method; the angle of ray is changing with the height of ground point.

Project Direction　　　　Project Direction



a. Orthophoto　　　　b. Stereo Orthophoto Partner

Fig. 5 Non-Parallel Projection Method

The parallax function of Non-Parallel Projection Method is:

$$P = \frac{BZ}{H - Z} \qquad (6)$$

The height of ground point can be calculated by the following formula,

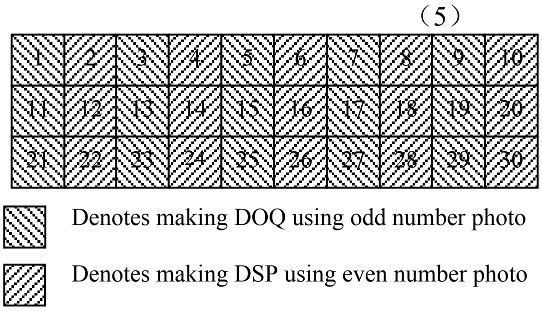
$$Z_i = \frac{PH}{B + P_i} \qquad (7)$$

4. The Method for Generating Seamless Stereo Orthoimage Database

The principle of Seamless Stereo Orthoimage Database has been described above. As the stereo orthophoto pair is limitted only a pair of photos.However, Seamless Stereo orthoimage Database requires seamless roaming and viewing the stereo model in a large area.So it should be considered the whole working area and meet the requirement of DOQ and DSP coming from left and right image while producing Seamless Stereo Orthoimage Database. For this, the rule for producing Seamless Stereo Orthoimage Database must be observed. Now, take three tripes with ten photos of each as a exapmle to illusiate the rule.

Firstly, the photos is encoded along stripe direction as shown follows.

（5）



Denotes making DOQ using odd number photo

Denotes making DSP using even number photo

Fig.6 The Data Organization of Stereo Orthoimage Database

According to the above way of data origination, the steps of generating Stereo Orthoimage Database are as follows.

Step1: Digital Orthophoto Quadrangles (DOQ) generated from left image (1,3,5) and DEM

Step2:Image database generated from DOQ to construct a large seamless area through digital mosaic.

Step3: Digital Stereo-orthophoto Partner (DSP) generated from right image (2,4,6) and DEM using above method

Step4: Automatic retrieve of stereo orthophoto pair from DOQ and DSP image databases

Step5: Using liquid crystal glasses /Anaglyphoscopeto to observe and measure continuous real 3D object by using image matching software.

In order to measure the height of ground details, the DSP should be produced by the methods of logarithm projection or non-parallel projection that can achieve better measurement precision. In the case of the area with little ground features, the slope parallel projection may be used, however, the slope angle should be the tangent of base line and flight height and the flight height should equal the average height of the stereo model. If the height doesn't be care about, DSP can be produced by simple slope parallel projection, which may be used for image stereoscopic interpretation.

5. The Measurement Accuracy Analysis of Sereo Orthoimage Database

The foundation of Stereo Orthoimage Database is based on stereo-photo pair. So the measurement accuracy of Stereo Orthoimage Database depends on the accuracy of stereo-photo pair. The planar accuracy of stereo-photo pair mainly depends on the quality and accuracy of orthoimage which have been discussed detailedly in many relative literatures It doesn't be discussed any more in this paper (Li Deren, 1988;Li Deren, 1992). The main content in this paper is to discuss the height measurement of Stereo Orthoimage Database. In order to make stereo-photo pair, DEM must be acquired in advance. Thus, the height of every position can be obtained directly by DEM interpolation computation. It seems as if it is worthless of calculating the height again after measuring the x-parallax. But that is not the fact. Because sometimes we need to know the height of some position in stereo model directly, the height can be obtained according to the x-parallax between orthoimage and orthoimage partner.

The height measurement accuracy analysis in theory will be discussed below in the case of DEM with errors. Before discussion, two concepts are introduced.

1. Projection parallax: The parallax, which is formed by center projection between left and right photo.
2. Artificial parallax: The parallax, which is introduced according to DEM through the parallax function.

In figure 7,the left photo is to make orthoimage and the right photo is to make orthoimage partner. Assuming that there is a height error ΔZ_1 at ground point(X，Y) in the DEM for making orthoimage , the displacement along x direction caused by the height error ΔZ_1 in orthoimage is Δx_1 . Further more, assuming that there is a height error ΔZ_2 at ground point(X，Y) in the DEM for making orthoimage partner, the displacement along x direction caused by the height error ΔZ_2 in orthoimage partner is Δx_2 .

Well then, the parallax error along x direction is：$\Delta x_1 - \Delta x_2$。
According to the geometry relationship in figure 7:

$$x_1 - x_2 = B \tag{8}$$

Where, B is the photo base. For orthoimage, the error of DEM only affects the projection parallax. We can obtain from the geometry relation:

$$\Delta x_1 = -\Delta z_1 \frac{x_1}{H-h} \tag{9}$$

For orthoimage partner, the error of DEM simultaneously affects both the projection parallax and the artifical parallax.，assume that

$$\Delta x_2 = \Delta x_2' + \Delta \bar{x}_2' \tag{10}$$

Where ： $\Delta x_2'$ *is the* part affected by the original parallax
$\Delta \bar{x}_2'$ *is the* part affected by the introduced parallax

For the effect on the projection parallax, according to figure 7,we can obtain：

$$\Delta x_2' = -\Delta z_2 \frac{x_2}{H-h} \tag{11}$$

For the part of $\Delta \bar{x}_2'$ ， as different method for artificial parallax introduction has different result, we will discuss respectively. At the ground point (X，Y)，the whole parallax error caused by DEM is：

$$\Delta p_x = \Delta x_1 - \Delta x_2 \tag{12}$$

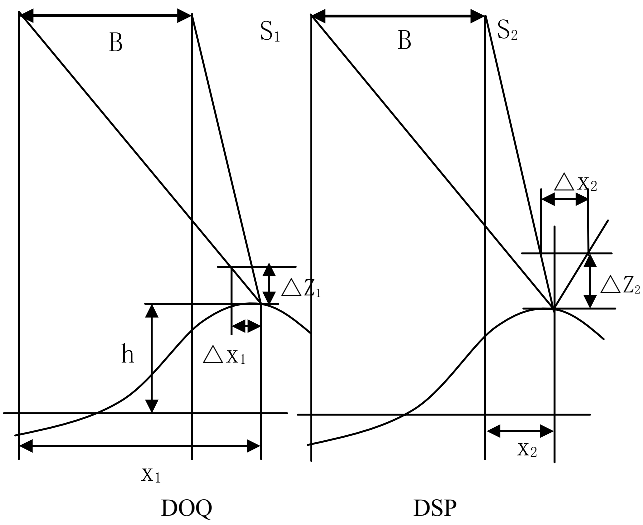


Figure 7 The height measurement theory analysis

1. Parallel Projection Method
After differential to formula 2, we have:

$$\Delta P = k\Delta Z = \frac{B}{H}\Delta Z = \frac{x_1 - x_2}{H}\Delta Z \tag{13}$$

The whole parallax error caused by DEM equals:

$$\Delta p_x = \Delta x_1 - \Delta x_2 = -\Delta z_1 \frac{x_1}{H-h} + \Delta z_2 \frac{x_2}{H-h} + \frac{x_1 - x_2}{H}\Delta z_2$$

$$= \frac{\Delta z_2 x_2 - \Delta z_1 x_1}{H-h} + \frac{x_1 - x_2}{H}\Delta z_2 \tag{14}$$

2. Logarithm Projection Method
After differential to formula 3, we have:

$$\Delta P = \frac{B}{H-h}\Delta Z \tag{15}$$

$$\Delta p_x = \Delta x_1 - \Delta x_2 = -\Delta z_1 \frac{x_1}{H-h} + \Delta z_2 \frac{x_2}{H-h} + \frac{B}{H-h}\Delta z_2$$
$$= -\Delta z_1 \frac{x_1}{H-h} + \Delta z_2 \frac{x_2}{H-h} + \frac{x_1 - x_2}{H-h}\Delta z_2$$
$$= \frac{x_1}{H-h}(\Delta z_2 - \Delta z_1) \qquad (16)$$

3. Non-Parallel Projection Method
After differential to formula 3, we have:

$$\Delta P = \frac{B(H-h) + Bh}{(H-h)^2}\Delta Z = \left(\frac{BH}{(H-h)^2}\right)\Delta Z \qquad (17)$$
$$\approx \left(\frac{B}{(H-h)}\right)\Delta Z\,(当\, H \approx H-h 时)$$
$$\Delta p_x = \Delta x_1 - \Delta x_2 = -\Delta z_1 \frac{x_1}{H-h} + \Delta z_2 \frac{x_2}{H-h} + \left(\frac{B}{(H-h)}\right)\Delta z_2$$
$$= \frac{x_1}{H-h}(\Delta z_2 - \Delta z_1) \qquad (18)$$

After the analysis above, we can get the following conclusions:

1. If the height errors of DEM used to generate orthoimage and orthoimage partner are equal, viz $\triangle Z_1 = \triangle Z_2$, well then:

- For parallel projection method, the parallax error caused by height error of DEM is: $\Delta p_x = -\frac{Bh}{H(H-h)}\Delta Z$
- For logarithm projection method and nonlinear projection method, he parallax error caused by height error of DEM is: $\Delta p_x = 0$

2. The parallax error for logarithm projection method and non-parallel projection method is 0 when x equals 0.That is to say, the error is always 0 at the photo bottom point The parallax error for parallel projection method is:

$$\Delta p_x = \frac{x_2 h}{H(H-h)}\Delta Z$$

3. The parallax error has a proportion relation with the distance of photo bottom point when the method is logarithm projection method or non-parallel projection method.

In the above three conclusions, the first conclusion is very important and the condition is very easy to be meet with. When the DEM used to generate DOQ and DSP is identical, the error $\triangle Z_1$ equals $\triangle Z_2$. The error equals 0 for logarithm projection method and nonlinear projection method In other words, the height error of DEM has no effect on the parallax of the stereo mode.

In addition, the following conclusion can be obtained. The parallax error caused by DEM error is the least for the logarithm projection method; The error result of non-parallel projection method is identical with logarithm projection method when the ground is flat（$H \approx H-h$）. The parallax error caused by DEM error is the most for Parallel Projection Method.

6. The Experiment Results and Conclusions

According to above principle, two test areas with different image scale are taken. The parameters of the photo are as follows:

	Test I	Test II
Principle Distance	153.710mm	152.400mm
Photo Scale	1：25000	1：8000
Format	23cmX 23cm	23cmX 23cm
Photo Type	Panchromatic	True Color
Pixel Size	25um	50um
Average H	4225m	2090m
Resolution of DEM	12.50m	5m
Resolution of orthoimage	1m	0.5m
Data Range	2 Strips X 3 Stereo Models	5 Strips X 5 Stereo Models

Table 1 The Parameters of Photography

6.1 The Experiment on Foundation of Seamless Orthoimage Database

During experiments, DOQ database and DSP database are founded. The stereo model can be observed with crystal glasses or anaglyphoscope. The following two experiment results are a part of the whole stereo model and the stereo model can be directly observed with anaglyphoscope.

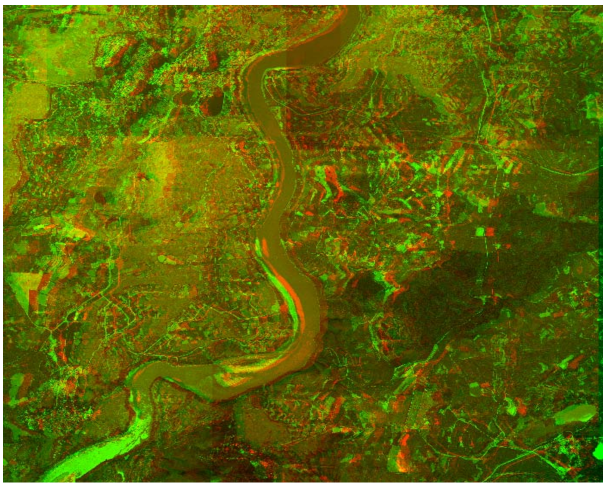


Figure 8 a Test Area I: Guangxi Province in south China

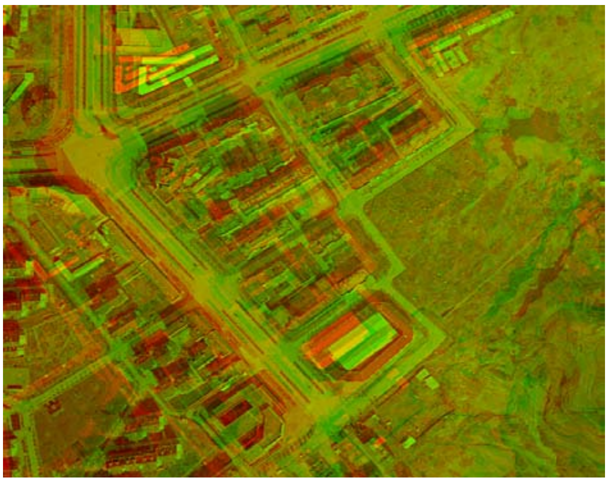


Figure 8 b Test Area II: Three Gorges Project Area

Figure 8 The Experiment Results

All kinds of ground features can be really viewed during stereoscopic observation. At the same time we can roam the whole stereo model across stereo pair and measure the height of interested ground features with stereo mark. It is sufficiently proven the feasibility and prospect of seamless stereo orthoimage database.

6.2 The Height Measurement Experiments

For the first group experiment data, the original DEM, DEM with 5m gross errors, DEM with 10m gross errors and DEM with 15m gross errors are separately used to generate DOQ and DSP in above three different methods to form seamless orthoimage database. The height measurement is taken at twenty different ground control point. The experiment result is as follows.

	Parallel Projection	Logarithm Projection	Non-Parallel Projection
Original DEM	0.963	0.946	0.951
DEM with 5m Coarse Errors	1.2978	0.962	0.9778
DEM with 10m Coarse Errors	1.4256	1.2809	1.3065
DEM with 15m Coarse Errors	1.9359	1.4511	1.5879

Table 2 The Result of Height Accuracy Analysis (The Unit is m)

From above experiment results, the following conclusion can be obtained:

1. For the height measurement of relief, there are no obvious differences among these three methods. That is because the parallax is introduced according to rigorous mathematic formula for each method.

2. When DEM has gross errors, there is the robust ability against DEM errors for each method. However, the Logarithm Projection Method is better than the other two ones. That accords very well with theory deduction

3. As there are errors in DEM used to generate DOQ and DSP, the height measured from stereo orthophoto pair can reduce the effect of DEM errors. Consequently, the height measured from stereo orthophoto pair is better than original DEM. This result is identical with Prof. Kraus (Kraus, 1984)

Seamless stereo orthoimage database has many advantages and it can work under GIS/CAD environment, so as a new product it may be used in many fields. Using stereo seamless orthoimage database, the forest engineer can measure the height and crown of trees; the geologist can measure the geologic shape and perform 3D interpretation; civil engineer can design transect and vertical section; the hydrologist can make 3D measurement and analysis. the urbanist can perform plan and design under 3D landscape. All of these applications and other potential applications are under experiment stage.

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Acknowledgment

The research described in this paper was funded by the Excellent Key Laboratory Foundation of National Nature Science Committee. (No. 40023004) This support is valuable.