A METHOD FOR GLOBAL-SCALE ARCHIVING OF IMAGING DATA BASED ON QTM PIXELS

Wenbin Sun[1], Xuesheng Zhao[1, 2], and Jun Chen[2]*

[*1] *Department of Surveying and Land Science, China University of Mining and Technology (Beijing), Beijing, China, 100083*
Email: swb1996@126.com
[2] *National Geometrics Center of China, No.1 Baishengcun, Zizhuyuan, Beijing, China, 10004*
Email: zxs@cumtb.edu.cn

ABSTRACT

A global multi-resolution image data model and a feasible solution for its seamless management and archiving remain a challenging vision. The traditional methods of the raster pixel data structure based on the idea of map projections are effective to support local or small-scale areas. However, if this structure is applied to large-scale or whole global image archiving, some significant drawbacks are unavoidable, such as data discontinuity (or overlapping), geometric distortions, etc. To overcome these deficiencies, in this paper the Quaternary Triangular Mesh (QTM) (Dutton, 1989), as a continuous, hierarchal quadtree data structure with uniform grids on a sphere, is proposed for global-scale seamless image archiving. First, the mapping relation between raster image pixels and QTM pixels is approached based on the QTM subdivision and Quaternary coding scheme (Bartholdi & Goldsman, 2001), and a corresponding algorithm of QTM pixel grey level calculation is also developed. Then, the storage structure of global-scale image archiving based on QTM pixels is presented in detail. In the end, an experiment is described using the 1km resolution NOAA data for China, comparing the differences in pixel grey levels between original image pixels and QTM pixels. The result indicates that the QTM pixel data structure can keep global-scale images seamless, and the accuracy of transformation from the imaging pixel to the QTM pixel is a loss of less than 2 grey levels for 94.5% of all pixels, the loss from 2 to 4 is 1.9%, the loss from 4 to 10 is 2%, and the rest is 1.6%. The results are good and acceptable.

KEY WORDS: Image archiving, QTM (Quaternary Triangular Mesh) pixel, Quaternary coding

1   INTRODUCTION

As remote sensing technology develops rapidly and more and more global image datasets are acquired easily, a global multi-resolution, image data model and a feasible solution for its seamless management and archiving are urgently needed. The traditional methods of raster pixel data structure based on the idea of map projections are effective to support local or small-scale areas, but it is impossible to keep global data seamless and consistency (Wang et al., 2001; Hu et al., 2005). In particular, the problem of image pixel duplication and loss is often unavoidable during image coordinates system conversion between different projections (Mulcahy, 1999 & 2001; Seong & Usery, 2001; Kimerling, 2002; Seong, 2003).

So far, a number of approaches to manage global images seamlessly have been proposed (Wang et al., 2001; Clayton et al., 2003; Zhang, 2004; Seong, 2005). Wang (2001) uses a belt-divided storage mode and an over-belt algorithm for seamless image management. This method can provide seamless image visualization on a large scale, but the discontinuity in image archiving caused by projection still exists. Seamless storage is similarly important as seamless visualization on a global scale (Hu et al., 2005). The methods of sphere and ellipsoid grids for global images seamless index and visualization have also been proposed, such as equal-interval longitude/latitude grids (Zhang, 2004), triangular meshes based on hexahedron subdivision (Clayton et al., 2003), etc., in which seamless image archiving is not actually acquired too. Seong (2005) proposed an alternative method to archive global images based on equal-area grids. The equal-area grids are constructed on ellipsoid surfaces directly so that the continuity and seamlessness of global-scale images are kept, but their adjacent relations are very complex. This is a fatal drawback for hierarchical storage, multi-resolution, image index and neighbor finding in managing global image datasets. Therefore, an efficient method to archive global-scale image seamlessly still needs to be found.

This paper presents a QTM-based method for archiving a global image dataset seamlessly and efficiently. Quaternary Triangular Mesh (QTM), first proposed by Dutton (1989), is a tessellation of the Earth's surface with seamless, hierarchical, and regular triangular cells on the spherical surface. Its hierarchical grid structure can be used to efficiently

manage multi-resolution global data, and it allows spatial phenomena to be studied at different levels of detail in a consistent fashion across extensive regions of the sphere (Lee & Samet, 2000; Chen et al., 2003). It has become one of the most efficient methods for seamlessly keeping images, managing and indexing multi-resolution images, and compressing and analyzing image datasets on a global scale. However, in present approaches, there is little work involving the expression of global seamless image archiving.

Following this introduction, we describe a method to construct the mapping relation between raster and QTM pixels. This is followed by the presentation of a QTM pixel value calculation method according to image raster pixels. Section 4 discusses image storage structures based on QTM pixels. Section 5 describes an experiment to analyze precision loss of transformation between QTM pixels and raster pixels by comparing the difference in grey levels between them on a projection planar. Finally, the conclusions are presented.

2   THE MAPPING RELATION BETWEEN RASTER AND QTM PIXELS

Many methods of partitioning sphere surfaces based on inscribed polyhedrons have been proposed, such as the tetrahedron, the hexahedron (Snyder, 1992; Clayton et al., 2003), the octahedron (Dutton, 1989; Otoo & Zhu, 1993; Goodchild &Yang, 1992), the dodecahedron (Wickman & Elvers, 1974), and the icosahedron (Fekete, 1990; Lee & Samet, 2000). In this section, the octahedron is selected to archive global scale image datasets. The reason for this selection is that it can be readily aligned with the conventional geographical grid of longitude and latitude. Its vertices occupy cardinal points, and its edges assume cardinal directions, following the equator, the prime meridian, and the 90th, 180th, and 270th meridians, making it simple to determine which facet a point on the planet occupies. Traditionally, however, spatial reference of an image is constructed on a projection planar. To accomplish transformation from a raster pixel on the projection planar to a QTM pixel on a sphere surface, the mapping relation between them should first be set up.

2.1   Selection of encoding scheme

The address code is a unique identifier in QTM, and the encoding scheme is related to the operation and indexing of global images. Several encoding methods have been proposed, such as Dutton's codes (Dutton, 1990), Goodchild's codes (Goodchild & Yang, 1992), Fekete's spherical codes (Fekete, 1990), Otoo's semi-quadcodes (Otoo & Zhu, 1993), and Quaternary codes (Bartholdi & Goldsman, 2001). Among these, the Quaternary code is selected in this section because it is continuous and has simple neighbor relations among QTM cells (shown as Figure 1). They are very useful for spatial clustering operation and image compression, especially when large volume image datasets are stored on slower secondary storage devices such as hard disks.
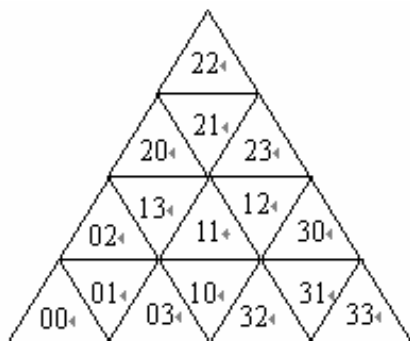

Figure 1.   Level 2 code of a quaternary

2.2   Transformations between QTM codes and longitude/latitude

To archive images based on QTM pixels, transformation between QTM codes and longitude/latitude must be done first. In the QTM tessellation, the position of a point is identified by the mid point of a decomposed triangle. The accuracy of the point location improves with increasing levels of decomposition. That is to say, if the subdivision level is small enough, the QTM cell can be substituted by a point, and we can consider that there is no loss during transformation between the QTM code and longitude/latitude.

Several methods of transformation between QTM codes and longitude/latitude have been approached, such as ETP (Equal Triangles projection) (Goodchild & Yang, 1992), ZOT (Zenithal Ortho Triangular) (Fekete, 1993), and RCA (Row & Column Approach algorithm) (Zhao & Chen, 2003). Among them, the principle of ETP method is simplest, but it is based on Goodchild's code with discontinuity. To improve the efficiency of transformation, an improved ETP method based on Quaternary code is given in detail in this section.

Suppose that the geography coordinate of the transferring point is (*B,L*)

[1] Geography latitude B is transferred to a reduced latitude U.

[2] Planar coordinates (EtpX, EtpY) on the ETP surface are calculated according to reduced latitude U, longitude B, and ETP projection as from the formulas given below.

$$\begin{cases} EtpX = \dfrac{2^n}{\pi}\left[U + 2B(1 - \dfrac{2}{\pi}U)\right] \\ EtpY = \dfrac{2^n\sqrt{3}}{\pi}U \end{cases} \qquad (2.1)$$

[3] Distances between the point and the four triangle midpoints of each subdivision are computed. The sub-triangle whose distance among them is the least is selected as the next subdivided triangle as shown in Figure 2, and the level code is recorded. The detail steps of acquiring the level code are as follows:

Suppose that I level Quaternary code is $a_1 \cdots a_i$

   1) Numbers of '1' and '3' in the code of father QTM cell are determined.

   2) Level code is ascertained by parity of '1' and '3' numbers.

- If the '1' and '3' numbers are even, the left QTM cell level code of I+1 subdivision is '0,' right is '3,' top/down is '2,' and mid is '1';
- If the '1' number is even and '3' number is odd, the left is '2,' right is '3,' top/down '0,' and mid is '1';
- If the '1' number is odd and '3' number is even, the left is '3,' right is '2,' top/down is '0,' and mid is '1';
- If the '1' and '3' numbers are odd, the left is '2,' right is '0,' top/down is '3,' and mid is '1.'

[4] If subdivision levels are filled, those level codes are connected to form a Quaternary code. This can be considered as the transformed Quaternary code from the point (B,L)
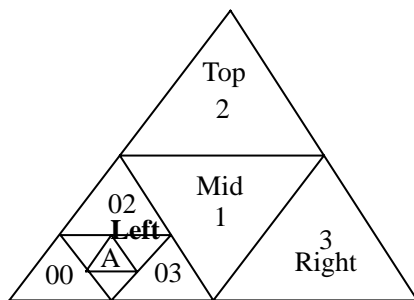

Figure 2.   Subdivision of father triangular meshes

According to the principles discussed above, transforming longitude/latitude to QTM codes can be implemented easily. On the other hand, the opposite transformation can also be done in the same way.

2.3   Constructing the relation between raster and QTM pixels

Traditionally, remote sensing images are stored and expressed in raster data. However, it is different with QTM directly tessellated on a spherical surface. The number of QTM cells at each latitude line is increasing constantly from the pole to equator, and each cell of QTM is approximately equal to a spherical triangle. Therefore, it is impossible to set up a one to one correspondence relationship between a planar raster pixel and a QTM pixel on a spherical surface (shown as

Figure 3).
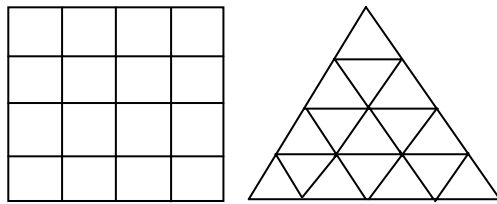
(a) Raster pix on planar   (b) QTM pixel on ETP

Figure 3. The difference between plane grids and sphere triangular meshes

According to the difference between raster pixels and QTM cells, the correspondence relation between them is described as N:1, 1:1, 1:N. To simplify relations between them, sub-pixel parts are introduced. Each pixel is subdivided into four or more equal parts, and those parts are smaller than a QTM cell on a spherical surface, i.e., each part should be completely encircled by one QTM cell; in this way, the correspondence relations between subdivided sub-pixel cells and QTM cells are translated as N:1. Based on those correspondence relations, a method to construct the relation between raster and QTM pixel is proposed. The detailed steps are as follows:

(1) QTM level of subdivision is assured by formula:

$$N = floor\,[\log_2(\pi \times R / 2d)] + 1$$

where R is the radius of the sphere, d is the size of the image pixel, and floor is the integral function.

(2) Each image pixel is subdivided into four or more equal parts, and planar coordinates (X,Y) of the midpoints of each part are redrawn.

(3) Those coordinates are transferred into ETP surface coordinates, according to image spatial projection, and then a set of Quaternary codes is acquired from the coordinates of the image sub-pixels based on principles of ETP projection and transformations between QTM codes and longitude/latitude.

(4) Those codes are sorted. If a code and the next one are equal, the next one should be eliminated; if not, they both are kept. Then, the spatial range of the remaining codes is the original image range.

(5) The edge QTM cell code, the only part of a whole QTM cell located in spatial range of the original image when it is projected to the planar surface (as Figure 4 shows), is removed. The range denoted by the remaining QTM cells is the corresponding range of image.
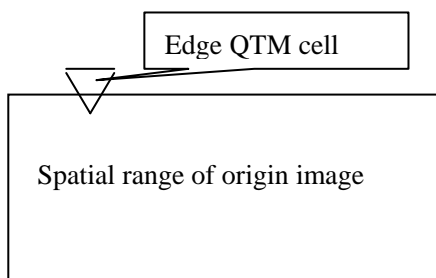

Figure 4.   The discard of brim triangular meshes

In this way, the mapping relation between raster and QTM pixel is constructed.

3   THE ALGORITHM OF QTM PIXEL VALUE CALCULATION

The grey level of a QTM cell is computed using intersection areas as the weights between raster pixels and the

projected range of the QTM cell on the planar surface according to the mapping relation constructed above. The detailed steps are as follows.

(1) First, three vertex coordinates of a QTM cell on ETP projection surface are chosen based on the Quaternary code of this cell.

(2) Then those coordinates are translated into geographical coordinates (B,L) using formulas 3.1, 3.2, and 3.3 below.

(3) Next, three points of the QTM cell projected on the image projection surface are connected, and a planar triangle is constituted.

(4) As Figure 5 shows, the detailed intersection is as follows: a) the intersection between the projected QTM cell and one pixel; b) the intersection between the projected QTM cell and two pixels; c) the intersection between the projected QTM cell and three pixels; d) the intersection between the QTM cell and four pixels. Intersection areas, as the weights of computing QTM cell value, are acquired based on the intersecting relations of the QTM cell and image pixels.

(5) Finally, the QTM value is calculated according to formula 3.4.

$$\lambda = \frac{\pi}{2^{n+1}} \frac{\sqrt{3}x - y}{\sqrt{3} - 2^{1-n}y} \qquad (3.1)$$

$$\phi = \frac{\pi}{2^n \sqrt{3}} y \qquad (3.2)$$

$$B = \arctan(\tan\phi\sqrt{1 + e'^2}) \qquad (3.3)$$

where λ is longitude, ϕ is reduced latitude, B is geography latitude, x, y are coordinates on the ETP projection surface.
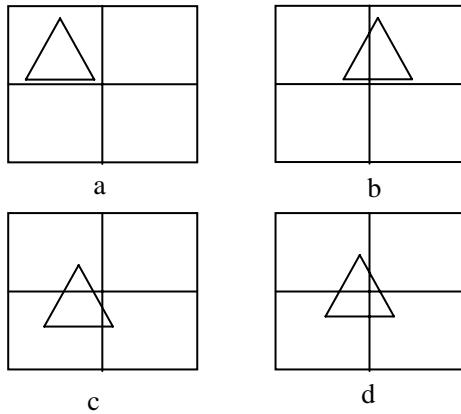

a   b

c   d

Figure 5. The intersection of plane pixel and projected triangular meshes

$$B = \sum_{i=1}^{4} s_i b_i \Big/ \sum_{i=1}^{4} s_i \qquad (3.4)$$

where B is the grey value of the QTM cell, s_i is the intersection area between the ith image pixel and range of the projected QTM cell, and s_i is the ith pixel grey value.

4   IMAGE STORAGE STRUCTURE

Many raster data formats are composed of header information and actual data. The header information provides an attribute description of actual data. In this storage mode, the header information includes: original pixel size, data type, QTM subdivision level, transformation precision, Quaternary code of data block, number of bands, byte numbers of actual data, etc. The QTM pixel size is decided by the QTM subdivision level. The Quaternary code of the data block

provides the reference coordinates of the image data. The geographic coordinates of each QTM pixel are obtained by transformation between the Quaternary code and the geographic coordinates. And the Quaternary code of the data block is also considered as the index of block data. The image data in each block is stored one by one as pixels in Quaternary order in BLOB format.

Image data storage has two formats in the database: file and BLOB field. Traditionally, global image data have been subdivided into many data blocks, and the pixel values of each block are only stored in some order to save storage space. In this paper, Quaternary code is selected as the storage ordering of each block, and that coding is applied to QTM pixel compression.

5   EXPERIMENT

The experiment proceeds by using the 1km resolution NOAA image for China to compare the differences of pixel grey levels between original image pixels and QTM pixels. This selected image lies in a rectangle area where its left-top corner coordinates (x, y) are (3210967.328m, 6218748.601m) and right lower coordinates are (3650967.328m, 5794748.601m), shown as Figure 6. In this image, the reference ellipsoid is Krasovsky; the Lambert projection is used; the latitude of the first standard parallel is 25°; the latitude of the second standard parallel is 47°; the longitude of the central meridian is 105°; the latitude of the origin of projection is 36°; false easting at the central meridian is 5000000m; and false northing at the origin is 5000000m. There are 187425 pixels in this image. According to the size of the image pixels, level 14 QTM cells are used in this test. Each pixel of the image is divided into 25 equal cells. The number of corresponding QTM cell is 699648. Figure 6 shows the intersections between QTM cells transformed on the Lambert projection surface and the raster pixels of the image. 100000 random points are selected and the grey level in the origin pixels and QTM cells are calculated respectively (shown as Table 1). The image, based on a QTM pixel, is displayed on the sphere as Figure 7.
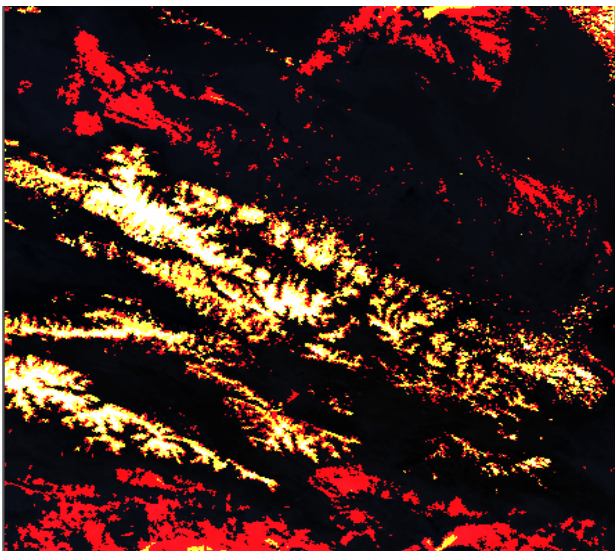

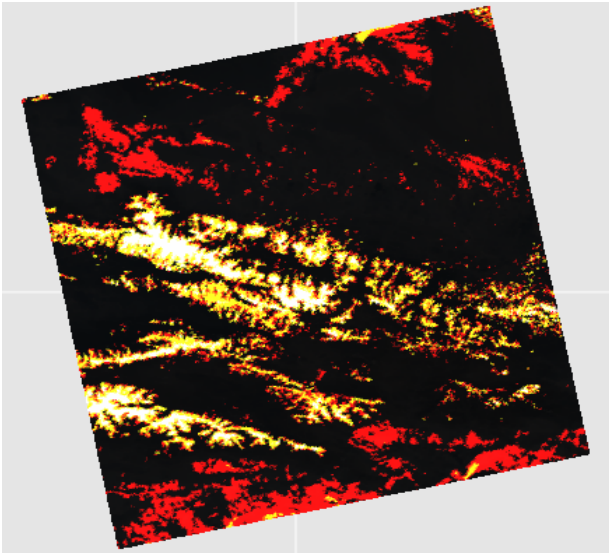**Figure 6.** The experiment data of 1km resolution NOAA image

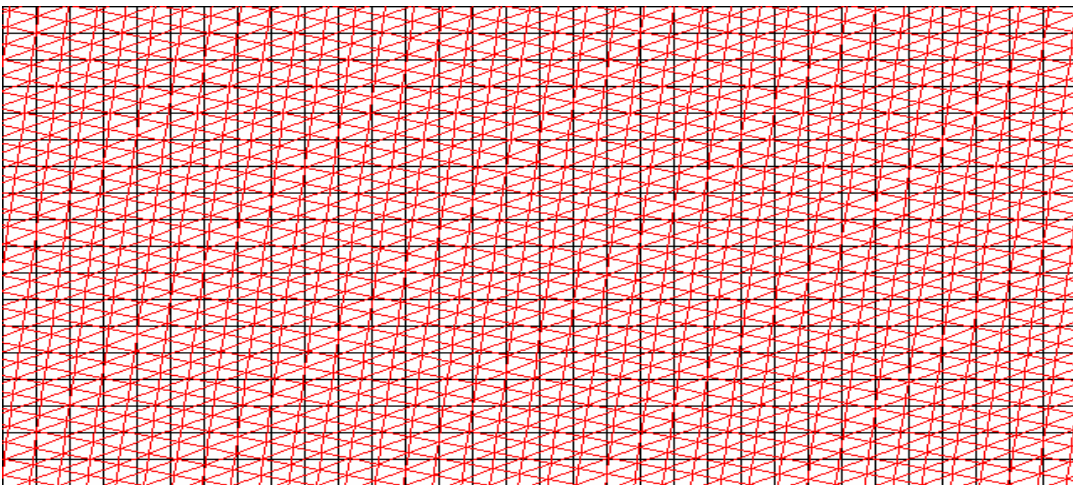**Figure 7.** The display of QTM pixels on sphere

Figure 8. The responsive relation of pixel and projected triangular mesh

From Table 1, it can be seen that the loss of less than 2 grey levels is 94.5% of all pixels, the loss from 2 to 4 is 1.9%, the loss from 4 to 10 is 2%, and the rest is 1.6%. The transformation results are good and acceptable. If a higher precision of transformation is applied, then more QTM levels should be constructed on the sphere.

Table 1. The Distribution of Transformation Error

Transformation Error	B1	B1 Percent Of All	B2	B2 Percent Of all	B3	B3 Percent of all	Average Percent
0-2	90177	90.2%	96267	96.3%	96938	96.9%	94.5%
2-4	3707	3.7%	1026	1.0%	894	0.9%	1.9%
4-10	3599	3.6%	1454	1.5%	896	0.9%	2.0%
>10	2517	2.5%	1253	1.2%	1272	1.3%	1.6%

6   CONCLUSION

A global multi-resolution image data model and a feasible solution for its seamless management and archiving remains a challenging vision. In order to overcome the deficiencies caused by the traditional methods of raster pixel data structure based on the idea of map projections, such as data discontinuity, geometric distortions, etc. a QTM-based method is proposed for global-scale seamless image archiving. The corresponding algorithms, which include transformation between QTM cell and raster pix, grey-level calculation of QTM pixel, and storage of global-scale images based on QTM pixels are developed in detail. An experiment is described comparing the difference in grey levels between original imaging pixels and QTM pixels by using the 1km resolution NOAA data for China. The results indicate that:

- The transformation from image pixels to QTM pixels can be done quickly by using the algorithm of mapping relations;

- Global imaging data archiving and managing based on QTM is continuous, hierarchal, and uniform without the problems of geometric distortion and the data discontinuity caused by planar map projection;

- The accuracy of conversion from the imaging pixel to the QTM pixel achieves a loss less than 2 grey levels in 94.5% of all pixels, a loss from 2 to 4 in 1.9%, a loss from 4 to 10 in 2%, and in the rest 1.6%.

The results are good and acceptable.

7   REFERENCES

Bartholdi,III, J.J. & Goldsman, P. (2001) Continuous indexing of hierarchical subdivisions of the globe. *International Journal Geographical Information Science, 15(6)*: 489-522

Chen, J., Zhao, X., & Li, Z. (2003) An algorithm for the generation of voronoi diagrams on the sphere based on QTM. *Photogrammetric Engineering & Remote sensing. 69(1)*: 79-89

Clayton, C., Dragan, P., & Salvador, B. (2003) Fast 3D visualization of large image datasets in a GIS. *Earth Observation Magazine*. Retrieved from the World Wide Web, April 29, 2007: Http://www.eomonline.com

Dutton, G. (1989) Modeling locational uncertainty via hierarchical tessellation. In: *Accuracy of Spatial Databases.* London: Tayor and Francis. 125-140

Dutton, G., (1990) Location properties of quaternary triangular meshes. In *Proceedings of the 4th International Symposium on Spatial Data Handling,* Zurich, 901-910.

Fekete, G. (1990) Rendering and managing spherical data with sphere quadtrees. In *Proceedings of Conference on Visualization'90*, Los, Alamitos CA, 176-186.

Goodchild, M.F. & Yang, S. (1992) A hierarchical data structure for global geographic information systems. *Computer Vision and Geographic Image Processing, 54(1)*: 31-44.

Hu, P., Liu, P.L. Hu, H. etc. (2005) Metric space of earth information and global GIS. *Geomatics and Information Science of Wuhan University. 31(5)*: 317-321.

Kimerling, A.J. (2002) Predicting data loss and duplication when resampling from equal-angle grids. *Cartography and Geographic Information Science, 29(2)*: 111-126.

Mulcahy, K.A. (1999) *Spatial data sets and map projections: an analysis of distortion*. PH.D Dissertation. Graduate School and University Center. City University of New York, New York. DAI-A 60/01,210p

Mulcahy, K. A. (2001) Two new metrics for evaluation of pixel-based change in data sets of global extent due to projection transformation. *Cartographica, 37(2):* 1-11.

Mulcahy, K. A. (2004) Map projection and spatial referencing for global data sets. Retrieved from the World Wide Web May 9, 2007: http://www.spatial.maine.edu/~onsrud/ucgis/testproc/mulcahy/mulcahy.html

Nebiker, S. (1998) Grids-an architecture for managing very large orthoimage mosaics in a database framework. *IAPRS, 32(4)* 428-435.

Snyder, J. P. (1992) An equal-area map projection for polyhedral globes. *Cartographica, 29(1)*: 10-21.

Lee, M. & Samet, H. (2000) Navigating through triangle meshes implemented as linear quadtree. *ACM Transactions on Graphics, 19(2)*: 79-21.

Otoo, E. & Zhu, H. (1993) Indexing on spherical surfaces using semi-quadcodes. In: Abel J. and Beng C. O.(Eds.), *Advances in Spatial Databases 3th International Symposium, SSD`93*, Singapore.

Seong, J. & Usery, E.L. (2001) Modeling the raster representation accuracy using a scale factor model. *Photogrammetric Engineering & Remote Sensing, 67(10):* 1185-1191.

Seong, J.C. (2003) Modeling the accuracy of image data reprojection. *International Journal of Remote Sensing, 24(11)*: 2309-2321.

Seong, J.C. (2005) Implementation of an equal-area gridding method for global-scale image archiving. *Photogrametric Engineering & Remote Sensing. 71(5)*: 623-627.

Usery, E. (2004) Global Representation and Modeling. Retrieved from the World Wide Web, April 29, 2007: http:// www.ucgis.org

Wang, M., Gong, J., & Li, D. (2001) Spatial seamless data organization of large-scale image database. *Geomatics and Information Science of Wuhan University, 26 (5)*: 419-424.

Wichman, F. E. & Elvers, E. (1974) A system of domains for global sampling problems. *Geografiska Annalar, 56(3/4):* 201-212.

Zhang, L (2004) Study on simplification of 3D terrain data and spatial analysis. *Journal of System Simulation. 16(3):* 608-611.

Zhao, X. S. & Chen, J. (2003) Fast translating algorithm between QTM code and longitude/latitude coordination. *ACTA Geodaetica & Cartographica Sinica, 32(3)*: 272-277.