Transformation Based Polynomial Model: In Case of Generating Orthophoto

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Abstract

A new approach for generating orthophoto based on polynomial models is proposed. Polynomial plays a key role in proposed transformation from 3D to 2D; meanwhile the Efficiency Index measures the accuracy of the results of orthophoto. Airborne laser and aerial photograph were two data sources for researching. Both manual and automatic functions were employed to assist and improve modes of gathering and increasing control points. Height constraint was considered in order to increase the accuracy of generating orthophoto. It was block processing as recursive applied for smaller area, when the accuracy of whole area or prior area was not accepted. Finally orthophoto with its accepted accuracy was produced. It can be summarized that polynomials could assist to generate orthophoto with acceptable accuracy (R^2>0.990) of output, which could further be increased with greater control points by recursive block processing.

I. INTRODUCTION

Transformation model is a technique, which is used to simulate both the movement and the manipulation of objects in two-dimensional (2D) and three-dimensional (3D) spaces. These processes involve translations, rotations, scalings, and reflections. Transformation model can operate either in rigorous or in non-rigorous forms. With the increasing number, and greater complexity of sensors becoming available, and the need for standard transformation [3], polynomials, a kind of non-rigorous, has been modified and represented with interesting solution for transformation with less complexities of polynomials and acceptable accuracy.

Generally polynomials are applied for various data sources. Kratky (1989), mentioned in [3], used polynomials to transform from object co-ordinates to image co-ordinates of SPOT data in the real time loop of a analytical plotter by fitting spatial grid through a least square solution. Theoretically, polynomial-mapping functions could be used in image matching [1]. Madani (1999), Ramon Alamus (2000) and Papapanagiotou (2000), mentioned in [3], reported on the use of rational functions (ratios of polynomials) based on a rigorous analytical triangulation adjustment, photogrammetry techniques, and simulating stereo-image geometry respectively. At the turn of the century, the rational functions was introduced by fitting the rational functions both to image and object-grids positioned at different elevations using rigorous image geometry model and least square adjustment [8]. It was also applied for digital photogrammetric workstations. It was concluded that the uses of polynomials were quite suited to be used for many sensors and provide an efficient and accurate way of using data [3]. However, the combination between different sources of tested data has not been experimented. Attempt so far have used single data source by experimenting in stereo pair platforms. This kind of experiments may have a limitation of losing some information for improvement of polynomials.

Practically complexities involved polynomials are a barrier for computation and are liable to accuracy degradation. Universal Sensor Model, USM, regarding on rational function [8] provides dynamic rational function polynomial allowing for the selection of minimum number of rational function polynomial coefficients in order to meet a desired fit accuracy relative to rigorous sensor model of complex sensor [10]. However, it occurred some disadvantages of complexities of modified polynomials, which represented to the fifth power of the two horizontal co-ordinates and up to third power for elevation [8, 3]. Obviously the modified polynomials become more complexities with higher power of polynomial function.

Considering the accuracy of polynomials, it was experimented on geometric accuracy of polynomial mapping functions with a SPOT's stereo pair. It was found that the accuracy represented with 1m in object and 1μm in image space [1]. Madani (1999), mentioned in [3], resulted RMS accuracy on checkpoints with 8.5m in planimetric and 6.8m in elevation and also Ramon Alamus (2000), mentioned in [3], reported the accuracy with 8m in planimetric and 17m in height. In 1999, USM fixed the problem of accuracy limitation in fitting to the rigorous image geometry model and a complex non-linear fitting process [8]. It was concluded that polynomials could improve geopositioning performance and could be accepted for accuracy [3].

However, reviewed methods separately fulfill in each part. It has not had a solution achieving for all requirements. Some methods are not rigorous and could lead to errors. Some

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failures come from image noisy and also some limited on accuracy assessment by using only check points. In addition, it shows some complexities of defining function and number of points required and also complexities of modifying polynomial functions. Noticeably most of works are still related on photogrammetric parameters.

Therefore, in order to fulfill the requirement of less complexity of polynomials and its computation with acceptable accuracy, new approach of non-rigorous (modified polynomials) transformation is a necessity.

II. PROBLEM OF GENERATING ORTHOPHOTOS

Nowadays the incremented numbers of sensors are a real situation. Generating orthophoto based on different sensors is the huge obstruction for its processing. It is likely to be a current limitation of producing orthophotos. In fact, simple solution should have been available for them in order to yield orthophotos with acceptable accuracy. Hence, in order to do the better way, this paper draws a new line of generating orthophoto with respect to polynomials and also shows its accuracy and testing procedures. Basically this research is organized to answer the question of how procedure of generating it is, how many control points are sufficient, and how to select control points. According to arisen questions, most of questions are still in doubt for answering and have not been tested. In addition, this research is going to answer for those questions by beginning from polynomial setup. That is polynomial degradation from complicated format to simple format based on acceptable accuracy. The optimal polynomial formula is related to U (column) and V (row) of aerial photograph and X,Y, and Z of airborne laser data. Global transformation model is defined after all positions accuracy are accepted. Those accuracy are calculated by Efficiency Index. Meanwhile, local transformation model is applied for increasing the position accuracy of output. Finally orthophoto is generated and fulfilled by interpolation method for overcome meaningless area.

III. OVERVIEW OF THE PROPOSED APPROACH

Definition of an orthophoto

An orthophoto is a photograph in which objects are shown in their true orthographic positions. Unlike conventional images, it can be used as a map from which direct measurements of distances, angles, positions, and areas can be made.

Objectives

The objective of this research is to generate orthophoto based on a new proposed approach, which employed polynomials for producing orthophoto with acceptable accuracy in positioning. Airborne laser data is brought for this experiment due to an appropriate its data density that it can support for transferring all data from 3D to 2D.

Process flow and methodology

Theoretically, the simple polynomial equation for three variables is defined as:

$$f(x,y,z) = a_0 + a_1x + a_2y + a_3z + a_4x^2 + a_5y^2 + a_6z^2 + a_7xy + a_8yz + a_9xz + a_{10}x^3 + a_{11}y^3 + a_{12}z^3 + a_{13}x^2y + a_{14}x^2z + a_{15}y^2x + a_{16}y^2z + a_{17}z^2x + a_{18}z^2y + a_{19}xyz \quad (1)$$

The polynomial function in Eq. 1 has difficulty in maintaining all constant values (a_0 -> a_{19}), particularly when the data volume becomes large. By experimenting on two sets of sample data, the appropriated numbers of constant values were obtained at eight constant values (a_0 -> a_7) serving for 3D transformation (not only for affine transformation) and maintaining EI value above 0.95 [7]. The result of testing is shown in Figure 1 by Efficiency Index (hereafter, EI) graph.

Before going to explain details of methodology, some questions should be answered such as how to select control points, how many control points are enough at the beginning and at the end, and why. Looking at Figure 2, clear corners of buildings are appropriate for choosing as initial control points. All allocated control points appear in both airborne laser and aerial photograph data. Generally, it is rather difficult to specify how many control points are appropriate for area interest. For this experiment EI is a major tool answering optimum number of control points. The value of EI represents an accuracy of positioning. It means that number of control points depends on defined EI value.

In general, EI is formulated as:

U_i is the original referenced point data.

$\overline{U}$ is value of referenced point data.

$\hat{U}_i$ is the calculated value.

e_i is the residue.

$$ST = \sum (U_i - \overline{U})^2 \quad (2)$$

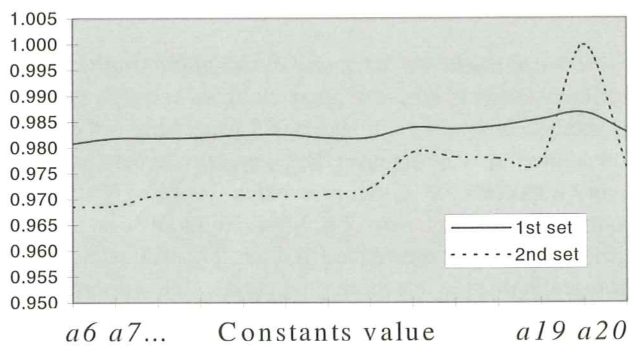


Figure 1. EI graph represents two sets of sample data with the value of EI when the constant values were changed from *a20 ... a6*.

(a) (b)

Figure 2. Control points allocation by X. (a) Control point on airborne laser data; and (b) Control point on aerial photograph

$$SSE = \sum (U_i - \hat{U}_i)^2 \rightarrow \sum e_i^2 \quad (3)$$

$$SU = ST - SSE \quad (4)$$

$$EI = SU/ST \quad (5)$$

From this EI graph, the shorten polynomial function is represented as

$$f(x,y,z) = a_0 + a_1x + a_2y + a_3z + a_4x^2 + a_5y^2 + a_6z^2 + a_7xy \quad (6)$$

According to Figure1, the proposed method with respect to polynomials is described as follows:

(1) Input data (X, Y, Z, U, V) are set as equations, while X, Y, and Z are obtained from airborne laser, U, and V are obtained from aerial photograph on matched positions. Hence U and V are computed as:

$$U = a_0 + a_1x + a_2y + a_3z + a_4x^2 + a_5y^2 + a_6z^2 + a_7xy \quad (7)$$

$$V = a_0 + a_1x + a_2y + a_3z + a_4x^2 + a_5y^2 + a_6z^2 + a_7xy \quad (8)$$

Using Eq. 7, constants $a_0..a7$ are solved from eight equations. EI is used to select the best control points of U, which are acting as group representative. Based on those selected control points of U, Eq.8 is calculated to provide $a_0...a7$ *of* V.

(2) Next step is, rechecking Eq.7 and Eq.8 by replacing the values of X, Y, Z.

(3) Finally, statistical correlations are used to compare the calculated results of U and V with referenced points X and Y.

Basically, the major processes encountered in the generating orthophotos are as follows:

1) Site work (airborne laser and aerial photograph):

Sufficient control points and good quality of aerial photograph are the two key factors in successful generating orthophoto. Considering at airborne laser data, appropriate control points is very important for further processing. As being known that the aerial photograph cannot be adjusted into its true position without precisely referenced points. Theoretically, aerial photograph display in central projection, while airborne laser data represent in parallel projection with higher density of cloud points 3D data (XYZ). Besides, aerial photograph also display some distortions, either caused by the lens or by the angles at which the aerial photograph are taken. They are very high distortion if appearance buildings are very tall. If they have enough sufficient co-ordinates of control points with respect to airborne laser data, those distortions might be removed in the process of generating orthophoto.

2) Height Consideration:

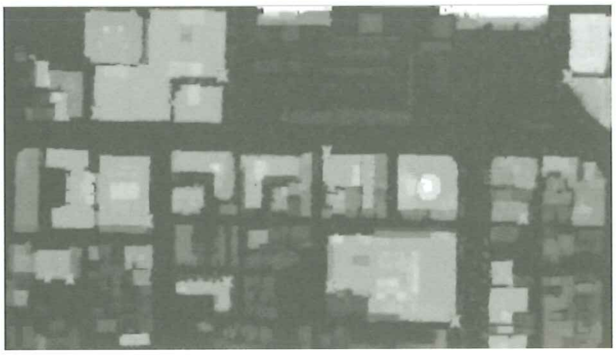
Normally airborne laser gives height of detected objects automatically. According to proposed polynomial model, it cannot directly be used for whole area. Some errors of transformation are occurred [7]. Hence, in order to compromise between acceptable result and sufficiency of using proposed transformation model, height data is divided into layers with mainly considering on its histogram as an indicator. In general, control points are extracted by considering whole area as in Figure 3(a). It is represented as Figure 3(b), when layers of buildings are allocated. It might be more layers, if the interested buildings are more complex. By considering histogram curve, the number of layer can be identified.

3) Major Control Points Selection:

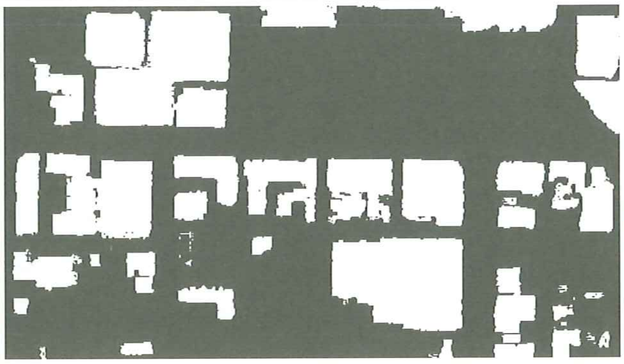
A selection of major control points can be undertaken by manual and automated selections. Manual selection of initial major control points, which a human being with normal vision is able to do, has been arisen so far, while automated procedure is just coming up in recent years. The problem of selection might be occurred both from human misunderstanding and from wrong selection by automated method. By experiment, it is manual selection used for selecting initial major control points [7] and then applies automated selection for supporting points.

4) EI Computation Based Selected Major Control Points:

The method find out value of Efficiency Index is already mentioned above. The acceptable EI value of this experiment is set at 0.999 (out of 1) that represents meaningful results. EI is computed throughout Matrix and Least Square Principals and then yields appropriate major control points regarding EI value. Finally the highest EI value is labeled, accompany with selected major control points and their constant values. In case EI value cannot reach 0.999, the additional major control points are added by manual. This process is named as *"Global Transformation."*



(a)



(a)

Figure 3. Height consideration. (a) Whole area with its control points; and (b) Layers by ground (black) and roof (white), according to histogram

5) Establishment of Transformation Model:
Polynomial models are set up and related to the given constant values from EI computation, which present in form of Eq.7 and Eq.8. This transformation model is employed as a bridge for transferring all intensity values (pixels) from aerial photograph to airborne laser data. Results of transforming are checked by correlation (R^2) between referenced position and modeled position. If R^2 is lower than 0.990, the supporting control points is automatically established and added into computational procedure as recursive system. This procedure is named "*Local Transformation*". The outstanding advantage of proposed transformation model is that it enables to transform all data from central projection to parallel projection.

6) Edge Extraction (Preparation for Automated Increasing of Supporting Control Points):
Edge extraction is a method creating data being used in local transformation model. Normally an edge is a boundary where some properties (brightness, color, or texture) are changing suddenly [5]. There are many techniques to extract edges, for example using gradients, templates and parametric edge model [4]. However, meaningful edges will be detected by *A' Trous* Wavelet filter [9] for this experiment.

7) Automated Matching Algorithm (After Edge Extraction):
Generally there are two matching algorithms: area based matching and feature based matching. Area based matching considers at an intensity of the pixels, meanwhile feature based matching takes on symbolic descriptions of images for establishing correspondence. In this paper, area based matching is tested by considering pixel neighborhood. Edge is a feature being considered. Local 5x5 window searching is applied for finding out corresponding points. Those mismatched points are avoided, if corresponding edge and detected relative neighborhood between airborne laser and aerial photograph are not equivalent. On the other hand, matched point can be selected under 5x5 window. Finally selected points will be computed by EI and checking the correlation (R^2)

8) Recursive Method:
As it is mentioned earlier, recursive method is applied as block processing. The whole area is calculated firstly, then result the value of EI and correlation. If the correlation between referenced position and modeled position is not acceptable. Area of consideration is narrow to half of them and continually processing until the correlation value is accepted. Practically it is figured as Figure 8.

IV. EXPERIMENT AND RESULTS

There are two data sets being experimented: airborne laser data and aerial photograph as in Figure 4. Airborne laser data performs its position and height in X, Y and Z, while aerial photograph represents in U (column) and V (row).

According to proposed methodology, manual selections on control points were undertaken. The corners of buildings were mostly chosen as control points. They were ten control points selected and then computed their position accuracy through least square principal. It found that the accuracy of output was 0.999 of EI, 0.990 of XU, and 0.983 of XV values. The orthophoto result was drawn as in Figure 5.

Actually the input control points could be increased more than 10 points but time processing might be incremented if the size of input data is enlarged. Also the study area is city; the proposed model could not applied directly to this kind of data. It might be possible to maintain higher accuracy than city area, if it is a flat or almost flat. Hence, in order to keep speed of processing with acceptable accuracy of output, height constraint is considered as a factor of accuracy.

According to height constraint by dividing height data into each group, they were two kinds of method experimented on city data. One was user-based method. Another was histogram-based method. By result of experimenting as in Table 1, histogram-based method was selected as a tool of dividing. Finally, it maintained all output accuracy above 0.999 of EI and 0.983 of correlation that were better than the prior result proceeded without height constraint.

(a) (b)

Figure 4. The study area (a part of Kyoto city), with no.1 for roof and no.2 for ground performing as control points. (a) Airborne laser data ; and (b) Aerial photograph

After histogram-based method was selected, airborne laser data was separated into two layer based on histogram. Then manual selection on major control points was undertaken in both 1st and 2nd layers. Ten major control points and those correspondences on aerial photograph were initially allocated in each layer by manual method. Also the transformation models regarding two sets of divided height data were established as Eq.9 and Eq.10 for 1st layer and Eq.11 and Eq.12 for 2nd layer.

$$U = -59.413151 + 1.023815x + 0.044316y + 0.235144z + 0.000019x^2 + 0.000018y^2 - 0.003658z^2 - 0.000086xy \quad (9)$$

$$V = -3.675463 + 0.015382x + 0.899646y - 0.096163z - 0.000033x^2 + 0.000272y^2 - 0.000340z^2 - 0.000054xy \quad (10)$$

$$U = -10.428100 + 1.034893x - 0.015527y - 0.714826z - 0.000028x^2 + 0.000120y^2 + 0.003010z^2 - 0.000022xy \quad (11)$$

$$V = -29.280567 + 0.007535x + 0.944499y + 0.462047z + 0.000005x^2 + 0.000198y^2 - 0.002319z^2 - 0.000136xy \quad (12)$$

Figure 5. The result of computed model based on 10 control points

Proposed transformation models above, which was named as global transformation model, concentrated to all surrounding points by transforming all intensity values from aerial photograph to airborne laser data, and then generated matched area as in Figure 6. In addition, outputs were checked in terms of accuracy positioning by statistical correlation between referenced position and modeled position as shown in Table 2.

From Table 2, the accuracy of resulted data involving height constraint was better than the data without considering on height.

The difference of generating orthophoto by considering whole area with separated two layers and without separated layers was an output's accuracy. According to experiment, the accuracy of multiple layers was better than single layer. Obviously the output as in Figure 6 is more closed to nature of objects than output in Figure 5.

In order to improve the existing accuracy of generated orthophoto, local transformation model was proposed to increment accuracy. Local transformation model was a model running automatically throughout all position of data. After using global transformation model as initial point, the local transformation model started its processing as recursive with block processing.

Table.1. Result of experiment on height dividing

Number of designed layers	Height	EI at referenced points	Correlation of X and U	Correlation of Y and V	Method of dividing
2	0-85	0.999	0.995	0.999	Histogram-based
	86-255	0.999	0.994	0.996	
3	0-100	0.999	0.996	0.998	User-based
	100-150	0.997	0.994	0.995	
	150-255	0.999	0.997	0.995	

more than 3, it cannot produce acceptable accuracy, due to less number of matching.

Basically edges filtering and matching algorithm were two factors to be considered. It was *A' Trous* algorithm and 5x5 window matching, having been experimented [7], giving a meaningful result.

Thus, this experiment, edges of the 1st and 2nd layers of output of matched area were extracted by using *A' Trous* algorithm as in Figure 7, while the edges of airborne laser data were also extracted.

According to extracted edges data from orthophoto and its airborne laser data, automated local transformation was applied for each layer by matching the same edges appearing within 5x5 window. The 5x5 window mask ran from up-left corner till bottom-right corner by working from left to right site. In matching stage, 5x5 window-matching algorithm considered the relative neighborhood inside its window. The center point of 5x5 mask was selected if all pixels in window of both sets of data were the same. All matched control points showed in Table.3. After matched points have been detected, the calculation of accuracy was employed. Then, EI and correlation of XU and YV were calculated.

As mentioned about recursive method, the way of working performed as in Figure 8.

Table 2. Result of experimenting on two set of divided height data compared with prior result.

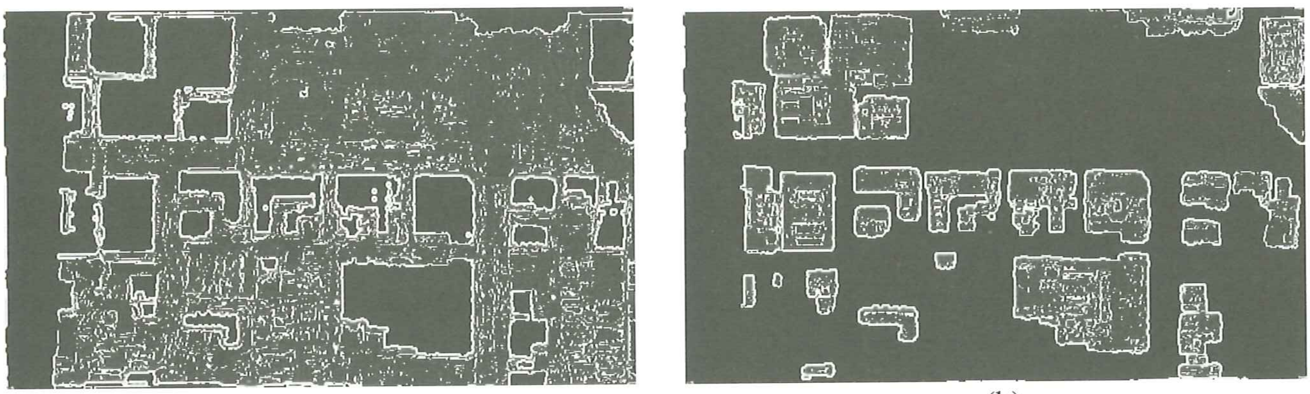
EI at referenced points	Correlation of X and U	Correlation of Y and V
With height constraint:		
1st layer: 0.999	0.995	0.999
2nd layer: 0.999	0.994	0.996
No height constraint:		
0.999	0.99	0.983

The calculated data of EI, XU ,and YV of 1st and 2nd layers were represented as in table.4. Practically, the computation of EI, XU, and YV were applied in 1st block firstly, then went to 1a, 1b, 1c, and 1d, in order to result values of EI, XU, and YV. Next it was 2nd block and made the same thing as 1st block. It worked as recursive until completing whole area. It was found that some blocks were improved, while some blocks gave lower accuracy than prior computation.

According to Table 4, it was summarized that local transformation model was able to improve the position accuracy of orthophoto when those positions had not been saturated. On the other hand, it was not able to increase

(a) (b)

Figure 6. Orthophoto based on global transformation model. (a) 1st layer; and (b) 2nd layer



(a) (b)

Figure 7. Result of edges extraction on airborne laser data regarding aerial photograph. (a) 1st layer (ground) (b) 2nd layer (roof)

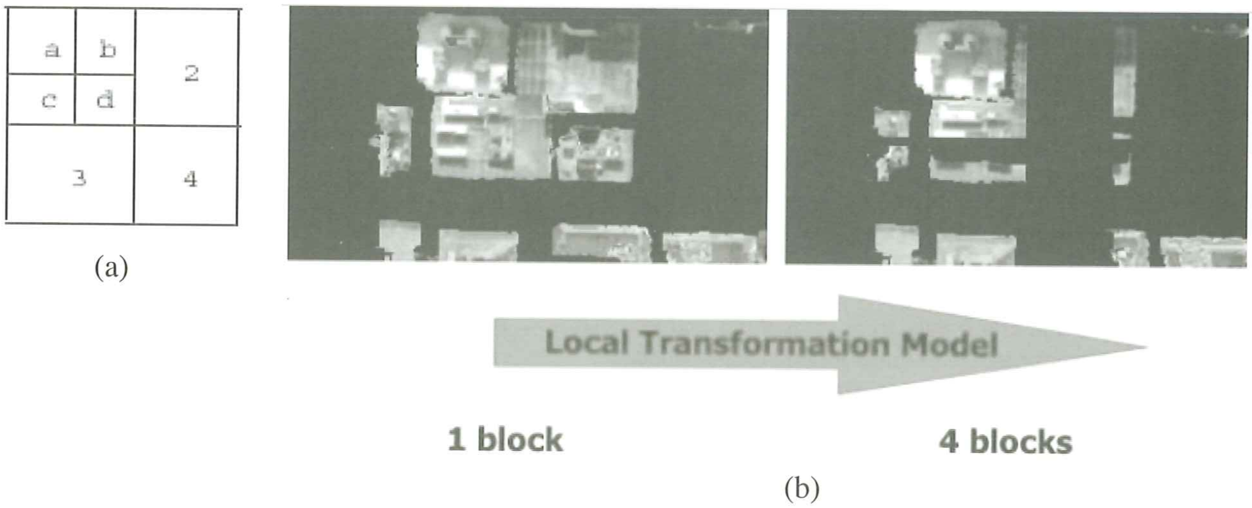


Figure 8. Recursive method starting from 1st block, then processing down to a, b, c, and d. Next go to 2, 3 and 4. (a) Method for recursive; and (b) Recursive down to 4 blocks (roof)

accuracy if the accuracy of those positions already reached highest level of accuracy. From beginning, global transformation model was proper method to be applied for establishing matched area with some accuracy. Then it was local transformation model arising higher accuracy, based on automatic processing.

Finally it was interpolation method to be applied for all output, due to incomplete color of orthophoto. Thus the following algorithm was stepped as

- The 5x5 windows mask was applied for searching the problem area
- Uncertain area was checked relatively with neighborhood by considering intensity value from aerial photograph and height of buildings from airborne laser data
- Then it was selection of appropriate intensity value after considering earlier procedure.

Table 3. Automated matched control points

Block	Number of matched	Block boundary (left top to right bottom)
1st block	17	(0,0) to (144,266)
1a	20	(0,0) to (72,133)
1b	18	(0,133) to (72,266)
1c	21	(72,0) to (144,133)
1d	22	(72,133) to (144,266)
2nd block	20	(0,266) to (144,532)
2a	20	(0,266) to (72,399)
2b	22	(0,399) to (72,532)
2c	23	(72,266) to (144,399)
2d	23	(72,399) to (144,532)
3rd block	24	(144,0) to (288,266)
3a	20	(144,0) to (216,133)
3b	20	(144,133) to (216,266)
3c	20	(216,0) to (288,133)
3d	20	(216,133) to (288,266)
4th block	24	(144,266) to (288,532)
4a	23	(144,266) to (216,399)
4b	24	(144,399) to (216,532)
4c	23	(216,266) to (288,399)
4d	23	(216,399) to (288,532)

Table 4. EI, XU, and YV values on recursive processing

	1st layer			2nd layer		
	EI	XU	YV	EI	XU	YV
1st block	0.999	0.968	0.975	0.999	0.977	0.99
1a	0.999	0.953	0.97	0.999	0.971	0.99
1b	0.999	0.967	0.969	0.999	0.974	0.985
1c	0.999	0.959	0.974	0.999	0.97	0.988
1d	0.999	0.969	0.98	0.999	0.975	0.991
2nd block	0.999	0.995	0.987	0.999	0.987	0.982
2a	0.999	0.993	0.984	0.999	0.987	0.98
2b	0.999	0.994	0.984	0.999	0.99	0.972
2c	0.999	0.995	0.986	0.999	0.99	0.975
2d	0.999	0.995	0.988	0.999	0.991	0.977
3rd block	0.999	0.993	0.997	0.999	0.99	0.987
3a	0.999	0.993	0.993	0.999	0.989	0.989
3b	0.999	0.993	0.994	0.999	0.989	0.989
3c	0.999	0.993	0.995	0.999	0.989	0.99
3d	0.999	0.993	0.995	0.999	0.989	0.991
4th block	0.999	0.995	0.998	0.999	0.992	0.994
4a	0.999	0.994	0.996	0.999	0.993	0.994
4b	0.999	0.995	0.996	0.999	0.993	0.994
4c	0.999	0.995	0.997	0.999	0.994	0.995
4d	0.999	0.995	0.997	0.999	0.994	0.995

- It was the process of filling up those area with selected intensity value
- At the last, completed output was delineated.

By testing, the result of orthophoto can exactly be featured over 3D airborne laser data as in Figure 9.

V. DISCUSSION AND CONCLUSIONS

In general, polynomial models are served in several kinds of applications in the field of mathematics. For this research, the polynomial model has also supported for four variables (X, Y, Z, U or V) that are applied for generating orthophoto as well as transformation methods of Kratky (1989), Baltasavias and Stallmann (1992), Madani (1999), Ramon Alamus (2000), OGC (1999) and Dowman and Dolloff (2000), mentioned in [1][3][8]. Due to limitations of polynomial function, it does not provide directly for generating orthophoto purpose. Some certain procedures are established for this experiment. A manual model is the initial stage of procedure for generating matching points. Modified polynomial model is proposed as a new contribution working on generating orthophoto without parameter limitations regarding photogrammetry field, which always happened in the past; for example Baltasavias and Stallmann (1992), Madani (1999), Ramon Alamus (2000), and Papapanagiotou (2000), in [1][3]. In the experiment, the proposed method demonstrates excellent performance, even large number of noisy in both aerial photograph and airborne laser data. Due to the high frequency of reflective value of objects corresponding to edge detectors, especially airborne laser data; all edges can be detected clearly. It provides the alternative solution for generating orthophoto and avoids the complexities of photogrammetry techniques that are serious barrier for previous researches [3]. Practically, polynomial is an extraordinary transformation function, including of *global transformation model* that shows efficiency of generating orthophoto with accuracy more than 0.990 (R^2) and of *local transformation model* with 0.999 (R^2).

Recursive processing is a basic method to be used for computation. In each step of recursive, EI, XU, and YV are resulted. Finally whole area of orthophoto can be established by local transformation model. According to this experiment, they are some discussions being mentioned as follows: (a) the polynomial model can be applied directly for a whole area; for example city as one model, but the orthophoto result could not be directly accepted, due to height constraints (b) the consideration on height-constraint can eliminate some distortions of generating orthophoto (c) major control points defined by manual are very important part for automated functions (d) corner of buildings can be the significant position for selection as major control points (e) number of control points can be defined by considering on result of EI value, basically, acceptable level of EI should be more than 0.999 (f) the edges of the aerial photograph that are generated by existing filters can serve sufficiently for the matching process (g) local transformation model can improve the position accuracy of matching and generating orthophoto in some blocks.

In fact, the proposed model serves for various kinds of sensors and also fulfills the complexities of polynomial functions and computation with acceptable level of accuracy particularly in generating orthophoto.

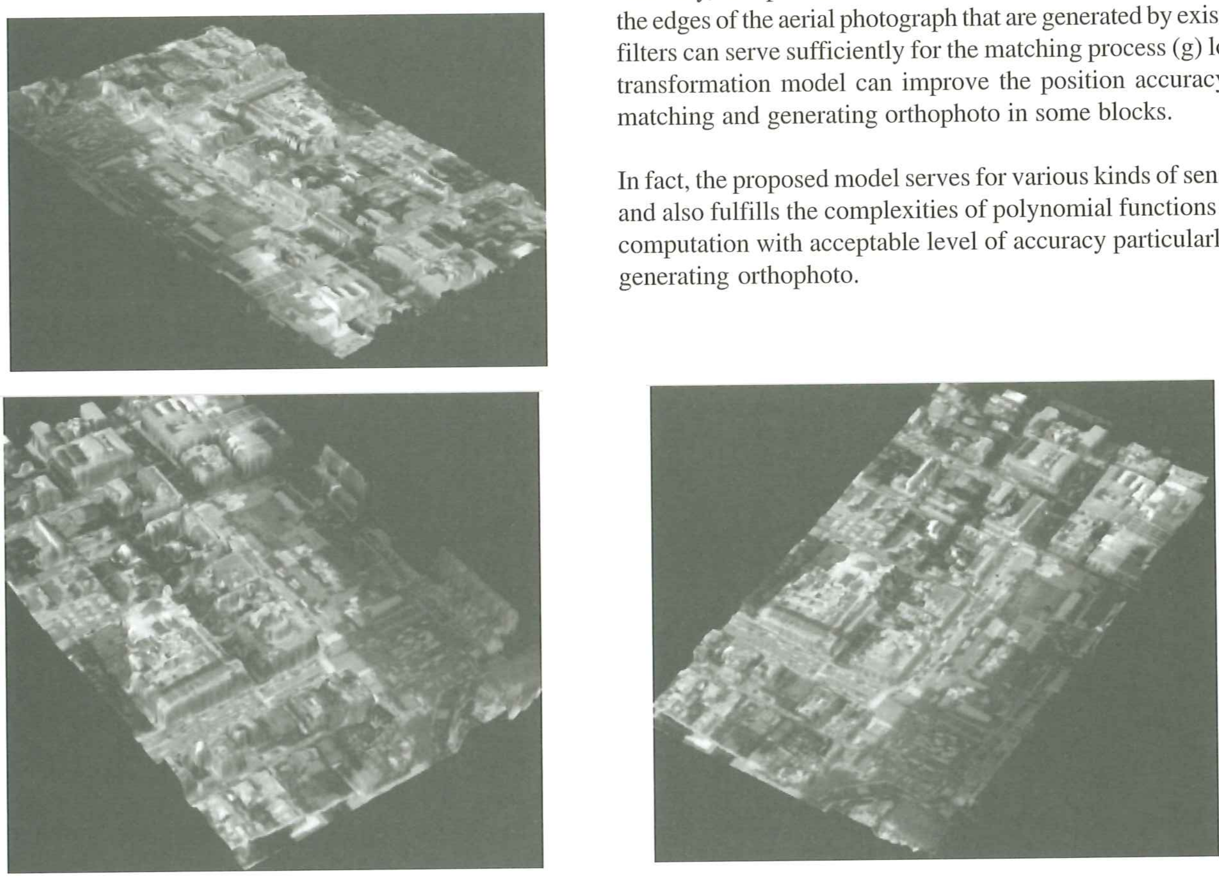


Figure 9. Orthophoto results representing on 3D surface

VI. FURTHER WORK

The result of matched area would be more accurate, if the edges on aerial photograph serve with clearer than current aspects.

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