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A Study on the Distortion Correction for the Digital Cadastral Maps

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Abstract

The cadastral maps, as many as about 750,000 map sheets to cover 34,751,000 parcels of land of Korea, are being digitalized. The problem of shrinkage-expansion of the paper cadastral maps has to be resolved for the new digital maps, where the nodes and vertices of the parcel boundaries are represented by coordinates. The photo coordinate refinement techniques, two dimensional projective transformation and local area transformation as in the reseau grid method, were introduced for this distortion correction. Using the fact that original maps drawn on the plane tables in field from 1910 to 1918 have grid lines and have been preserved well, a strategic flow to apply the refinement techniques to the digital maps with the original maps as controls was developed. To accommodate the presence or absence of the original maps and grid lines, and different scales and sizes of the maps, the strategy was implemented by a computer program package. Various distortions and corrections were simulated and errors were evaluated. The RMS errors in the corrected digital maps were allowable, thus, the method developed in this study was to be applicable for the digital cadastral maps.

Keywords : Cadastral Map, Distortion Correction

1. Introduction

The land of Korea consists of 31,331,000 parcels of land and 3,420,000 parcels of forestry land as of the year of 2000. The total of 34,751,000 parcels are maintained in the forms of cadastral records and cadastral maps: Cadastral records are composed of land records, house records, and forest records; Cadastral maps are composed of land maps and forest maps[1).

The records in text format and maps in straight line and polygon format had been written and drawn by hands and stored in the paper forms, then photocopied for public users until 1990. The land records and house records in text format had been typed to create a national database from 1982 to 1991 and began to be provided to the users through the nation-wide networks from 1991. For the maps, digitalization began in 1999 after a success of a pilot project, 'Digitalization of maps of Yuseung-gu, Daejeon', conducted in 1997, of which the area is 176km^2 and the number of parcels involved are 75,000. The total number of map sheets (the size of the border rectangle of a map sheet is about 30cm*40cm in 7 different scales of 1/500, 1/600, 1/1000, 1/1200, 1/2400, 1/3000, and 1/6000) to cover the whole land of Korea is about 750,000 which hold the 34,751,000 parcels[2),3)]. About 182,000 map sheets (24%) have been digitalized as at the end of year 2000, and the rest are scheduled to be completed by the year 2004.

The records for a parcel, by the laws, are the bases of the property, whereas the maps for the parcels are just a reference to show the locations for registration, taxation, and transactions. The maps, however, are the basis for the parcel restoration. That is, for example, when the area of a parcel is recorded as 100m^2 but the area by the map measurement is 99m^2, the record is adhered to. On the other hand, when the parcel boundary lines are restored, the map is the basis, and results in 99m^2 of land.

One problem raised by the digitalization of the maps is that the area on the maps can be calculated easily

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because boundary points will be in coordinates, thus the discrepancies between records and maps can be exposed in public and also the statistics of the land by the records and by the maps do not coincide. The correction of the maps to compensate for the shrinkage-expansion of the map sheets has become more essential in digitalization.

A couple of algorithms to deal with the shrinkage-expansion problem on the digital maps (digitalized cadastral maps) have been presented and are being used but no satisfactory results have been obtained. One is to restore the four corner points of a map sheet to the original dimension, and the other one is to divide a map sheet into 9 sub-regions (3*3 sub-regions) and apply separate scale factors to each sub-region. Both did not work well because of the irregularity of the distortions and the lack of the references for the scale factors for the sub-regions.

2. Proposed Methods for Shrinkage-Expansion Corrections

The original cadastral maps (OCM) have been discovered in the National Record Preservation Facility, the map sheets with needle marks drawn on plane tables by pencils in field in 1910~1918. And also these OCM have fine nominal grid lines as a background. The grid lines are in the dimensions of 30.303mm*30.303mm, which is one tenth of the Korean ancient unit of length[2]. OCM are also distorted but the grid can be used as the references for the distortion correction as in the reseau grid method of photo coordinate refinement in photogrammetric works. The idea of this research is to use the grid lines of the OCM to correct the shrinkage-expansion distortion of the digitized cadastral maps (DCM). In this paper the term 'paper cadastral maps(PCM)' is used to separate the two different forms of maps. The paper cadastral maps are the ones being used today. The nodes/vertex and lines appearing in the OCM are called the original nodes/ vertex (ON/OV) and the original lines (OL). The point where a line is bent is called a node and the point where two or more lines intersect is called a vertex. The public land in Korea has never been re-measured or re-drawn, (that is, the OLs are still valid) but, the parcels are divided or merged. The newly created nodes, vertex, and lines are called NN, NV, NL, respectively.

We do not know yet whether all the OCM exist for the 750,000 map sheets and all the OCM have the grid lines. Thus, three types of correction methods are proposed: Type A - using grids on the OCM when OCM and the grid exist; Type B - using OCM when OCM exists but no grid is available; Type C - no OCM exists.

2.1 Type-A Correction

It is assumed in this Type-A correction that the OCM exists for the DCM map sheet and the grid is available. The OCM's distortions are corrected by inversely applying the distortions for each and every grid cells. In this corrected OCM, the ON/OV/OL are also corrected. The nodes and vertices on the OCM are to be the reference points to correct the nodes and vertices on the DCM which is obtained by digitalization of the PCM. Figure 1 shows the flow of the Type-A correction.

In step 1 in the figure, all the points in the OCM are digitized including the four corner points of the border rectangle, the grid intersection points, and all the nodes and vertices (ON/OV) of the parcels. In step 2, the nominal coordinates of the four corner points and the grid intersection points are calculated, which depend on the particular maps (land cadastral maps and forest cadastral maps have different sizes on the map border lines) and the particular scales of the maps. The digitized points in step 1 are then transformed to the nominal map coordinate system as shown in step 3. In this transformation, two algorithms are applied in

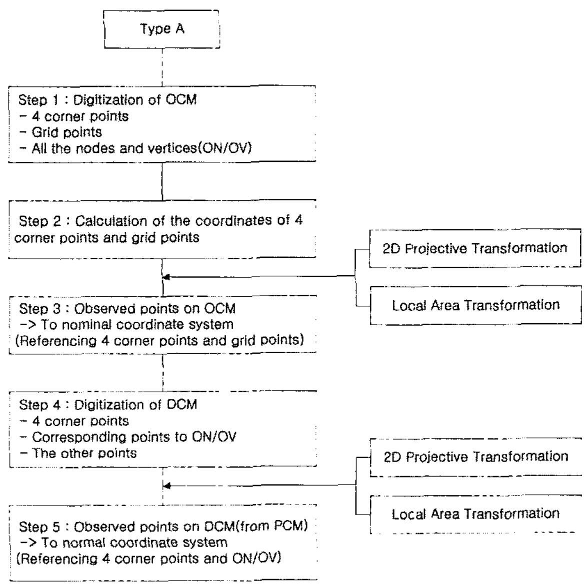

Fig. 1. Flowchart of Type-A Correction.

sequence: a 2D projective transformation using the nominal 4 corner points as control points to transform the measured points on the OCM; a local area transformation algorithm using the nominal grid points as control points to transform the measured points. The next step, step 4, is to digitize the paper cadastral maps (PCM), which are currently being used, into digitalized cadastral maps (DCM). All the points (four corner points, points corresponding to the ON/OV, and the other points, NN and NV, generated by partitioning after the OCM were drawn) are digitized. The same transformation procedure as in step 3 is applied on these digitized points. This time, however, the ON/OV are used as controls for the local area transformation. The final product as shown in step 5 is the DCM, in which all the points are in the nominal map coordinate system.

2.2 Type-B Correction

In Type-B correction, the assumption is that there exists the corresponding OCM for a PCM to be digitalized but grid lines do not exist or do not appear clearly. The idea is the same as in the Type-A correction, but an application of the local area grid transformation to the OCM using grid intersections is omitted. The flowchart of Type-B correction is shown in Figure 2.

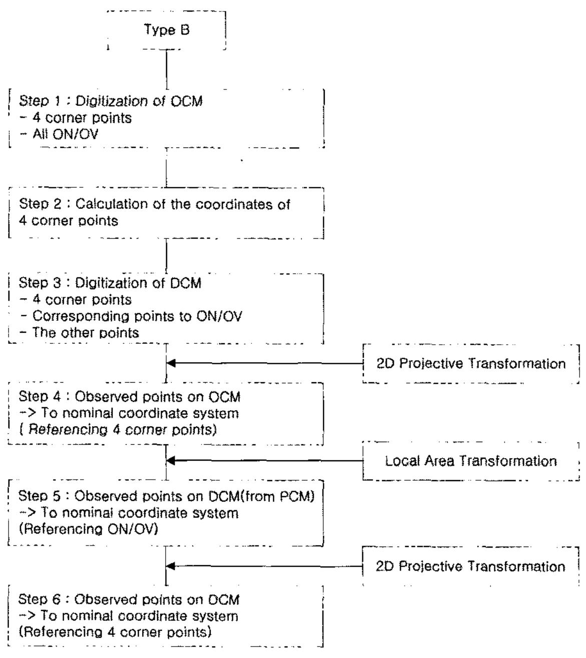

Fig. 2. Flowchart of Type-B Correction.

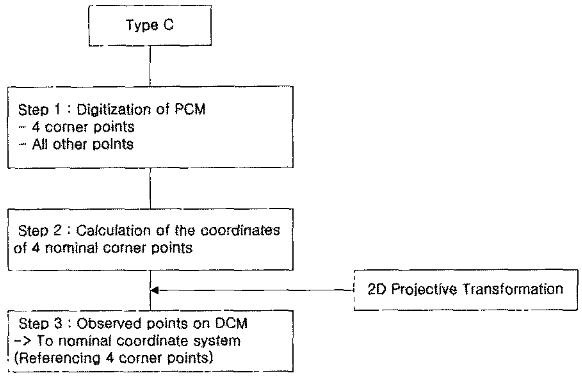

Fig. 3. Flowchart of Type-C Correction.

2.3 Type-C Correction

In Type-C correction, it is assumed that there is no OCM available. The only controls to be used are the four corner points of the nominal border lines. That is, the points on the DCM are transformed using 2D projective algorithm with the transformation parameters calculated by the four corner points of OCM and DCM. The flowchart of this type is shown in Figure 3.

3. Implementation of the Strategy of Distortion Corrections

As mentioned earlier, there are seven different scales used for the cadastral maps in Korea. These are 1/500, 1/600, 1/1000, 1/2000, 1/2400, 1/3000, and 1/6000. The maps of scale 1/500 and 1/1000 are currently constructed and being used, thus these do not have the OCM. Also, we have found that the nominal dimension of the border rectangle of OCM is slightly different for certain regions of Korea. A strategy of distortion corrections for any given digital cadastral map is set as shown in Figure 4, and a computer program package is developed accordingly to accommodate all situations.

To run the program, the user is asked to provide the information about the map sheet(where it is located, what its scale is, whether it has OCM and grid) and the digitalized map files for OCM and DCM. The program is implemented under MS window 98, in C++.

4. Algorithms of the Local Area Transformation

A simple idea is adopted in the local area transformation to correct the coordinates of points. The nearer a control point is to a point, the heavier the control point's movement influence to the correction of the

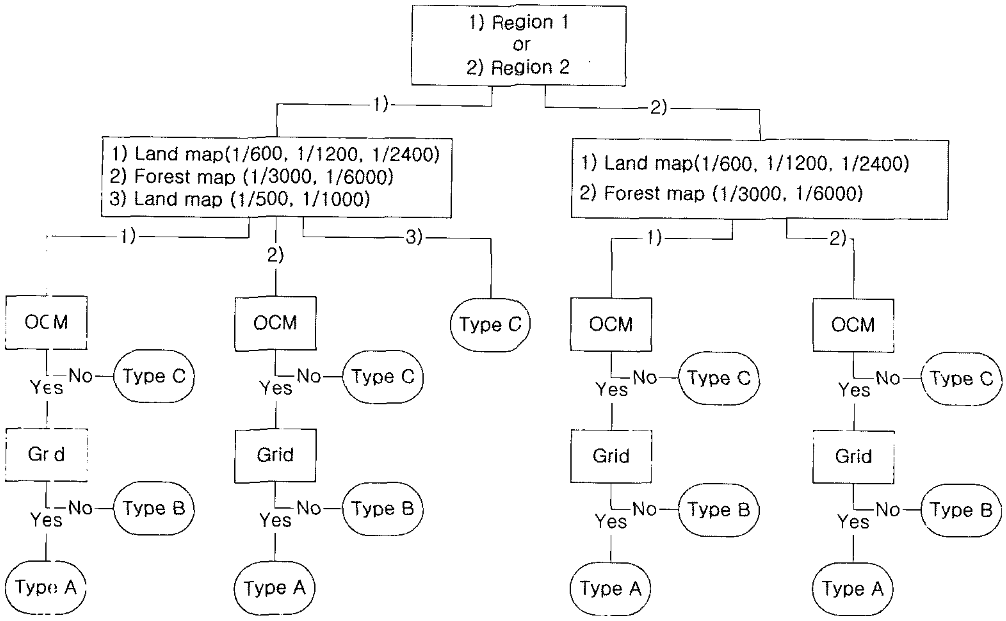

Fig. 4. Menu Diagram for Distortion Correction.

point. Two schemes are tried. One is inverse-distance-weighting and the other one is inverse-distance-square-weighting[4].

Inverse distance weighting: On a smooth surface, the height at a point, $F(x, y)$, can be interpolated from fixed heights, $f(x_i, y_i)$, of surrounding points using Equation 1.

$$F(x,y) = \sum_{i=1}^{N} w_i f(x_i, y_i) = \sum_{i=1}^{N} \frac{\frac{1}{d_i}}{\sum_{j=1}^{N} \frac{1}{d_j}} f(x_i, y_i) \quad (1)$$

N is the number of points used in the interpolation and d_i is the distance from the point to the i^{th} fixed point. The sum of weight is 1. In this study the equation is altered as in Equation 2 for a two dimensional plane.

$$\Delta x_a = \sum_{i=1}^{N} \left(w_i(\Delta x_i)\right) = \sum_{i=1}^{N} \frac{\frac{1}{dx_i}}{\sum_{j=1}^{N} \frac{1}{dx_j}} \Delta x_i$$

$$\Delta y_a = \sum_{i=1}^{N} \left(w_i(\Delta y_i)\right) = \sum_{i=1}^{N} \frac{\frac{1}{dy_i}}{\sum_{j=1}^{N} \frac{1}{dy_j}} \Delta y_i \quad (2)$$

Where, Δx_a and Δy_a are the corrections for the target point 'a' in x and y direction, respectively. dx_i and dy_i are x and y direction distance from the point 'a' to the i^{th} control point.

Inverse distance square weighting: Distortion may not occur just inverse-proportionally to the distance in sheet distortion. The logic is the same as the inverse-distance-weighting except the square of the distance is used instead of the distance, as shown in Equation 3.

$$\Delta x_a = \sum_{i=1}^{N} \frac{\frac{1}{(dx_i)^2}}{\sum_{j=1}^{N} \frac{1}{(dx_j)^2}} \Delta x_i \quad (3)$$

The two algorithms are tested by simulation of distortions and corrections on a grid sheet.

5. Simulation of the Local Area Transformation

A grid pattern is drawn using AutoCAD in the same size as the OCM(border rectangle: 416.667mm wide * 333.333mm high; grid line interval: 27.778mm * 22.222mm) and six cases of distortions are applied as shown in Figure 5.

The second order polynomial curve is applied in Case 1 distortion. Linear distortion is applied for Case 2 (in Y direction) and for Case 3(in X and Y directions).

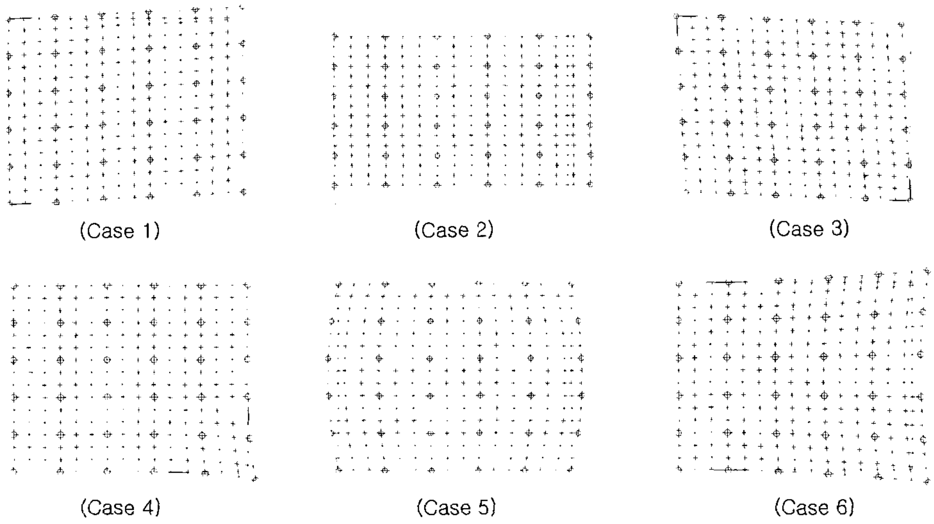

Fig. 5. Simulation of Distortions.

Irregular ones are applied for Cases 4 and 6, which would be the typical cases for the cadastral maps. A bulging distortion is applied for Case 5. The distortions in opposite direction can occur, but, these are omitted in the simulation because the correction accuracies would be the same for distortions in either direction. In addition to the generated distortions, a random error of 0.1mm of standard deviation is added to the distorted coordinates, which is the allowance for reading error when a trained person is digitizing the cadastral maps.

The circles in Figure 5 are the control points. All the intersection points are distorted accordingly, and corrected by the two local area transformation methods (inverse-distance and inverse-distance-square weighting methods). The 2D projective coordinate transformation, using the four corners of the border rectangle, is applied first in all cases before the local area transformation. This is because the 2D projective transformation is applied first no matter what kind of correction type is used, as seen in Figures 1, 2, and 3. The resulting coordinates of the non-control intersection points are compared to the originally generated ones. The RMS errors are tabulated in Table 1 for the six distortion cases and for the two weighting methods.

From the figures in the Table 1, it can be assumed that the Inverse-distance-square-weighting is more adequate for this work than the other one. Case 2 and

Table 1. RMS Errors from Simulation(mm)

Distortion Cases	Direction	Inverse Distance Weighting	Inverse Distance Square Weighting
Case 1	X	0.002	0.002
	Y	0.002	0.002
Case 2	X	0.002	0.003
	Y	0.000	0.000
Case 3	X	0.002	0.002
	Y	0.002	0.002
Case 4	X	0.360	0.281
	Y	0.339	0.264
Case 5	X	0.706	0.609
	Y	0.002	0.002
Case 6	X	0.805	0.588
	Y	0.265	0.190

Case 3 would be perfectly restored by 2D projective transformation, if no random error of 0.1mm had been added. The local area transformation worked well for Case 1. For the irregular distortions as in the Cases 4, 5, and 6, the RMS errors in Y direction are about 0.2mm, which is tolerable in the cadastral works, but the RMS errors in X direction are about 0.6mm. The biggest RMS error happened on the target points along the borderline. For the borderline targets, it would be better if the targets are corrected only by the controls along the line. That is, the controls, not on the border line, adjacent to the targets made the corrections worse. Another way to deal with the points along the borderlines is needed.

6. Application of the Strategy on the Cadastral Maps

A sample area in Daejeon-City is chosen to test the developed strategy for the distortion correction. This area, shown in Figure 6, is covered by four 1/600 digital cadastral maps. For the sake of evaluating the preciseness of the strategy, the OCMs for this area are generated using these DCMs (to have the true positions of the points) even though the real OCMs exist. The generated OCMs and the DCMs are distorted and random errors are added. Then the Type-A correction with the inverse-distance-square weighting method is applied.

6.1 Generation of the Distorted OCM[5)6)7)]

OCMs are preserved well under the stable temperature and humidity condition and have not been used often. Therefore, relatively small and well distributed distortions are introduced as follows:

map 1: case 1 distortion
map 2: case 2 distortion
map 3: case 3 distortion
map 4: case 5 distortion.

6.2 Generation of the Distorted DCM

DCMs (digitized for the PCMs) are the ones being used for everyday public land registration and other services. Therefore, unpredictable distortions must have occurred on the maps, and thus, have to be applied for the simulation. The combined distortions in the order they are introduced to make the worst situation are as follows:

map 1: case 2 - case 1 - case 4 distortions
map 2: case 2 - case 5 distortions
map 3: case 4 - case 5 distortions
map 4: case 3 - case 1 - case 6 distortions.

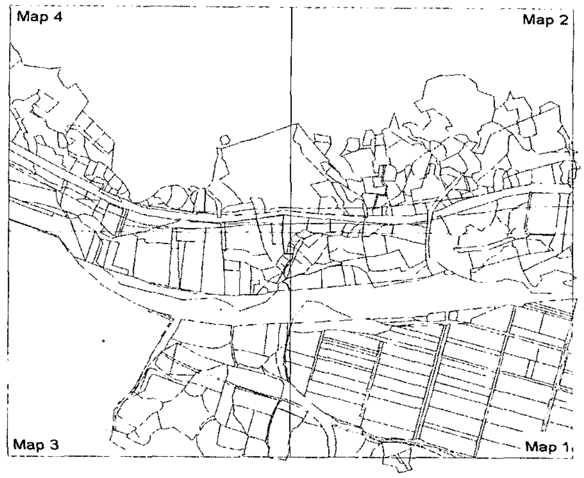

Fig. 6. Digital Cadastral Maps in Daejeon-City.

Table 2. RMS Errors for Type-A Correction(mm)

Map	Direction	RMS(mm)
Map 1	X	0.090
	Y	0.095
Map 2	X	0.148
	Y	0.000
Map 3	X	0.158
	Y	0.114
Map 4	X	0.303
	Y	0.056

6.3 Results of the Application

All the distorted points are corrected and the errors from the true positions are calculated. The RMS errors of each map are shown in Table 2.

The Type-A correction produced a fairly good result, mostly within 0.2mm, a tolerable error, except in the x direction of map #4. This must have been caused by the ill-distribution of the control points (ON/OV) in the map #4.

7. Conclusions and Future Study

A new strategic method was developed to deal with the distortion problem on the new digital cadastral maps. The fact that original maps drawn on the plane tables in field have been preserved well with grid lines encouraged us to apply the photo coordinate refinement techniques, that is, two dimensional projective transformation and local area transformation as in the reseau grid method. A computer program package was implemented to accommodate various situations, such as, the presence or absence of the original maps and grid lines, and the different scales and sizes of the original maps and the digital maps in different regions. Simulations of distortions and correction were performed on the generated grid sheets to test the local area transformation algorithm. We found that the inverse-distance-square-weighting was suitable for the distortion corrections. Simulations on the cadastral maps showed fairly good results, mostly within the tolerance of 0.2mm.

We also found that the method could produce undesirable errors when the distortion occurred along the borderline where control points lay in a line or on one side.

A problem of the proposed strategy, beside the preciseness of correction, is efficiency or workability. The amount of the digitizing work to apply the method is twice the planned work because the PCM and the corresponding OCM have to be digitized. Workability would be improved by adopting the 'scanning and vectorization' procedure instead of 'human digitization', and this is under test now. The point matching problem for the control points in two maps is another problem (this has been studied and resolved, but not been described in this paper). The third problem is that the borderlines of the resulting digital maps do not result in a straight line due to the local area transformation, which appear to be straight but are not so numerically.

It is thought, however, that the distortions in the new digital cadastral maps have to be corrected eventually and the proposed method would contribute to the accuracy of the maps, provided further work is done on the problems mentioned above.

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