Map conflation of geo-spatial object in old cadastral maps with UAV ortho-images for efficient cadastral re-surveying project in Rep. of Korea

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Abstract

In Rep. of Korea, the cadastral re-surveying project is a national-wide government project to revise and update old graphic cadastral map into accurate digital cadastral data. Initial cadastral field surveys which conducted to meet the user requirement, at that time, has very low precision and characterized by poor quality, however such precision and quality is completely unacceptable at present time. Moreover, old cadastral paper maps have been deformed, so that a simple digitization of the map still has positional accuracy problem. Current terrestrial surveying with global positioning system or total station to address the above problem requires significant time and cost, so that a new method with fast and low-cost data acquirement is necessary. Ortho-images taken by unmanned aerial vehicle have attracted great attention because of efficient and effective spatial data acquisition. Comparing to old graphic cadastral maps and up-to-dated high quality UAV ortho-images, out-of-dated geo-spatial objects in the map can be removed and new real-world entities which do not reflected in the maps can be updated. Moreover, low positional accuracy of objects in the map can be improved or adjusted by means of finding corresponding features in the images with higher positional accuracy. The process mentioned above is referred as map conflation. Conflation is the process of matching features between datasets created at different times and based on different levels of accuracy and precision. Map conflation usually encounters locally uneven positional discrepancies between corresponding objects of the datasets. To address these discrepancies, corresponding point pairs are necessary to align one dataset with another. In general, given a point in one dataset, several candidate points in another dataset within a distance threshold are evaluated with similarity measures such as distance, and a single point with the highest similarity is chosen as the corresponding point. However, these similarities are easily affected by the aforementioned discrepancies. Thus, a transformation model, such as an affine or a rigid model, is applied to explain the locally auto-correlated positional discrepancies of each corresponding polygon object pair. This study proposed a method of recognizing corresponding points on UAV ortho-imagery and performing a block-wise map transformation in order to reduce errors in farmland cadastral map.

Keywords: UAV, Cadastral Resurveying Project, ortho-images, map conflation

1. Introduction

Rep. of Korea's cadastral system has played a pivotal role in government's land policies, such as land valuation and taxation, land-use planning, and land management, for over a century since it was launched in 1910, constantly evolving with remarkable technological advances. The basic procedure pertaining to this system is the registry of land in the record at the land parcel level, assigning a unique land parcel ID to each plot and determining its land use category, boundaries, ownership, etc. based on cadastral surveying and mapping. However, the coordinates of the land parcel boundaries in the current cadastral information system are the ones estimated from old drawings on paper maps instead of accurate coordinates of surveying points, themselves. With increasing penetration and application of high-tech surveying tools such as the global positioning system (GPS) and Total Station, there are growing problems arising from the discrepancy between the conventional drawing-based inaccurate coordinates of land parcels and the accurate coordinates computed using state-of-the art techniques. To address this issue, an accurate coordinate calculation with the angle and distance information was adopted for the cadastral surveying performed in 1975 on urban development sites. However, this method was applied only to urban development sites, and as of 2015, accurate coordinates can be obtained only for 2,330,000 land parcels out of the land total of 35,700,000 (6%), and the coordinates of the remaining 94% should be obtained from paper maps. With the entry into force of the Special Act on Cadastral Re-surveying in 2012, a large-scale field resurvey project was launched, targeting 14.8% of the land parcels across the country till 2030. This means that there is a need to find a method to solve the problem related to the remaining 80% of the total land parcels. This study proposes a method to find cadastral boundaries with incorrect coordinates on the cadastral maps of the areas not included in the cadastral resurveying project and correct those coordinates, using images obtained from an unmanned aerial vehicle (UAV), a remotely controlled aircraft with no onboard crew. Using cameras, GPS/IMU, and telecommunication equipment mounted on a UAV, it is possible to obtain images of the surveying area and calculate exact positions of features (manmade and natural ground structures) with UAV imageries. Leveraging the advantage of rapid and economical spatial information acquisition of small areas about several square kilometers and supported by continuous advances in related equipment and software, the UAV-based land surveying and mapping technologies are developed towards the level of obtaining accurate digital elevation models as well as ortho-images (ground images geometrically corrected to adjust for topographic relief). Thus, it is now possible to find corresponding points by overlapping a cadastral map and an ortho-image with high spatial resolution and high positional accuracy of only several centimeters. A cadastral map that matches the real boundaries with high accuracy can thus be created in one run by performing map transformation to match the cadastral map with the ortho-image using these corresponding points. In particular, in cases where the reference points disappear in the areas surveyed many decades ago, such as farmland, it is impossible to calculate the coordinates or, if any, the obtained coordinates are not accurate enough, even if parcel boundaries are clearly marked on drawings. In this study, coordinate pairs of corresponding points of the features on farmland will be identified by overlapping a cadastral map and a UAV ortho-image, and map transformation will be performed using the corresponding points spotted on the ortho-image in order to assess the concordance with the field survey results.

2. Project area selection and experimental data generation

Figure 1. Testbed located in Asan, Chungnam

Acquisition of high-quality ortho-images is prerequisite for comparing the cadastral boundaries with UAV imagery. The operational definition of high quality here is spatial resolution and positional accuracy within the range of several centimeters. Considering the performance of the cameras commonly mounted on a UAV, a high spatial resolution of just several centimeters can be achieved only at reasonably low flight heights. Therefore, areas with safety risks due to high-rise buildings or transmission towers should be avoided. Additionally, given the relatively light weight of an UAV, it is also necessary to select a flat inland area at a safe distance from the coastline or mountains in order to minimize the influence of the wind during the flight. As the testbed for preparing the cadastral map and UAV ortho-imagery, we selected the Hwangsan site located in Asan, Chungnam (Figure 1). As the UAV to take ortho-images from, a Q-200 Surveyor (QuestUAV Ltd, U.K.) was used, and the target resolution was set at 5 cm. The testbed extends over 1,241 m2 and consists of about 500 land parcels. The parcel boundaries extracted manually from a paper cadastral map are obtained in arbitrary coordinates. Therefore, the reference points taken at the time of field survey should first be spotted on the paper cadastral map and their coordinates should be transformed to the coordinate system used for the UAV ortho-imagery. UAV imagery also has arbitrary coordinates and all its pixels should be given their respective coordinates by geo-referencing them to the GPS-based coordinates after spotting the ground marks, which were placed at the time of image capturing, on the image. Figure 2 shows the result of overlapping the cadastral map and the UAV ortho-image after map transformation. The accuracy of the ortho-image was then assessed by comparing four check points with their corresponding GPS coordinates; as a result, it was confirmed that errors were less than 4 cm (Table 1).

Figure 2. Cadastral reference points (black triangles) and ground marks (green circles)

Table 1. UAV ortho-image's positional accuracy assessment

Check point	GPS-based coordinates (m)		Geo-referenced coordinates (m)		Coordinate error (m)		Error (m)
	X	Y	X	Y	X	Y	
1	196550.51	461868.25	196550.48	461868.25	0.017	0.003	0.017
2	196442.02	462177.51	196442.02	462177.52	0.000	-0.010	0.010
3	196318.89	461635.30	196318.88	461635.33	0.009	-0.033	0.034
4	196179.52	461948.88	196179.53	461948.89	-0.009	-0.017	0.020

3. Research methods and evaluation

1) Cadastral map and ortho-image generation	‣ Selecting reference points for UAV ortho-imagery and shooting images ‣ Overlapping the cadastral map and the ortho-image

2) Corresponding point extraction	‣ Spotting the corresponding points for manmade features ‣ Spotting the corresponding points for adjacent fields and ditches

3) Extraction of field blocks and map transformation	‣ Extracting field blocks split by access roads and ditches ‣ Extracting block-wise corresponding points on the ortho-image ‣ Computing coordinates via boundary adjustment using corresponding points

4) Accuracy assessment	‣ Performing field surveys ‣ Assessing the positional accuracy of parcel boundaries

Figure 3. Workflow of this study

3.1 Cadastral map and UAV ortho-image creation

The workflow for UAV ortho-image generation is similar to common aerial photogrammetry. Flight route and shooting height are determined via prior field inspection, and take-off/landing location is selected taking into account safety-related features in the target area such as high-rise buildings and transmission tower. For fixed-wing UAVs, in particular, it is important to secure a reasonably large space for take-off/landing as required by equipment specs. Moreover, locations for ground marks should be inspected in advance. Ground marks are used for obtaining reference points for ortho-image generation and check points for positional accuracy assessment of the ortho-imagery. At least 9 ground marks per 1 km2 should be spread evenly throughout the target area. Ground features that can be spotted on the UAV imagery, such as a road marking, as shown in Figure 4, can also be selected as ground marks.The test-bed which is the farming village is located in Jungep-myun, Junlabuk-do same as the Fig. 1. The UAV image geometry has been conducted in Aug, 19th, 2015 through the prior exploration.

Figure 4. Placing a ground mark

3.2 Selection of corresponding points for map transformation

Farmlands are prone to terrain changes over time due to agricultural practices, with the changes accumulating as time passes after the last survey. Extracting corresponding points without taking into account such changes, assuming that the terrain has not changed since the last survey, tends to yield unstable map transformation. This can be forestalled by identifying the boundaries of unchangeable features and selecting primarily the corners formed by these boundaries as the corresponding points, as shown in Figure 5. If map transformation is performed using these points, the boundaries on the cadastral map and the corresponding ground features of the ortho-imagery can be matched with high accuracy, as shown in Figure 6.

Figure 5. Selection of the corresponding points

Figure 6. Boundaries on the cadastral map and ortho-imagery

3.3 Extraction of the field blocks and computation of the target coordinates

Figure 7. Extraction of the parcels classified as lot, access road, and ditch

Looking at Figure 6, while the boundaries between fields and roads or fields and ditches on the ortho-imagery coincide well with the corresponding boundaries on the cadastral map, field boundaries do not, because crop boundaries do not always coincide with parcel boundaries. Therefore, we looked for corresponding points for matching the cadastral map and the ortho-imagery among the points on the boundaries with roads or ditches that are robust against terrain changes and expected to have the same crop and terrain boundaries. Additionally, we narrowed the target area for corresponding points from the cadastral map of the entire project site to field blocks surrounded with roads/ditches and performed map transformation of each of such blocks. To implement this process step, we extracted the parcels classified as lot, access road, and ditch on the cadastral map of the project site according to the land use category, as shown in Figure 7, and clustered the farmland parcels surrounded by them, as shown in Figure 8. Map transformation is performed after spotting the corresponding points to match the boundaries of the blocks highlighted in different colors on the UAV ortho-imagery and cadastral map.

Figure 8. Clustering of the farmland parcels surrounded by lots, access roads, or ditches

3.4 Field surveying and accuracy assessment

Field surveys were performed to assess the accuracy of the cadastral map transformed in 3.3 (Figure 9), applying Total Station based on the cadastral reference points obtained with RTK-GPS in compliance with the Standards for the Practice of Cadastral Surveying guidelines. Field surveys were performed on over 40 parcels to ensure a reasonable sample size for statistical analysis.

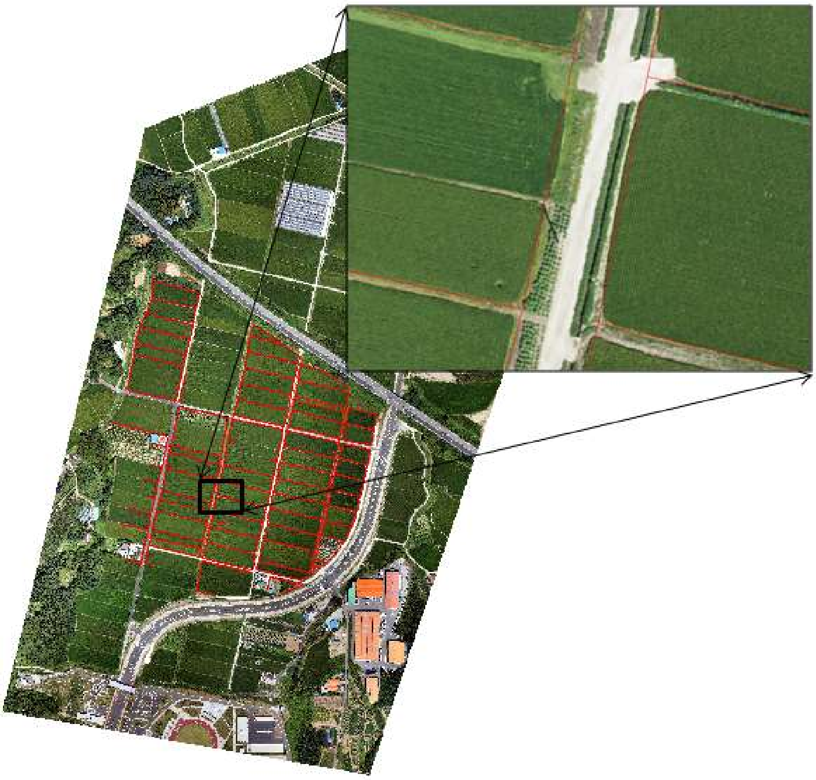

Figure 9. An example of field survey performed for accuracy assessment

Table 2 outlines the results of map transformation performed on the basis of the reference points marked on the cadastral map and spotted in the testbed (currently used method) as well as the accuracy assessment, and Table 3 presents the results yielded by the proposed method using ortho-imagery as described in Section 3.3 above. Checking Table 3 against Table 2 reveals that using the proposed method results in reducing errors as compared with the existing method.

Table 2. Results of the map transformation based on the reference points on the cadastral map and accuracy assessment

Reference point	Transformed coordinates (m)		Surveyed coordinates (m)		Coordinate error (m)		Error (m)
	X	Y	X	Y	X	Y	
1	196324.04	461671.89	196322.92	461672.05	1.12	-0.16	1.13
2	196330.64	461701.77	196330.65	461701.36	-0.01	0.41	0.41
3	196337.13	461731.26	196336.82	461731.36	0.30	-0.11	0.32
4	196343.87	461761.00	196344.02	461761.50	-0.15	-0.50	0.52
5	196350.25	461789.34	196350.61	461789.34	-0.36	0.00	0.36
6	196356.87	461818.87	196357.11	461819.08	-0.24	-0.21	0.32
7	196363.44	461848.47	196364.19	461847.82	-0.75	0.65	0.99
8	196376.50	461905.99	196377.35	461906.44	-0.85	-0.45	0.96
9	196279.78	461927.08	196279.37	461926.92	0.41	0.16	0.44
10	196271.67	461888.56	196270.89	461888.90	0.78	-0.34	0.85
11	196260.99	461839.40	196261.23	461839.86	-0.24	-0.46	0.52
12	196254.90	461810.18	196254.72	461810.47	0.18	-0.29	0.34
13	196248.63	461780.31	196249.02	461781.46	-0.39	-1.15	1.22
14	196242.52	461751.45	196242.14	461751.82	0.38	-0.37	0.53
15	196238.69	461733.32	196237.98	461734.16	0.71	-0.84	1.10
16	196236.32	461722.04	196235.02	461722.34	1.30	-0.31	1.34
17	196230.11	461693.89	196229.06	461693.64	1.05	0.25	1.08
18	196223.25	461663.66	196222.23	461664.36	1.02	-0.70	1.23
Mean					0.24	-0.25	0.76

Table 3. Results of the map transformation of the cadastral map based on the corresponding point on the UAV imagery and accuracy assessment

Corresponding points	Transformed coordinates (m)		Surveyed coordinates (m)		Coordinate error (m)		Error (m)
	X	Y	X	Y	X	Y	
1	196323.55	461671.94	196322.92	461672.05	0.63	-0.12	0.64
2	196330.27	461701.86	196330.65	461701.36	-0.38	0.50	0.62
3	196336.88	461731.38	196336.82	461731.36	0.06	0.02	0.06
4	196343.75	461761.17	196344.02	461761.50	-0.27	-0.33	0.43
5	196350.24	461789.55	196350.61	461789.34	-0.37	0.21	0.42
6	196356.99	461819.12	196357.11	461819.08	-0.12	0.04	0.13
7	196363.68	461848.76	196364.19	461847.82	-0.51	0.95	1.07
8	196376.98	461906.37	196377.35	461906.44	-0.37	-0.08	0.38
9	196280.12	461927.85	196279.37	461926.92	0.75	0.93	1.20
10	196271.86	461889.28	196270.89	461888.90	0.97	0.38	1.04
11	196260.97	461840.05	196261.23	461839.86	-0.26	0.18	0.32
12	196254.76	461810.79	196254.72	461810.47	0.04	0.32	0.32

13	196248.36	461780.87	196249.02	461781.46	-0.65	-0.59	0.88
14	196242.14	461751.97	196242.14	461751.82	0.00	0.15	0.15
15	196238.23	461733.81	196237.98	461734.16	0.25	-0.35	0.43
16	196235.82	461722.51	196235.02	461722.34	0.80	0.17	0.82
17	196229.49	461694.32	196229.06	461693.64	0.43	0.68	0.81
18	196222.50	461664.05	196222.23	461664.36	0.27	-0.30	0.41
Mean					0.07	0.15	0.56

However, the proposed method still show positional errors of over 30 cm in comparison with the surveyed coordinates. Such errors are ascribable to the fact that ortho-imagery alone does not deliver boundary lines and corners as accurate as does ground-level surveying, as shown in Figure 10. In general, the bottom line of a paddy levee is where the cropland parcel ends. Therefore, the spot indicated by the arrow in Figure 10 should be defined as the parcel boundary. In this case, however, the bottom line is located in the section hidden by the trees along the roadside, resulting in a difference of several centimeters between the UAV imagery-based and surveyed boundaries. If map transformation is performed using the corresponding points located in such boundaries, the resulting coordinates can significantly affect the overall performance of map transformation even though the corresponding errors are cancelled out by the remaining corresponding points.

Figure 10. Boundary line error

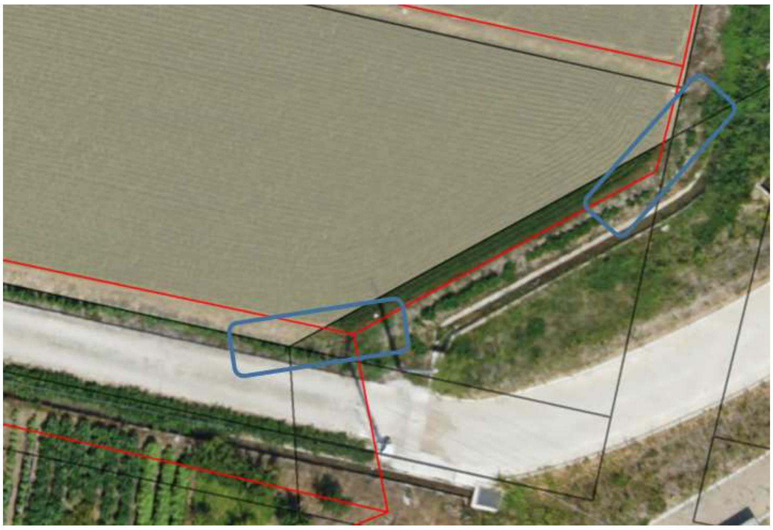

Figure 11. Boundary corner error

Furthermore, the surveyed parcel shape does not always coincide with the shape on the cadastral map, as shown in Figure 11. On the cadastral map transformed to the World Geodetic System, the center and upper-right boundary corners should be adjusted to the 2- and 7-o'clock positions, respectively. If such corresponding points are included in map transformation, the corresponding coordinates affect the overall results of map transformation. This problem arises from the discrepancy between the real shape and the one expressed in a cadastral map and can only be addressed by a field inspection of topographic elevation. As such, it cannot be solved by map transformation based on UAV ortho-imagery.

4. Conclusion

This study proposed a method of recognizing corresponding points on UAV ortho-imagery and performing a block-wise map transformation in order to reduce errors in farmland cadastral map. Map transformation using only cadastral reference points resulted in errors in excess of 70 cm when checked against the results obtained from field surveying. The target coordinate computation errors could be reduced to approximately 50 cm by applying the proposed method, in which farmland blocks surrounded by access roads and ditches were extracted, corresponding points were spotted on the UAV ortho-imagery for each block, and map transformation was performed based on those corresponding points. The still high errors can be ascribed to the inaccuracy in spotting the corresponding points on the ortho-image because of its inability to acquire elevation-related information necessary for accurate recognition of boundary lines and corners. Shadows drawn by crops and other types of vegetation also act as obstacle to recognizing correctly the boundary lines on the ortho-image. Although fixed boundaries such as walls and other structures may be used, this possibility is very limited because only a small part of the parcels have such structures.

Such limitations can be addressed only by on-site inspection of topographic features that cannot be recognized accurately on UAV images. Areas requiring field inspection are densely spread across the project area, as confirmed in the pilot project. Therefore, at the current level of UAV technology, an approach relying on UAV ortho-imagery is not efficient enough for project implementation in comparison with field surveying using survey tools such as GPS and Total Station. However, if the ongoing advances in the UAV technologies reach the level enabling the generation of 3-D spatial information required for improving the efficiency of aerial photogrammetry, a great part of the aforementioned limitations are expected to be overcome. In South Korea, recent research efforts have led to generating high-accuracy UAV ortho-imagery of 2-cm-level resolution, and global industry leaders are launching UAV products such as Trimble UAS Master capable of generating 3-D spatial information. If such technologies can be tailored to cadastral surveying, UAV imagery-based error correction is expected to be used for improving the accuracy of farmland cadastral maps.

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