Improving Data Quality of Cadastre Parcels Using Parcel Fabric Module:Rubber Sheeting and Least Squares Adjustment Methods Case Study: UQ Campus (12588)

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Key words: Map accuracy; Affine Transformation, Rubber Sheeting; Least Squares Adjustment; Parcel Fabric

SUMMARY

This experimental study aims to improve the accuracy of cadastre maps using multiple approaches to maintain an effective cadastral system. Accurate mapping, providing more accurate location information, is a vital need in modern society to maintain essential services on the land. A small area at the University of Queensland (UQ) in Australia was chosen to carry out the project. By using Affine Transformation, Least Squares Adjustment (LSA) and Rubber Sheeting methods, which are traditional geodetic methods, in ArcGIS Parcel Fabric module, the accuracy of the cadastre map was tried to be improved to match the orthophoto map. The research aims to answer "Can better maps be produced with lower cost and effort?" In line with the results, map accuracy will be evaluated regionally for parcel elements in the parcel network. The UQ study may provide insight for subsequent research aimed at improving mapping accuracy over a wider area.

ÖZET

Bu deneysel çalışma, etkin bir kadastro sistemini sürdürmek için çoklu yaklaşımlar kullanarak kadastro haritalarının doğruluğunu artırmayı amaçlamaktadır. Daha doğru konum bilgisi sağlayan doğru haritalama, modern toplumda arazideki temel hizmetleri sürdürmek için hayati bir ihtiyaçtır.İyi haritalanmış bir kadastro verisi sağlamak,kadastro temel bir bilgi katmanı olduğu için dünya üzerindeki tüm faaliyetleri yansıtmak ve yönetmek açısından önemlidir. Projeyi yürütmek için Avustralya'da Queesland Üniversitesi'nin(UQ) küçük bir alanı seçildi. Geleneksel jeodezik yöntemlerden Affine Dönüşümü,En Küçük Kareler Dengelemesi (LSA) ve Rubber Sheeting metodları ArcGIS Parcel Fabric modülünde kullanılarak,kadastro haritasının doğruluğu Ortofoto harita ile eşleşecek şekilde iyileştirilmeye çalışılmıştır. Bu deneysel araştırma, "Daha düşük maliyet ve çabayla daha iyi haritalar üretilebilir mi?" sorusuna cevap vermeyi amaçlamaktadır. Sonuçlar doğrultusunda, harita doğruluğu parsel ağındaki parsel elementleri için bölgesel olarak değerlendirilecektir. UQ çalışması, daha geniş bir alanda harita doğruluğunu iyileştirmeyi amaçlayan sonraki araştırmalar için bir fikir sağlayabilir.

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1. INTRODUCTION

Successful economies require sustainable land management and cadastral systems. Cadastre is defined as an official record that determines the boundaries, dimensions, areas and ownership of properties (Sisman, 2014). Understanding the location of field objects on the land is fundamental to maintaining field services. In this context, maps are defined as tools that visually express the relationship between objects on earth (Axis Maps, n.d.).

Cadastre maps graphically reflect cadastral parcels and their relevant details (Queensland Government, n.d.). and is used as a basis for the development of map-based digital systems in Queensland/Australia. They are frequently used by institutions, professionals and the public for various purposes in the worldwide. It is therefore important to examine the existing problems related to these maps and seek solutions to improve their accuracy (ICSM, n.d.).

1.1 Problem

A small area in St Lucia Campus of The University of Queensland was chosen to conduct this study. Orthophoto and cadastral maps of the study area with different resolutions are compared in figure 1. In the 1/2000 scale cadastral base (a) with 1 m resolution, there is no obvious alignment problem between cadastral parcels and border fences. The positional accuracy of the cadastral map is ±2.5 m. However, when compared to the 0.1 m resolution orthophoto (b), it is clearly seen that the parcel boundaries and border fences do not match. The positional accuracy of the orthophoto was recorded as ±0.3m.

In Queensland, a digital cadastral system called DCDB (Digital Cadastral Database) has been used for approximately 30 years to control land activities more effectively (Effenberg & Williamson, 1997). DCDB’s spatial accuracy varies from place to place as it is derived from different source maps and survey plans (Queensland Government, n.d.).The incompatibility between cadastral maps and Orthophoto causes authorities and the public to be misled in important land-related plans and projects.

a. Cadastre map (0.5 m res.) b. Ortophoto map(2015)(0.1 m res.)

Figure 1. Comparison of UQ Ortophoto map and cadastre map
Resource: Pullar D.&,Donaldson S.,2022

In this context, the need to match cadastral bases with Orthophoto maps, which have higher accuracy, has arisen. However, it is not possible to reflect and update all ground points in residential areas on cadastre maps based on orthophoto. For example; In the orthophoto, there is no clear border strip for the section below the road (Pullar et al., 2022). An alternative solution to accurately reflect parcel boundaries is to better integrate cadastre maps with measurement plans in a developed software in terms of topological integrity.

1.2 Literature

Spatial and physical changes occurring in the cadastre require different solutions to update parcel boundaries. Merritt (2005) explained the importance of adjusting digital cadastre in a study. Spatial cadastral adjustment of cadastral parcels in the digital cadastre system means aligning parcel boundaries using adjusting methods such as Least Squares (LSA) and Rubber Sheeting (Macduff & Valerie , 2018). There are numerous studies on the subject in Australia. The one of the most inriguing study was chosen to discuss.

The study carried out in Australia is a study that aims to improve map accuracy throughout the state, mentioned in the problem section, which will also be discussed in the UQ example. A 4-stage Cadastral Modernization Project that will last 3 years has been implemented by the government in the state of Victoria/Australia (Department of

Environment, Land, Water and Planning , n.d.). In order to increase the positional accuracy of digital cadastral bases, Least Squares Adjustment was applied to the parcel corners using DynAdjust software, using all highly accurate survey plans of area (Department of Environment, Land, Water and Planning, n.d.). All measurement data and geometric connections for the region It was created in the cadastral system. The approach is to increase the accuracy of parcel nodes. A cross-section of adjusted parcel nodes and connection vectors is given in the figure 2. With this method, the use of repetitive measurement plans in the state digital cadastre system was prevented and the positional accuracy of the parcels was improved.

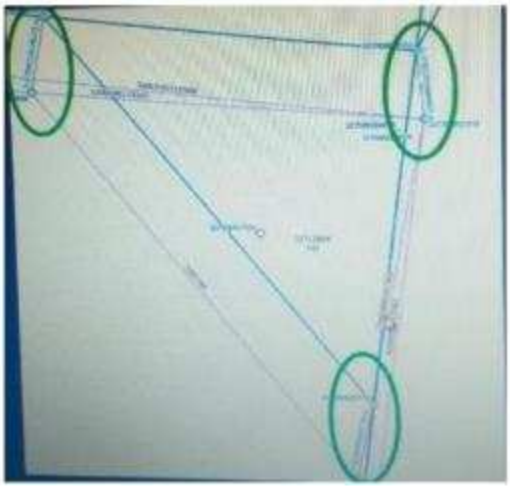


Figure 2. Adjusted nodes and change vectors
Source: Locate Conference, 2021

The study differs from the UQ study in that it uses the DynAdjust module as an alternative to Parcel Fabric, uses all measurement plans of the parcel network and covers a wider area.

1.3 Aim of Study

The study mainly consists of two objectives:

- In order to develop coordinate-based cadastre, increasing the effectiveness of cadastral measurements and cadastral maps by using reliable GNSS data. In this context, it is aimed to increase the accuracy of parcel boundaries mainly by the Least Squares Adjustment (LSA) method, in line with existing landmarks and measurement plans.
- Inferring from the study results by using the Parcel Fabric module, which is not very common in the literature, the question "Can cadastral maps be developed with land measurement data with less effort and cost?" is aimed to answer.

2. DATA AND METHODS

2.1 Data

Dataset includes materials below:
Digital cadastral data: Contains the cadastral base containing cadastral parcels, roads and parcel features, downloaded from the Queensland Cadastral Database website of the state of Queensland.
Cadastre measurement plans (survey plans): Plans from different historical measurement plans of UQ Campus for the years 2001, 2007 and 2021, purchased from the Queensland Government website, were used.
Ground control marks: In the study, 6 permanent ground marks (Permanent Survey Marks (PSM)) were used near the corners of the parcel.
Ground control signs report: The report of the 3 permanent landmarks used in the study was obtained from the Queensland government database. The table showing the status of these signs is given below.

Table 1. Status of control marks

Mark number	Last visited date	Horizontal uncertainty(m)
145956	2007	2.0
204243	2019	0.025
10425	2019	0.025

Resource: Queensland Government, n.d.

2.2 Method

Changing the characteristics of existing parcels or adding new parcels creates the necessity of increasing the accuracy of the parcels with spatial adjustment methods. In this study, different methods were used to increase the geometric consistency of the parcels in the digital system.Parcel Fabric module which has high topological integrity and sensitive error detection was preffered. The project was carried out using the Parcel Fabric module in ArcGIS Pro version 2.8. Parcel Fabric basically presents cadastre parcels and their qualitative and quantitative information, connections called COGO (coordinate geometry) from parcel corners to control points, and other connections in the parcel network (Esri, n.d.).

Affine Transformation, Rubber Sheeting and Least Squares Adjustment (LSA) were used to adjust the parcels, respectively. The basic steps to be followed in the study are listed below:

- A parcel record called "UQ sample parcels" was created in the Parcel Fabric environment.

- Then, the relevant parcels in the study area were converted into parcel lines, including distance and angle details.
- Connections were created from the corners of the parcel to the control points whose lengths and elevations were given in the measurement plan.
- After the parcel topology and connections were created, the map geometry was verified by establishing a connection to the correct coordinates of the control points with the **Affine Transformation**. While the points, lines and the ratios between the two are preserved with this method, the angles and lengths between the points change (Mann et al., 2021).
- Finally, **Rubber Sheeting** and **Least Squares (LSA)** adjustment methods were applied to maintain the spatially-aligned cadastre (L4) level, which is the 4th level of the cadastre.

  The scheme of the project is given below:

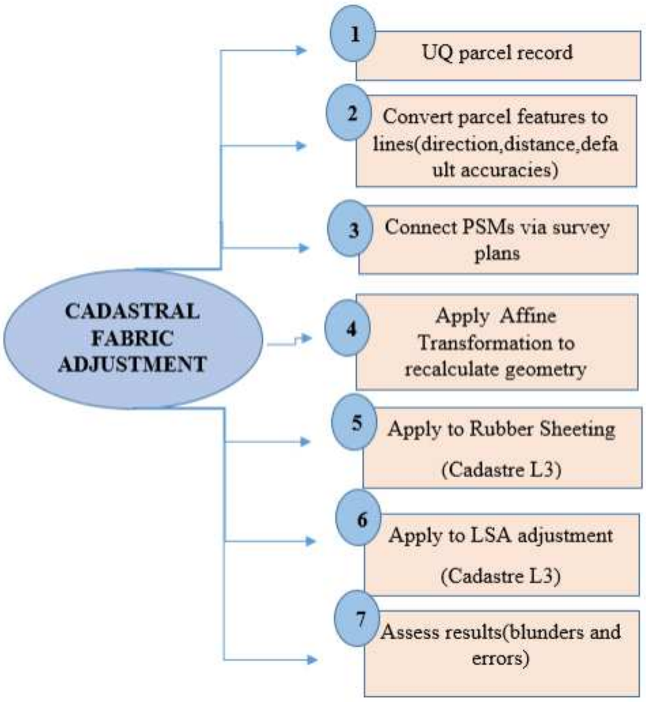


Figure 3. Project workflow

The logic of the Rubber Sheeting approach is to interpolate the coordinate change in the parcel network. The parcel geometry created in the cadastral base and Parcel Fabric environment is aligned according to the control points. For this process, new control points used in the Affine Transformation have been added. With this method, 12 connections were provided from 5 parcel corners to control points and it was observed how the parcel geometry was affected.

Finally, the Least Squares Adjustment (LSA) method was applied to adjust the parcels. This method is a traditional approach used mathematically to increase accuracy and reliability in the parcel network (Esri, n.d.). LSA minimizes the difference between observed and measured values. Low accuracy points have a lower impact on the parcel network (Esri, n.d.). In this study, the locations of parcel points were determined using the weighted LSA approach in the Parcel Fabric module, using control points and lengths of parcel lines. Occlusion errors are compensated with this method and the errors of the plarcel lines are recalculated from the adjusted point coordinates (Esri, n.d.). With this method, connection was made to 6 unevenly distributed control points from 5 parcel corners in the study area. The distribution of control points is important in LSA. Control points with high reliablity are important in updating cadastre parcels (Pullar et al., 2022).

3. RESULT AND DISCUSSION

3.1 Result

Within the scope of the study, firstly Parcel fabric was created. Then, connections called COGO were created from the parcel corners to the control points in line with the survey plans. Adjustment results were briefly given for the adjustment methods below.

Affine Transformation

First of all, Affine Transformation (1st Degree polynomial) and Rubber Sheeting methods were used to determine the correct positions of the measurement points as illustreted in figure 4.

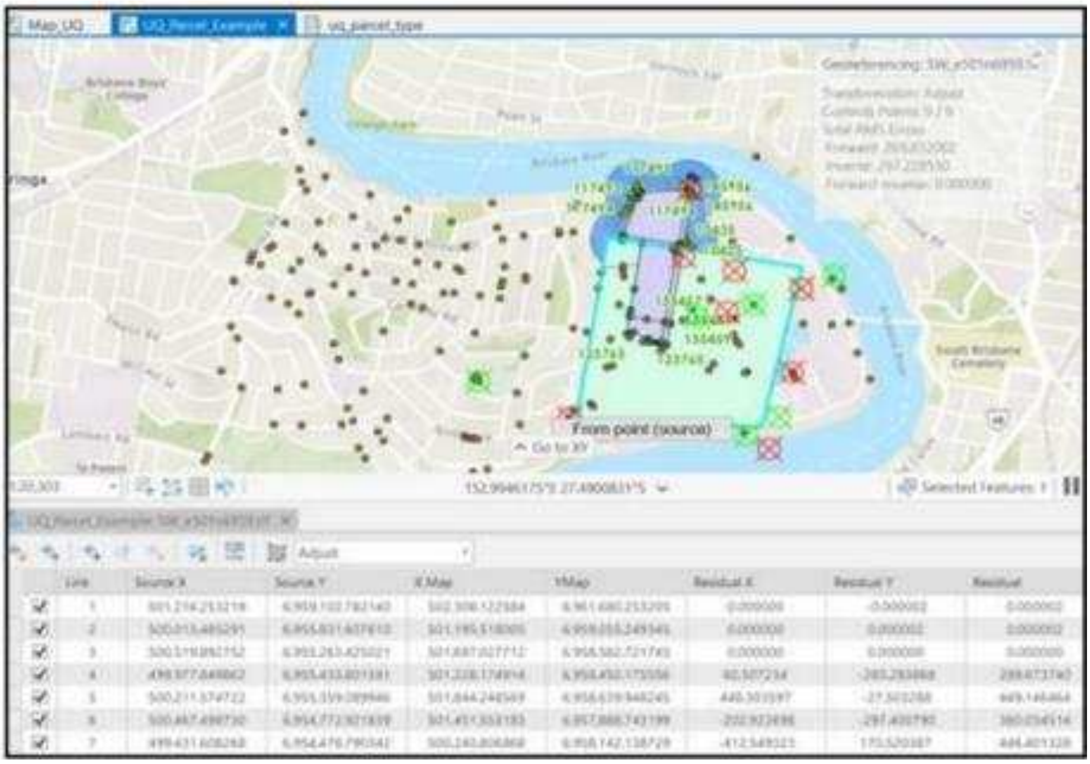


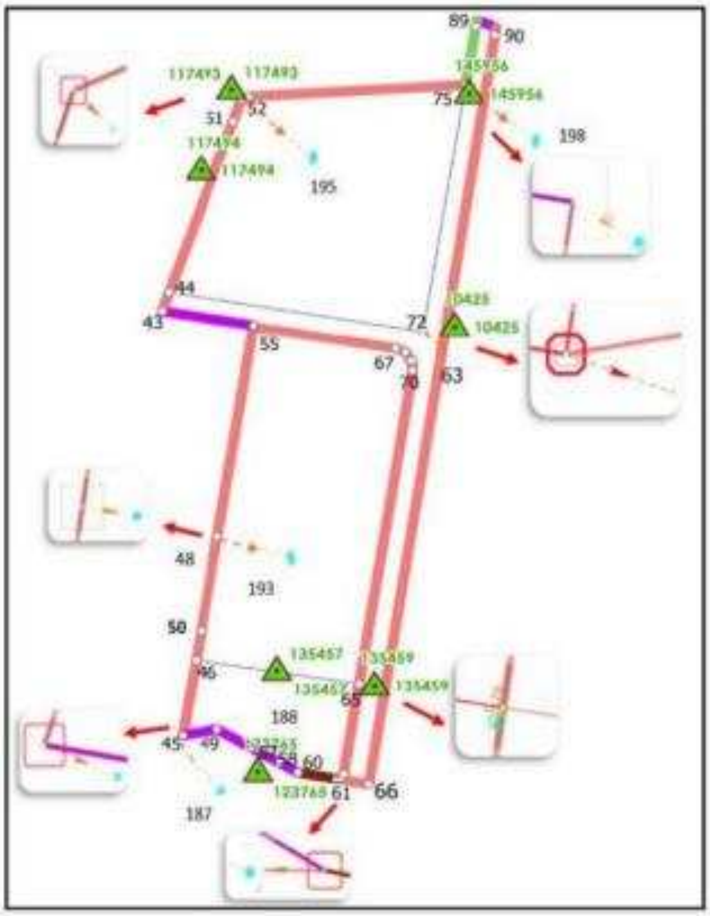
Figure 4. Positional verification of points

Rubber Sheeting

After the Affine Transformation was achieved, more control points were added and the Rubber Sheeting method (2nd Degree polynomial) was applied. Thus, a more precise layer was created for the target layer.

LSA(Least Square Adjustment)

Finally, the LSA method was used to determine more probable coordinates of the connection points (Fan, 2010). Once the COGO geometry is created, LSA provides an efficient result. Parcel geometry that belongs to study area and main control points where the connection was provided is given in figure 6. 5 connections were created using lengths and facades from parcel corners to 6 control points. The error amount of the created adjustment vectors varies from 0.0021 m to 5.1 m. The figure 5 shows connections from parcel corners to control points and error ellipses. Unreliable values were interpreted in line with these statistics. The adjusted lengths of the parcel lines were compared with the values in the measurement plan. The parts with error values exceeding +-1.96 are mostly parcel connections shown with purple in Figure 5.



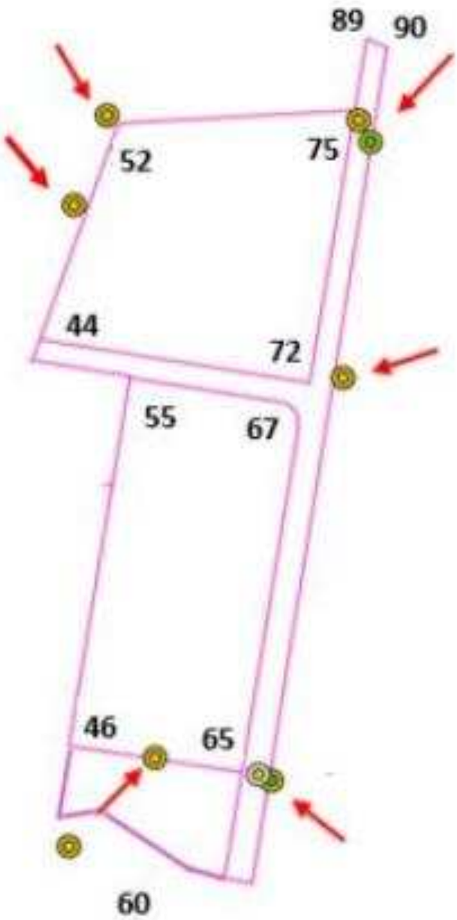


Figure 5. Adjusted parcel points and error ellipses Figure 6. Parcel geometry and control points

Two important parameters, positional uncertainty and error ellipses, were used to determine the reliability of parcel coordinates in table 2. Error ellipses show the accuracy of x and y coordinates (Esri, n.d.). While the highest error ellipse value was 0.525 m, the smallest was recorded as 0.438 m. Finally, positional uncertainty (XY) ranges from 1.15 m to 0.93 m.

Table 2. Adjustment statistics of parcel points

Parcel point number	Point number	Adjusted x	Adjusted y	XY uncertainty (positional uncertainty) (m)	Error ellipse semi major	Error ellipse semi minor	Error ellipse direction	StdDevE	StdDevN
45	187	500889,765	6958812,720	1,117	0,525	0,354	3,986667	0,355	0,524
46	188	500896,837	6958832,407	1,036	0,483	0,336	6,999167	0,339	0,482
48	191	500928,333	6958478,745	0,932	0,467	0,169	10,491944	0,186	0,461
49	192	500941,994	6958375,230	1,025	0,438	0,400	23,079722	0,406	0,432
50	193	500943,721	6958576,949	1,152	0,474	0,467	124,224722	0,472	0,469
51	194	500959,895	6959010,823	0,977	0,485	0,208	35,321389	0,328	0,414
52	195	500968,097	6959033,627	0,968	0,494	0,011	46,238611	0,357	0,342
75	198	500979,219	6958798,078	1,069	0,483	0,380	10,596667	0,384	0,479

3.2 Discussion

Cadastre maps are the basic basis for the correct execution of all activities on the land. With the development of location-based information technologies day by day, more users have access to these maps (Williamson, 1996). For this reason, updating cadastre maps is important to meet the demands of users at all levels (Kumar et al., 2013).

In this context, in the case of UQ Campus, different adjustment methods have been used to increase the spatial accuracy of the digital cadastral map. According to the adjustment results, the positional accuracy standards specified by Grant et al. (2018) (10-20 cm (urban), 0.50 cm (rural)) were not be reached. However, the accuracy of the current cadastre map which was recorded as 2.5 m was improved up to 1.15 m at the point where the uncertainty was highest, and an average positional accuracy of 1 m was achieved in Parcel Fabric. Since the positional uncertainty did not exceed +-1.96 m on average, no additional research was needed.

Going deeper, parcel lines were examined regionally according to their error amounts with Least Squares Adjustment (LSA). In particular, although the bottom parcel lines 60-61 and 75-89 did not have the highest error rates in the parcel network, measurement correction was high in these sections. This shows that it is affected by the parcel lines with high errors around it. The other outlier is observed between the lines 43 -55. The increase in the amount of error on this line affects the parcel network. Because the control points were not evenly distributed in this region, no connection could be made to any control point from the corner of parcel number 43. In the small study area, lack of connection to sufficient geodetic control point affected the results. If additional connections are provided from parcel corners to control points, positional uncertainty can be improved with the LSA method in Parcel Fabric (Esri, n.d.).

From this, it is understood that in order to adjust the entire cadastral fabric, there is no need to create all the measurement plans of the study area in the survey-compliant (L4) phase of the cadastre. There is no need to create the entire parcel geometry given in the measurement plans in the parcel network. With the LSA method, in line with reliable GNSS measurements, map accuracy can be significantly improved by connecting from only the parcel corners to high quality ground control points without spending much effort and time without connecting to all points in the network in Parcel Fabric. The accuracy of the parcel network provides higher accuracy if there is a connection from the parcel corners to evenly distributed control points (Pullar et al., 2022).

In cases where the control points cannot be connected equally from all corners of the parcel, it is possible to individually evaluate the error rates of the parcel lines and provide extra control point connection from the parcel points where the error is observed in Parcel Fabric, or alternatively, to increase the accuracy by using high-accuracy measurement values obtained from the original measurement plan in the parts where the anomaly occurs (Pullar et al.,2022).

In the Victoria Cadastral Modernization Project, all measurement plans of the study area were used for 3 million parcels. However, using all measurement plans and control points does not significantly affect the positional accuracy in the parcel network in LSA method. Installing additional reliable connections at points where the error rate is high saves time, effort and finances.

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BIOGRAPHICAL NOTES

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