Advancing Cadastral Mapping with UAVs and Automated Boundary Delineation

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Thesis summary

Keywords: cadastre, land, boundary, detection, UAV, deep learning

Received: July 26, 2024

Visible land boundaries allow for automatic detection using remote sensing data with optical sensors. The dissertation aimed to improve cadastral mapping using unmanned aerial vehicle (UAV) photogrammetry. The aim was to evaluate the accuracy of cadastral data concerning land boundaries and to develop an automated approach for delineating these boundaries. The data captured by UAVs was analyzed to identify discrepancies between physical (visible) and formal (cadastral) land boundaries. The process includes boundary detection, geo-referencing, evaluation of up-to-dateness, and vectorization of the predicted boundary maps. Initially, image processing methods were tested for automatic detection. Subsequently, deep learning methods were used to improve the detection process using UAV data. Manual delineations were also carried out to validate and assess the accuracy of the automated detections. Different approaches and methods were tested in case studies, especially in rural areas where visible land boundaries are more common. Although primarily tested with drones, it can also be adapted to satellite or aerial imagery and provides a cost-effective way to detect and revise cadastral maps. Automatic detection identifies areas needing cadastral updating and is supported by manual verification to ensure accuracy.

Povzetek: Doktorska disertacija preučuje izboljšanje katastrskih načrtov z uporabo UAV fotogrametrije. To je razširjeni povzetek disertacije, katere cilj je bil raziskati neskladja med katastrskimi in dejanskimi mejami ter razviti pristop za posodobitev obstoječih katastrskih načrtov na podlagi podatkov iz UAV fotogrametrije.

1 Introduction

Efforts to establish cadastral systems have primarily targeted countries with low cadastral coverage. However, maintaining and updating land data in countries with complete cadastral systems has received comparatively less attention. In countries with complete cadastres, scanning and vectorizing analog maps created the digital ownership layer. In such cases, discrepancies between physical and formal land boundaries may exist due to the dynamic nature of cadastres and changes in land boundaries over time [1,2].

Detection of physical or visible boundaries using remote sensing, particularly UAV imagery due to its accuracy and flexibility, opens new possibilities. While many case studies report manual delineation of land boundaries, it is argued that a significant number of cadastral boundaries are visible and coincide with natural or man-made physical features. Automatic detection approaches, such as image processing and deep learning, can be applied to detect these land boundaries from images [3,4].

The main objective of this doctoral dissertation [1] was to design a UAV-based cadastral mapping approach to evaluate the currency of land boundary data and update cadastral maps.

2 Methods and results

2.1 Inconsistencies in land boundaries

The study [2] presents an approach to identify inconsistencies in the cadastral boundary data and evaluate the digitization process.

The focus was on the importance of survey-based cadastres and the digitization process. This is illustrated with examples from Slovenia and North Macedonia, both of which have complete cadastral coverage. Challenges in digitization and boundary definition were identified, with significant differences in horizontal accuracy (about 0.5 meters) and area deviations (about 25 square meters).

A systematic workflow was designed for the digitization of analog cadastral data and the resolution of discrepancies in land data, classified into the following categories: i) inconsistencies between cadastral and land registry data, ii) within cadastral data, and iii) between cadastral data and the situation on the ground. Furthermore, we present a model for cadastral data maintenance to identify inconsistencies between physical and cadastral boundaries using UAV data.

2.2 Delineation approaches of visible land boundaries

Land boundaries can be delineated manually or automatically from UAV data, with automation ranging from semi-automatic to fully automatic. This research developed a general workflow to investigate UAVs in cadastral mapping. Manually vectorized land boundaries served as a benchmark to evaluate the quality and reliability of automatic delineation. We quantitatively assessed the discrepancies by overlaying the automatic and existing cadastral boundaries [3-5].

We tested several classic edge-detection and segmentation algorithms, with Envi FX outperforming the others by providing vector-format parcel boundaries without additional image processing. However, further simplification was necessary for cadastral applications, and fully automating the process remains challenging [3]. Semi-automatic approaches are required, particularly in complex urban areas.

The study also compared UAV-based mapping to traditional ground-based methods. When boundaries were delineated manually, UAV orthophotos demonstrated high planar accuracy, with an RMSE of 1 cm, compared to total station measurements [1].

2.3 Deep learning for land boundary delineation

Upscaling deep learning solutions, such as convolutional neural networks (CNNs), for visible land boundary detection is becoming increasingly important, especially for UAV data [4].

CNNs generally offer higher accuracy in delineating land boundaries than traditional image processing methods. However, collecting and processing thousands of UAV images for boundary delineation is challenging, even with data augmentation [4]. To address this, we used publicly available datasets like the Berkeley Segmentation Dataset and Benchmark (BSDS500), a standard for image segmentation and edge detection tasks. We applied this dataset to detect land boundaries in UAV imagery [5].

Model performance during training was monitored using the F1 score. High overall accuracy was not suitable due to the imbalance in class pixels—boundary pixels are much fewer than background pixels. The U-Net architecture was the most promising for our domain's complexity. Additionally, we customized U-Net to reduce the number of trainable parameters, which proved sufficient for our needs. The model was trained in Google Collaboratory, and implemented in Keras. The process was written in Python using the TensorFlow library.

The trained model was tested using UAV images sized 256 × 256 pixels. Determining a perfect F1 score for cadastral mapping was challenging since not all cadastral boundaries are visible, and testing scenes differ, making reliable comparisons difficult. An F1 score of 60 is considered sufficient for rapid analysis, especially in rural areas.

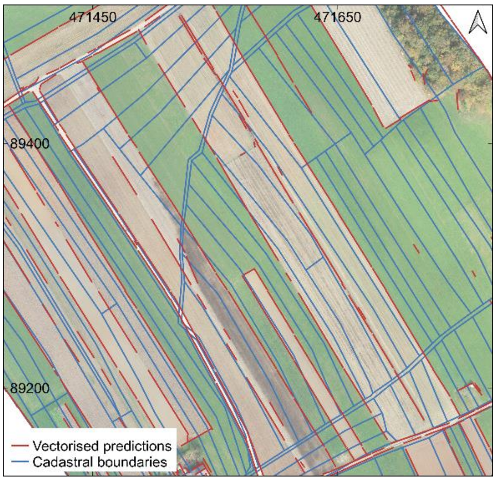

Figure 1. Example of map revision: Automated boundary delineation (red) vs. cadastral boundaries (blue).

The predicted boundary maps were then georeferenced, merged, and vectorized to comply with cadastral boundary formats. With this approach, we were also able to revise existing cadastral maps (Figure 1).

3 Conclusions

The research addressed the challenge of maintaining existing cadastral maps by proposing an automated approach. The workflow consisted of training a CNN to detect land boundaries from UAV imagery, georeferencing the predictions and vectorizing them to revise cadastral maps. This method, which has been tested with UAV imagery, could also be applied to satellite or aerial imagery to efficiently identify areas that need to be updated. It is important to note that automatically delineated boundaries are not final boundaries, but can be considered provisional, which increases the efficiency of cadastral mapping. Nevertheless, manual delineations hardly differ from ground-based methods in terms of positional accuracy and can still be used for verification and refinement.

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