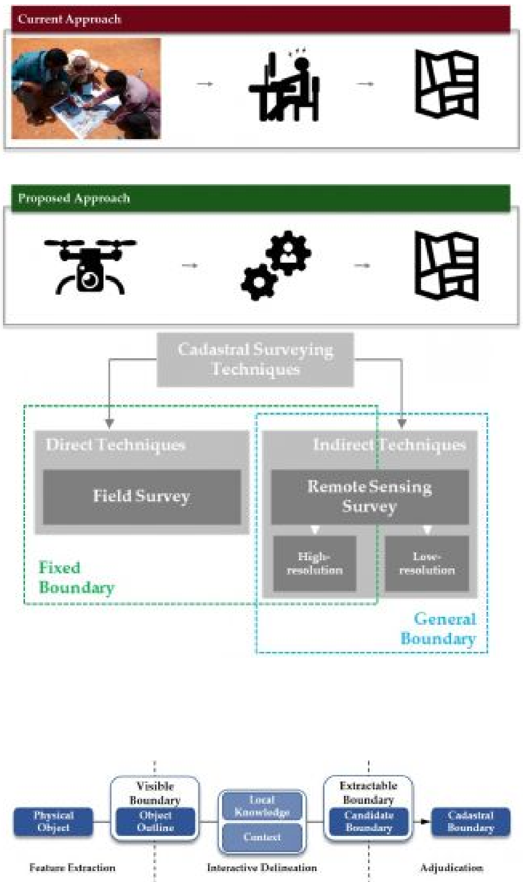
EXTRACTING VISIBLE BOUNDARIES FROM UAV DATA THROUGH IMAGE ANALYSIS AND MACHINE LEARNING

Towards cadastral intelligence?



How can the mapping of land tenure be automated to support the shift towards cadastral intelligence: the integration of human-based expert knowledge with automatically generated machine-based knowledge?

The inability to access formal land registration systems fosters insecure land tenure and conflicts, especially in developing countries. This calls for low-cost and scalable mapping solutions aligning with fit-for-purpose land administration. The work presented in this article supports the UAV-based mapping of land tenure inspired by state-of-the-art approaches from remote sensing, geoinformatics and computer vision. The guiding question is how to develop an automated approach that promotes the paradigm shift towards cadastral intelligence which integrates human-based expert knowledge with automatically generated machine-based knowledge.

Cadastral mapping contributes to the creation of formal systems for registering and safeguarding land rights. According to the World Bank and the International Federation of Surveyors (FIG), [75% of the world's population] do not have access to such systems. Furthermore, they state that 90 countries lack land registration systems, while 50 countries are in the process of establishing such systems. In these countries, cadastral mapping is often paper-based (Figure 2) or delineated from partly outdated maps or low-resolution satellite images which might include areas covered by clouds. The definition of boundary lines is often conducted in a collaborative process among members of the communities, governments and aid organizations. This process may be referred to as 'community mapping', 'participatory mapping' or 'participatory GIS'. Numerous studies have investigated cadastral mapping based on orthoimages derived from satellite imagery or aerial photography, and recently also from imagery from unmanned aerial vehicles (UAVs or 'drones').

The average geometrical precision is shown to be the same, or better, compared to conventional terrestrial surveying methods. As a consequence, UAVs are increasingly proposed as a tool for fast and cheap spatial data capture enabling the production or updating of cadastral maps.

Figure 1: Improving current indirect surveying by coupling high-resolution UAV imagery with automated feature extraction for cadastral mapping.

Visible boundaries

Cadastral surveying techniques can be divided into (i) direct techniques, in which the accurate spatial position of a boundary is measured on the ground using a theodolite, total station or global navigation satellite system (GNSS), and (ii) indirect techniques, in which remotely sensed data such as aerial, satellite or UAV imagery is used (Figure 3). Indirect techniques rely on the existence of visible boundaries demarcated by physical features such as buildings, hedges, fences, walls, roads, footpaths, crop types or water bodies. These features can be extracted by means of image analysis, as demonstrated by studies in remote sensing. Visible boundaries are assumed to make up a large portion of all cadastral boundaries.

Automated cadastral mapping

To investigate the potential of using UAV data coupled with image-based automatic feature extraction for land tenure mapping, a tool was designed that facilitates the delineation of visible cadastral boundaries from UAV data to support indirect cadastral surveying. In contemporary indirect surveying approaches, the operator creates nodes by clicking along a boundary. In the proposed approach, the operator has multiple options to create a boundary making use of the automatically extracted features along visible boundaries. One option consists of selecting nodes from a set of proposed nodes that are then automatically connected along visible object outlines derived from the UAV data. A machine learning approach is applied to learn which object outlines demarcate cadastral boundaries at the specific local scale.

Figure 2: (a) Paper-based cadastral data storage in Kajiado (Kenya), and (b) a paper-based map used in local land administration.

Automated delineation workflow

(a) Image segmentation delivers closed contours capturing the outlines of visible objects in the image. Multiresolution combinatorial grouping (MCG) has shown to be applicable to high-resolution UAV data and to deliver accurate closed contours of visible objects.

(b) Boundary classification aims to learn which lines from (a) are useful for cadastral boundary delineation. This is achieved by training a machine learning algorithm that takes into account the lines and their context. After being trained on a set of lines, it can then predict a boundary likelihood for lines from (a) that represents each line’s usefulness for cadastral mapping.

(c) Interactive delineation allows a user to start the actual delineation process: the RGB orthomosaic is displayed to the user, who is asked to create final boundaries making use of the automatically extracted boundary features and their boundary likelihoods. (c) is implemented as a publicly available QGIS plug-in (BoundaryDelineation).

Challenges

The proposed delineation workflow, which is entirely open source, has been evaluated on different UAV data, e.g. from Rwanda, Kenya, Germany and France. Given the complexity of cadastral boundaries, automating boundary delineation remains challenging; the variability of objects and extraction methods reflects the problem’s complexity, consisting of extracting different objects with varying characteristics. These circumstances impede the compilation of a generic model for a cadastral boundary and thus the development of a generic method. No standardized specifications exist for boundary features, and boundaries are often not marked continuously and/or maintained poorly.

Figure 3: Direct and indirect techniques for cadastral surveying.

Ongoing work

The authors are currently revising the workflow steps (b) boundary classification and (c) interactive delineation. For (b), they are investigating a deep learning based approach, and for (c), they are improving the usability and effectiveness of the plug-in by adding further delineation functionalities, speeding-up the processing and allowing the creation of polygons.

Extractable boundaries

To further develop automated cadastral mapping in indirect surveying, the authors suggest considering the extractable boundary rather than the visible boundary alone. Instead of focusing on the visible boundary comprising of outlines of physical objects, automated cadastral mapping should focus on the extractable boundary that incorporates local knowledge and context. Local knowledge helps in identifying boundaries, e.g. between two beacons. Context helps when closing an open gateway in a fence as a boundary, for example. This information is not inherent in the concept of the visible boundary, but it is extractable from remote sensing imagery.

Figure 4: Boundaries derived with the described approach overlaid on cadastral reference data from Ethiopia. For these automatically generated boundaries, a boundary likelihood is predicted to be used during the interactive delineation when generating final cadastral boundaries.

Conclusion

The delineation cannot be fully automated at the current state since the extracted outlines require (legal) adjudication and incorporation of local knowledge from human operators to create final cadastral boundaries. Image-based approaches hold potential to automatically extract use rights, which do not necessarily represent legal rights. These circumstances limit the scope of automated approaches. The authors observed that automating cadastral mapping dealing with sensitive land rights can only be successful when the interactive part that bridges the gap between automatically generated results and the final cadastral boundary is designed and implemented in correspondence to user needs.

Acknowledgements

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Figure 5: From physical object to cadastral boundary: reformulated boundary concepts for indirect surveying.

Further reading

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