UAV Technology: Opportunities to support the updating process of the Rwandan cadastre

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Abstract

Amongst others, Unmanned Aerial Vehicles (UAVs) are emerging as a tool for alternative land tenure recording. The advent of low cost, reliable and lightweight UAVs has created new opportunities for collecting timely, tailored and high-quality geospatial information. Even though UAVs appear a promising technology, it is not clear to what extent it can contribute to existing land tenure recording workflows of communities and governments. To address these questions, field data collection was carried out in Rwanda in February 2019, which encompassed several UAV flights and the consultation of relevant stakeholders. Additionally, a participatory mapping pilot study was initiated to allow the comparison of the existing cadastral base data with the boundaries that were delineated on top of the plotted UAV orthophoto. Results revealed a clear discrepancy of the spatial location and extent of both parcel datasets and pinned the need to update the cadastre. It was found that especially in areas with large developments and a poor quality of the first level registration, UAV-based orthophotos provide a profound and reliable base data for participatory boundary delineation to update the spatial extent of the cadastre. This paper is based on the achievements of “its4land”, a European Commission Horizon 2020 project. Grounded on cutting edge approaches such as fit-for-purpose land administration, “its4land” is using strategic collaboration between the EU and East Africa to deliver innovative, scalable, and transferrable ICT solutions that respond to sub-Saharan Africa’s immense challenge to secure land rights.

Keywords: UAV, participatory mapping, cadastre, tenure security, Rwanda

Introduction

Since the early 2000s, UAVs became a substantial gain for scientific as well as commercial applications worldwide. The advent of low cost, reliable, user-friendly lightweight UAVs, recent developments in digital photogrammetry and structure from motion (SfM) image processing software solutions, creates new opportunities for collecting timely, tailored, detailed and high-quality geospatial information. Due to their flexible operational setups, UAVs can bridge the gap between time-consuming but high accuracy field surveys and the quick yet relatively expensive classical aerial surveys. Resulting data products include true orthoimages, digital elevation models and 3D point clouds which can all serve as a basis for cadastral mapping applications. Various authors have tested the applicability of UAVs in western European cadastral systems [1,2] as well as in African and Asian countries [3–6]. Based on the pilot studies, those authors argue that UAVs might have the ability to revolutionize current land administration data collection strategies by reducing surveying costs, allowing flexibility in workflows, independence from satellites, and enabling timely and local data acquisition.

However, most pilot studies purely remained scientific investigations, and evidence on the implementation of UAV technology in existing land administration workflows is very scarce. Thus, this conference paper examines the opportunities of UAV technology in a real-world case study in Rwanda. The research data in this article is drawn from two main sources: 1) UAV data collection; 2) a participatory mapping activity with local inhabitants. Even though this case study does not reach the technology readiness which fully integrates technology in the existing operational environment, it is hoped that this research will contribute to a better understanding of opportunities of UAV technology to support the updating process of the Rwandan cadastre.

The conference paper begins with a brief overview of the study area. It will then go on with a description of the various data collection strategies and methods to analyse the data. The fourth section presents the findings of this research. Concluding remarks and recommendations complete the conference paper.

Country background and study area

Rwanda is a small land-locked country in Eastern Africa which shows one of the highest population densities within the African continent. A large and steady population growth unavoidably results in increased pressure on land and tenure insecurity. As a response to that, Rwanda has initiated major land tenure reform programmes during the past 20 years to bring land tenure security. This was reinforced by several institutional and legal reforms and culminated in a nationwide land registration program called “Land Tenure Regularization” (LTR) which is characterized as a one-off, low-cost, community-based process. Over eleven million parcels were surveyed, registered, demarcated and adjudicated within a period of a few years (2006-2013). The formalization of land in Rwanda was based on aerial images for the community-driven demarcation process, digitization of all land data collected and further centralization in a national land register and cadastre [7].

Even though the LTR tells a story of success, the challenge is ensuring that land transactions are being registered to keep the land data updated. [7] conclude that only one-third of all land transactions in rural areas are officially registered. Furthermore, areas with urban developments are likely to show large discrepancies between the reality and the spatial representation of the cadastre as well. Another problem was identified in the correctness of the boundaries. One of the land administration professionals at the national level literally said that “ almost all people in Rwanda have their land titles with errors on boundaries”. With regard to titles that were issued during the first registration, reasons for errors are seen in the poor training of the para-surveyors, the time delay between capturing aerial images and demarcation on printed orthophotos and cases in which parcel boundaries were not visible [8].

The study area for the UAV data collection covers 3km² of the northern part of Ruhengeri Cell, District of Musanze, Northern Province of Rwanda (cf. Figure 1). The area of interest was chosen due to large urban developments that occurred during the past years. These changes are not visible in the aerial images from 2009 and mainly also not updated in the Land Administration Information System (LAIS). Consequently, disputes arise as the current cadastre does not reflect the true situation on the ground, causing problems with updating mechanisms, correct compensations, and transactions. One of the villages in our study area was selected by Rwanda Land Management and Use Authority to conduct a systematic updating of the cadastre during the financial year 2019-2020. To show the potential of the use of UAV technology, we chose this village to trial the community-based participatory mapping activity.

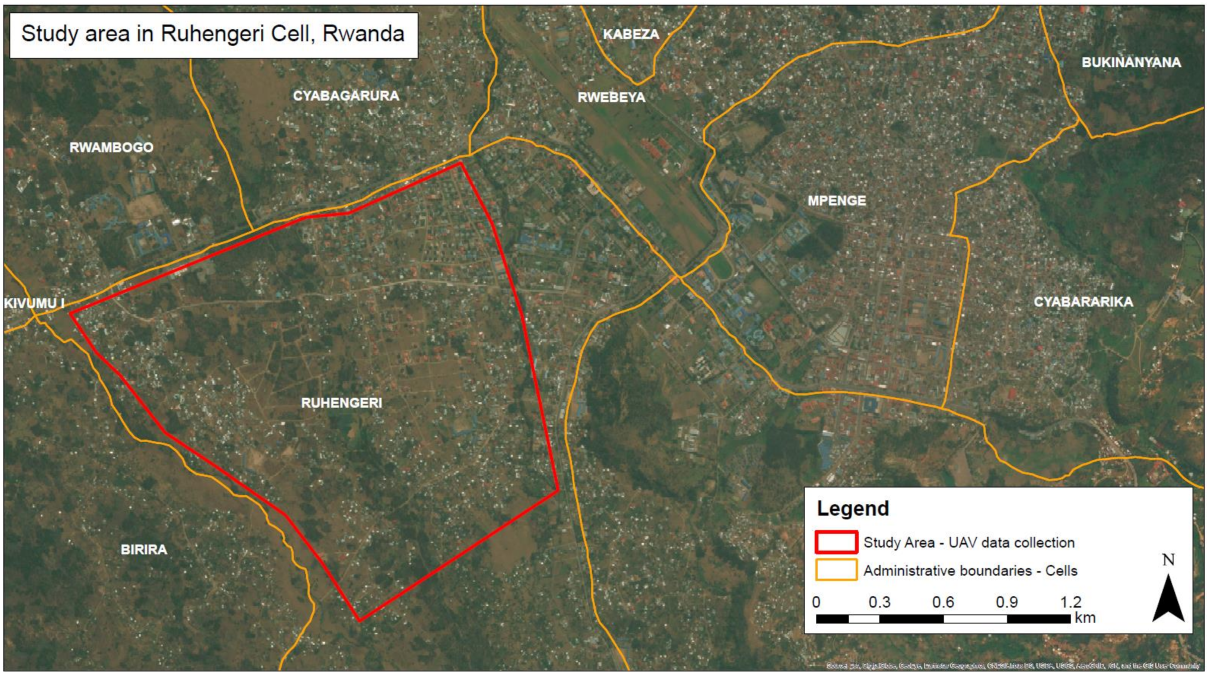

Figure 1: Overview of UAV data collection study area in Ruhengeri Cell (Musanze District, Rwanda), background data derived from google earth

Material and methods

A case study approach was used to conduct this exploratory study. The research data is drawn from two main sources: 1) UAV data collection, which was conducted in February 2019, and 2) a participatory mapping activity with local residents immediately after the UAV data collection.

UAV data collection

In collaboration with RLMUA, INES Ruhengeri and Esri Rwanda, we captured the area of interest with more than 8000 high-resolution images. The flights were carried out by the only licenced UAV company in Rwanda: Charis UAS Ltd. which holds all required licenses and permissions of the Rwanda Civil Aviation Authority to perform UAV flights. We employed a DJI Inspire Pro UAV (see Figure 2 left) with an RGB sensor to take pictures during the flight. The flight plan was programmed according to a flight height of 120m to reach a final ground resolution of 2 cm. Image overlap was set to 80% (forward) and 75% (side lap) to cater for unexpected wind turbulences and to ensure the creation of a reliable orthomosaic that is based on a strong image network. To always ensure a safe flight, the operational flight time should not go lower than 30% of the battery capacity, which corresponds to 12 min actual flights. Thus, in total 1.5 working days with 19 individual flights were necessary to cover the entire study area of 3km^2.

Additionally, to the UAV data, we also collected ground truth data with a survey grade GNSS (Trimble R8). For means of georeferencing, in total 14 visible ground control points were marked throughout the study area. The points were deployed with spray paint and had a round shape with a clearly identifiable centre (Figure 2 centre). All points were measured during two consecutive measurement campaigns with an accuracy below 2cm as the GNSS devices were connected to the RTK network of the continuously operating reference system.

The data was processed using the photogrammetric software package Pix4D (Figure 2 right). Here, 8 points were used as ground control points within the photogrammetric processing. Remaining 6 points were used as independent checkpoints for quality control.

Figure 2: UAV data collection. left: checking the UAV DJI Inspire Pro before the flight; centre: measurement of ground control points for georeferencing; right: data processing in Pix4D

Participatory mapping

The second part of the data collection was focused on a participatory mapping activity to see how local inhabitants demarcate their land on the orthophoto. Furthermore, this mapping activity provided exciting insights into the ability of locals to identify their houses and boundaries. For this, we selected an area in Susa village, which is known to have some land conflicts as well as several unrecorded land transactions during the past years. Relevant local government stakeholders were notified and informed about the data collection. The UAV data of the respective area was processed during the weekend and printed with a scale of 1:300 on an A0 sheet (Figure 3, left). The map was then protected with a thin lamination layer and waterproof markers were used for the drawing. Accompanied by a village elder, we approached local residents in their houses during the daytime on two consecutive days and asked if they could delineate their parcel boundary on the printed map (Figure 3, centre and right). If the parcel was drawn successfully, we additionally collected information on the identification number of the parcel and the situation of ownership.

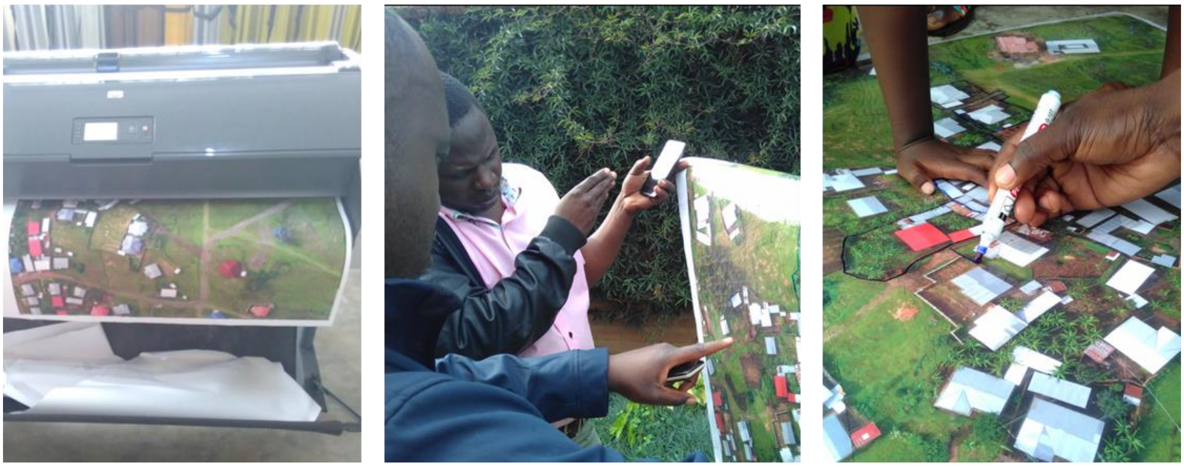

Figure 3: Participatory mapping activity. left: printing the orthophoto; centre: identifying houses on the orthophoto; rights: drawing the parcel boundary on the orthophoto

Results

During the photogrammetric processing, three main data products can be derived from the UAV images. Firstly, a 3D point cloud is reconstructed, which presents a 3D visualisation of the entire scene. As shown in Figure 4 (left), the surface, as well as rooftops, are represented consistently. Since the UAV only captured nadir images, the representation of vertical features such as walls of houses show lower point densities and are less consistent. Next, to the 3D point cloud, a digital surface model (DSM), as well as the orthophoto, can be derived. The DSM is a raster dataset that includes the calculated altitude of the surface as cell values (Figure 4, centre). The orthophoto represents the captured image scene in a predefined coordinate system, is constant in scale, which means that all objects are shown in their true planimetric positions. Thus, the orthophoto allows for measurements of objects and definition of point coordinates in the map (Figure 4, right). Even though all three datasets could be used to derive parcel information during a participatory mapping, the emphasis in this study was put on the orthophoto as this represents the dataset which is the easiest to interpret for local residents. The overall geometric accuracy of the orthophoto is 10.3 cm with a ground sampling distance of 2.1 cm.

Figure 4: Data products derived from UAV images. left: 3D point cloud; centre: digital surface model; right: orthophoto

During the participatory mapping activity, 32 parcel boundaries were delineated by local residents. It was found that 72% of all people could identify their houses without or with little guidance. Landmarks such as construction works, a road or special building that are known to everyone guided the orientation of local people. Furthermore, the high level of detail helped to accurately draw the boundary as fences, walls, special plants that usually demarcate the boundary and even slight changes in the paving of streets were easy to detect. Few people refused to participate in the mapping activity as they reported land-related conflicts.

The next step after successful delineation of the parcel boundary was to pose the question about the title document. In this context, only 37% of all local residents were able to present their titles. Reasons to not show the title varied largely, including those persons who were only tenants, women who did not have access to the title of the husband, or that the title is currently at the land office due to a planned land transaction process.

During data analysis, the parcel boundary drawn by the local resident was linked to the existing parcel outline in the LAIS. If possible, the link was made via the parcel ID, or via the location of the parcel if the parcel ID was not known. One-third of all parcels could not directly be linked to an existing parcel in the LAIS as none of the conditions mentioned above was fulfilled. An overview of both datasets – parcel outlines derived from the participatory mapping as well as parcel outlines from the cadastral data LAIS – are presented in Figure 5. It is clearly visible that some parcels have the same extent in both datasets, especially for parcels with a regular rectangular pattern (lower left area in the map of Figure 5). In other cases, two to three parcels from the participatory mapping activity form one parcel derived from the LAIS, which indicates that the land has not been officially subdivided yet. Lastly, in some instances, the drawn parcel boundary by local residents does not reflect the parcel outline from LAIS, neither in shape nor in size. This problem can be attributed to several issues: errors during first level registration in 2013, informal land transactions, or a faulty survey of the parcel during land transactions. In this specific case, especially the first level registration could be a potential source of errors as many developments took place during the period from 2009-2013, and the first level registration was carried out during 2012-2013 whereas the base maps were bound to the aerial image from 2009.

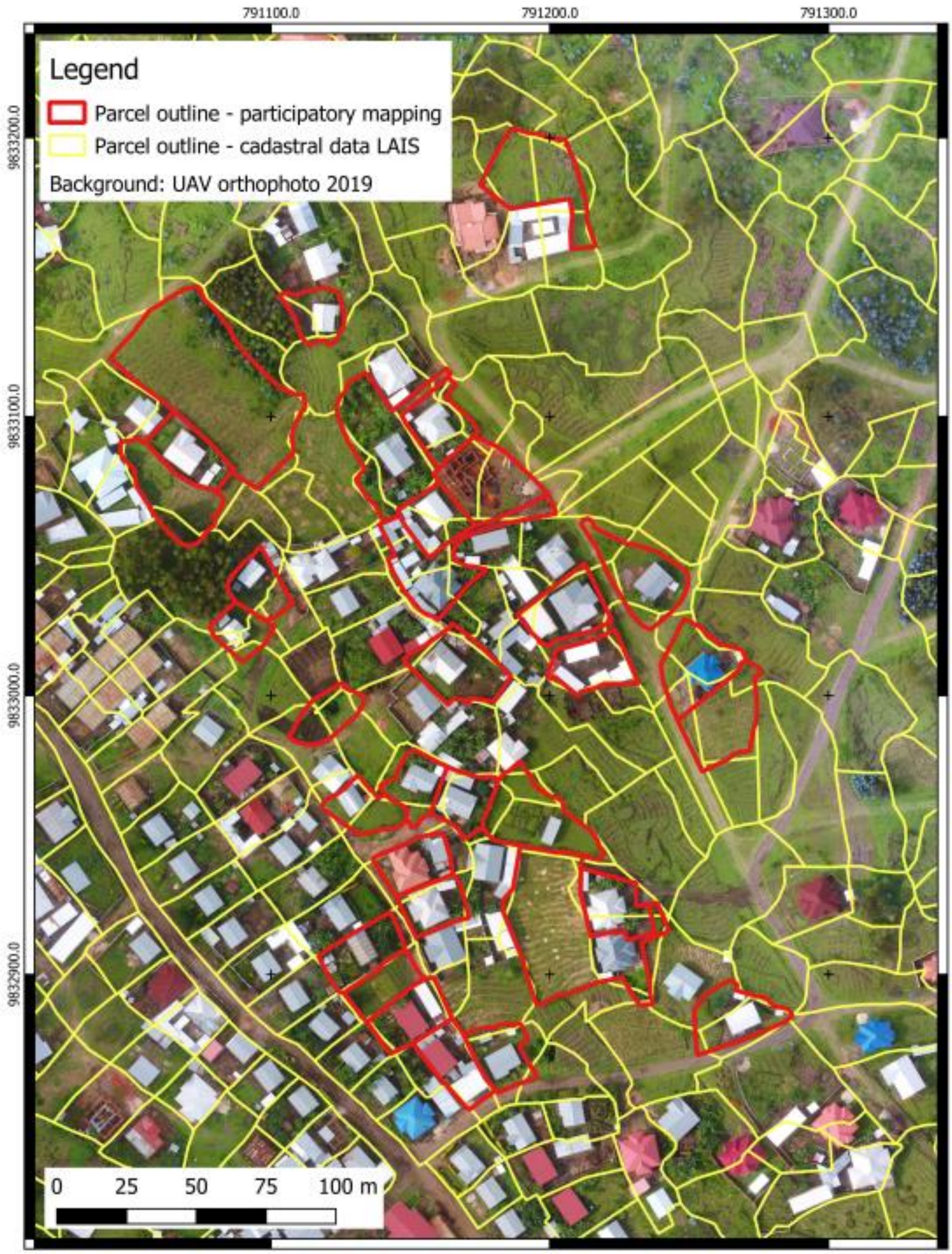

Figure 5: Overview of parcel boundaries derived from participatory mapping (red) and cadastral database LAIS (yellow)

A closer analysis of the parcel shapes reveals that on average 70% of the dawn parcels overlay with the official parcel data in LAIS. From the diagram in Figure 6, it can be seen that the range is very large and spreads from a minimum of 15% overlay to a maximum of 98% overlay. In this context, it should be noted that this average only refers to parcels that could be linked (25 out of 32), whereas the overall average might decrease when considering the „odd" parcels as well.

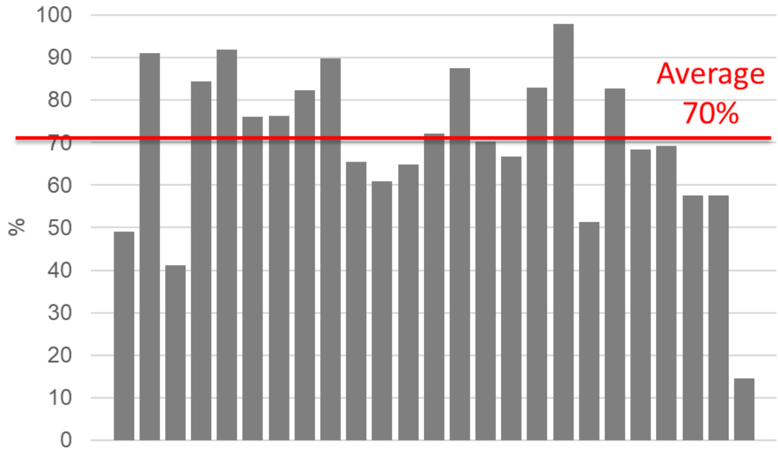

Figure 6: Percentage of overlay from parcel area derived from participatory mapping with parcel area from LAIS

As the percentage of overlay alone does not provide the full picture of discrepancies in the spatial extent, we further compared the sizes of parcels. Here, negative values indicate that the drawn parcel is smaller than the parcel in LAIS, whereas positive values indicate that the drawn parcel is larger than the parcel in LAIS. The diagram in Figure 7 indicates two extreme negative values with more than 1000m² of land. Both parcels refer to a case in which the parcel size in LAIS is significantly larger as the land has been informally subdivided. The maximum value on the positive balance reflects a case, where the owner has already bought the land of his neighbour but did not report this transaction to the District yet. Besides those extreme deviations, all remaining differences are in a range of +/- 300 m². Most of those deviations can probably not be explained by land transactions that are not yet processed but by an apparent discrepancy of the situation on the ground and the information in the cadastral database.

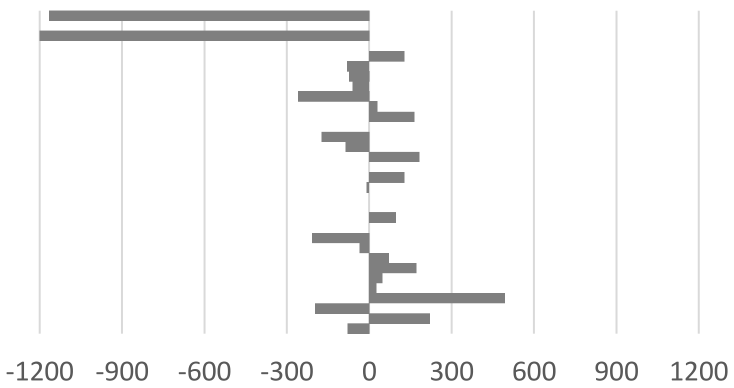

Figure 7: Difference in parcel size (m²).

Discussion

The discussion firstly reflects on potential consequences of the discrepancies of parcel data for local residents as well as for the government system. Afterwards, opportunities for UAV technology to address those negative implications as well as general recommendations are discussed. The Rwandan tax system is currently based on the areal extent of the parcel as well as the land use zone. As an example, landowners pay 40 RWF per m^2 annually in a residential area. Deviations in the parcel extents derived from this study ultimately imply that landowners pay too little or too much taxes. This might lead to conflicts, especially when residents come in touch with the conventional system. Re-surveying and fixing of existing parcel boundaries cause several problems. Firstly, almost all neighbouring parcels are affected by the survey and would require a re-survey as well. During the process of fixing boundaries, surveyors are still using the old aerial images or google earth to validate and adjust the polygon of the geodetic survey in the field not to raise concerns by the official land authorities. If the proposed cadastral parcel plan would deviate too much from the original parcel, the re-survey might be rejected. Missing survey standards and a lack of well-trained professionals add to this problem and cumulate in a cadastral updating process which is neither efficient nor reliable. Musanze is one of the fastest developing secondary cities in Rwanda and land prices are increasing tremendously. In this regard, it will be a matter of time until conflicts during land transactions arise, especially when people pay the wrong amount of taxes or do not get compensated correctly due to the discrepancy of the LAIS and the reality on the ground.

Even though the discrepancies that were revealed in this paper cannot be solely ascribed to one or another reason, it could be shown that UAV orthophotos can help to detect informal land transactions. Secondly, significant boundary offsets from the first registration can be spotted, especially when parcel boundaries are crossing houses and are not aligned to any visible boundaries on the ground. At a lower level of implementation, UAV data could further be used by the District government to validate geodetic surveys of professionals. Referring back to the situation that some regions in Rwanda were nominated for a systematic re-survey, UAVs would be a suitable technology to provide an up-to-date base map for those regions which extent is limited to a few km^2. Furthermore, the participatory mapping activity showed clearly, that people are able to understand the map and identify their houses, primarily due to the high resolution and clear visualisation of small features such as walls, surface characteristics of roads, and even particular forms of vegetation. The immediateness of the data delivery of only a few days from the UAV data collection and the printout of the map certainly helped in this procedure as we observed that people are more likely to identify small features such as small piles of sand or stones that they are used to see in their every-day life. The high level of detail further reduced disputes about the location of boundaries to a minimum. Although we went from house to house and did not include all neighbours during the process of boundary delineation, not even one party disputed the line which was drawn by its neighbour.

Conclusion

This conference paper set out to examine the opportunities of UAV technology for a real-world case study in Rwanda, namely to support the updating process of the Rwandan cadastre. The results of this exploratory research have shown, that in the study area the current LAIS data shows large discrepancies from the real situation on the ground. In this context, UAV-based up-to-date base data can significantly improve current surveying practices either for means of validation or even as a primary data source for participatory mapping activities. Especially the task of systematic re-surveying of small-to-medium scale areas should be considered to employ UAV technology as a cost-effective, fast and reliable mapping and surveying practice.

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