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Digital Pen Method

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Introduction

One innovation in cadastral data collection is in using satellite images and drawing boundaries in the field with land right holders as witness (Lemmen and Zevenbergen 2010). This chapter presents an evaluation of the use of a digital pen method as an example of a new unconventional approach in cadastral data acquisition. Conventional approaches, often of historical footing, are inadequate in many jurisdictions. For example, highly rigorous and accurate methodologies and procedures, practiced by registered or licensed surveyors, are characterized by long duration and delays in completing acquisition. These delays are represented by insufficient coverage of the registered land, and the required accuracy leaves much potential for errors. As these are not pro-poor approaches, alternatives to this mighty accuracy tradition in land administration are needed. Flexibility is needed in relation to the way of recordation, the type of spatial units used, the inclusion of customary and informal rights, the data acquisition methodologies, and in the accuracy of boundary delineation. It is less important to produce accurate maps. It is deemed more important to have a complete cadastral map and to know how accurate that map is (Lemmen and Zevenbergen 2010; Lemmen 2012). The hypothesis in this chapter is that the use of a digital pen method allows cadastral data acquisition can to be done in less time, with the same number of people, whilst preventing duplication of errors.

First, the participatory mapping approach for cadastral boundary mapping with the use of satellite imagery is presented. The technology behind the digital pen is described before an overview of the use of the digital pen is given on the basis of a study done in Rwanda (Rugema 2011). The results of this study are finally compared to an existing method for field data collection in Rwanda. These tests with the digital pen and the described outcomes add to the practice-based knowledge of participatory mapping and show under which circumstances the technology can be an alternative for conventional forms of cadastral surveying and data acquisition.

Theoretical Perspective

Participatory Mapping

One of the approaches to register land is the involvement of local people in the process of land registration through participatory mapping. The community involvement in land tenure regularization activities is seen as an instrument for engendering social capital and a strategy for resource mobilization toward securing tenure (Magigi and Majani 2006). In South Africa, in the Mpumalanga Province local people traced their views on how land reform would be done in their area on paper maps by using pencils and color markers (Weiner and Harris 1999). The value of participation in land registration is the agreement by local people on the consolidated information. For this reason, the first phase is to share public information. In Cambodia, land is registered systematically by using ortho-photos and printed maps. Local people participate to provide information about their parcels, and the adjudication officer and the demarcation officer literally go together to the parcel in question on an agreed date. During land adjudication, the existing rights to parcels are ascertained, not altering the existing rights or creating new ones. In demarcation of parcels, boundaries are delineated and agreed on with the adjoining owners or other interested parties (Törhönen 2001).

Transparency is important in participatory mapping to protect the rights of all parties. According to Weiner, Harris, and Craig (2002), "Community-based GIS projects simultaneously promote the empowerment and marginalization of socially differentiated communities. As a result, the nature of the participatory process itself is critical for understanding who benefits from access to GIS and why" (p. 3). According to Törhönen (2001), special attention has to be paid to vulnerable groups such as women or poor, disabled, or illiterate people. If this is not recognized, powerful people could take advantage and formalize land grabbing. Prevention comes in this case through transparency in the form of publicity.

Cadastral Data Acquisition

A cadastral map represents boundaries of ownership or land use rights, for example, customary land rights, or informal land rights as possession or occupation (Lemmen 2012). Those boundaries should represent the actual situation as it exists in the field. The cadastral map is, in fact, a map visualizing that people agree on the boundaries of their properties, living areas, or living environment. Even disagreement (overlapping claims) can be mapped. In this respect, it can be seen as a social map. It can also be seen as a map representing legal certainty in relation to ownership or factual land use. The map can be used as a basis for land tax; this is again a social issue in relation to the contribution of individuals, families, or groups to the development of society.

McCall (2003) argues that untrained people, with local spatial knowledge, can work effectively, easily, and happily interpreting aerial photos. Ortho-photos and satellite imagery may very well be used as a basis for data acquisition in the field of cadastral boundary data collection (Lemmen and Zevenbergen 2010). Cadastral boundaries can be identified in the field on top of such images. Identifiers of spatial units or parcels have to be included.

Using satellite imagery for cadastral applications is not new (Konstantinos 2003; Tuladhar 2005; Kansu and Sezgin 2006; Ondulo and Kalande 2006). Satellite images have been used for cadastral boundary acquisition in earlier doctoral research in Ethiopia (Haile 2005), as well as in pilot projects in Rwanda (Sagashya and English 2009) and Namibia (Kapitango and Meijs 2009). In Ethiopia, in 2008 a team conducted a simple field test using QuickBird satellite imagery in the program of rural land certification. The results showed that high-resolution imagery based on land adjudication is useful in participatory mapping. The data collection in the field was done with the help of land rights holders and local officials. The image quality of the plots at a scale of 1:2000 was sufficiently high to allow the parties to easily understand the images and contribute input, making the process very participatory (Lemmen and Zevenbergen 2010). Since 2013, Ethiopia has been registering land parcels systematically at a national level based on the experiences of Rwanda.

Cadastral maps can be used as a basis for spatial planning. Before changes are implemented, the existing situation on formal, informal, and customary land rights needs to be known. In combination with a registry of landowners or users, the map provides a basis for access to credit, for example, mortgage or micro-credit; further, the identified land rights can serve as collateral.

Often, a distinction is made between "general" and "fixed" boundaries; see the studies by Henssen (1995) and also Bogaerts and Zevenbergen (2001).

Henssen states that the English system mainly relies on physical boundary features: man-made or natural. The precise position of the boundary within these physical features depends on the general land law of the country concerned. This system is called the "general boundary system." Inclusion of the survey data in the cadastre implies the boundary to be "legally fixed." In some land administration systems, the location of the boundaries is guaranteed. According to Henssen, the choice between fixed and general boundaries depends on the pace of creating or updating the system, the existence of physical features, disputes to be expected, the amount of necessary security, and costs. Important observations in the field may be to identify to whom the physical boundary belongs. Fixed boundaries are based on observations (field surveys) in the field. Cadastral boundary measurements can result in calculated or observed (and transformed) coordinates, which are inputs for a cadastral mapping process. Enemark et al. (2014) in their joint FIG/World Bank publication on "fit-for-purpose" land administration highlight that land administration systems—and especially the underlying spatial framework of large-scale mapping—should be designed for the purpose of managing current land issues within a specific country or region, rather than simply following more advanced technical standards. The fit-for-purpose approach is flexible, participatory, inclusive, affordable, reliable, upgradable, and hence ultimately responsible.

Features of the Digital Pen

In the existing analogue method of general boundary survey, ortho-photos are first plotted and then boundaries of parcels are drawn on site and the parcel identifiers (IDs) are written with a pencil on field sheets. Post-processing has to be performed in the office. This concerns redrawing and rewriting over the pencil marks by using a normal pen on field sheets, scanning and geo-referencing field sheets, and vectorising parcel boundaries. This process induces different sources of errors because of many process steps. It is double work in terms of time. It requires a lot of space for archiving. This implies complex information management.

The innovation of technology has changed the ordinary pen into a smart pen called a digital pen that can directly record annotation in both analogue (ink-paper-based) and digital (computer-based) formats. The first modern digital pen was already released in 1996 by Anoto, a company based in Sweden. Anoto developed an ink pen equipped with a digital camera that takes snapshots to transfer ink into digital data. The digital pen works in conjunction with a special "digital paper," which is imprinted with dot patterns called Anoto patterns. The digital pen with digital paper by Anoto has become the most widely used standard for the digital pen technology (Schneider 2008).

On the basis of the Anoto standard, third parties have further developed the digital pen technology, which can be used in many applications including geospatial data collection. For this purpose, the technology was added as an extension to ArcGIS (ESRI Inc.), but dedicated solutions have also been built to function with other geographic information system (GIS) software. In this chapter, however, we refer to the solution provided by Adapx, which consists of a software extension for ArcGIS version 9. The digital pen for geospatial data collection has a capability to directly record spatial data (points, polygons, and lines) with predefined attribute data directly in digital format. With this capability, data can be processed with both computer-aided design and GIS software as a geo-database can be populated almost automatically after field data collection.

The pen's principal work is similar to that of a scanner. Each stroke of the pen in the paper consists of writing, scanning, and digitizing instantly. The digital sensor (camera) automatically scans the movement of the pen in conjunction with the pattern on the paper at a rate of 75 frames per second (Roe 2009). The pattern consists of numerous tiny black dots (0.1 mm in diameter), visible as a gray haze as they are arranged with a spacing of approximately 0.3 mm (Livescribe 2010). Each paper has a unique pattern with its unique combination of dots in every small area. The digital pen records the feature written in its exact position based on the dot's position in the paper. The pattern is printed in a black ink that reflects infrared light (800–950 nm) to be recognized by the pen's sensor. The accuracy when using the digital pen ranges up to around 0.1 m which is the effect of two conditions:

1. The Anoto pattern resolution is 0.3 mm.
2. The maximum error calculated by the location of the pen and the dot pattern is 0.7 mm (variation dependent on the angle of the digital pen against the paper).

The pattern can be printed on different types of paper that meet Anoto's pattern-enabling requirements such as opacity, reflection, surface roughness, and weight. It is possible to print satellite images or photos with a pattern. The printed image can then be brought to the field to draw the boundaries of spatial units with different land (use) rights. The superimposed Anoto pattern, however, reduces the contrast and definition of the printed image. The drawn boundaries can be loaded to a computer or transferred via Bluetooth and can be automatically overlaid on the maps or digital images available in GIS software or Google Earth.

Methodology

Rugema (2011) tested the digital pen in Rwanda. Three main aspects were investigated with respect to the use of a digital pen method. First was the acquisition of polygons, lines, and points of boundaries with the digital pen in the real-life situation of Rwanda. Second, the evaluation of these tests was done on the basis of the conventional approach used in Rwanda to understand how its use would affect the time required for data acquisition and what sacrifices would be made with respect to accuracy. Finally, it was assessed whether the method could be an appropriate alternative to the existing analogue method to achieve national coverage in accordance with current government policy.

Land registration in Rwanda has been done in a systematic way. In May 2013, about 10.4 million parcels were registered and 8.8 million printed land lease certificates were issued (see the case study on Rwanda by Enemark et al. [2014]). In the existing ortho-photo-based land adjudication, a pencil is used for data collection in the field on plotted maps for demarcating boundaries and writing parcel IDs. After fieldwork, the data are post-processed by first redrawing and rewriting the pencil marks on the field sheets with a normal pen to make the boundaries and parcel IDs more visible for scanning. Second, the field sheets are scanned and geo-referenced, and the drawn boundaries are digitized. This process implicates different sources of errors because of the many steps involved in it. It is double work (redrawing and digitizing), and a lot of space is required for archiving the field documents. The method, however, facilitates participatory mapping as stakeholders can "sit around the map" while constructing it. Data collectors do not need much training or education; anyone who is able to interpret the image, and can read and write, can do the job. The tools are easy to use, are suitable for field conditions, and facilitate collaboration in the field: the printed field sheets are on a large or small scale, and they are lightweight, portable, and reliable for fieldwork. Despite these advantages, there is a need to investigate alternative data acquisition methods to prevent the sources of errors that are present in this existing method of analogue field data collection and to improve efficiency (Rugema 2011).

The digital pen was tested in the field to assess whether it could reduce errors and improve efficiency. It captures what is drawn and written on digital paper, and it stores the drawn and written data to its internal memory and the operator can transfer the collected data to the computer by connecting the pen via a Universal Serial Bus (USB) adapter. The digital paper in the test included a legend: when touching a feature in the legend with the pen, it stores this as a classification for the next drawn information on the digital paper. For annotations on the map, a markup layer can be selected in the legend, and the operator can thus write as much extra information as needed on the field map next to the boundaries. The annotation on the map is used for instance to mark a parcel with the appropriate ID, indicate mistakes, and give remarks. Annotations are visualized as a separate layer in GIS after uploading the data. Within the used software (Capturx for ArcGIS), these annotations are unfortunately stored as vector information and not as digital attributes that can be displayed in a spreadsheet. This means that the parcel IDs must still be entered manually into the attribute table of the geo-database.

The following materials were used during field testing:

- ArcGIS and Capturx for ArcGIS software for producing and printing maps as digital paper.
- Penx digital pen (by Adapx) with USB adapter.
- QuickBird satellite imagery (0.60 m resolution) for the Nyamugali Cell, in Gatsata Sector/Kigali City.
- Ortho-rectified aerial photos/ortho-photos (0.25 m resolution) as used in the existing method for the land adjudication process at the national level.
- Plotted ortho-photos printed on A3 paper size at scales 1:1000 and 1:1500, respectively, for the test areas in Musezero and Kibenga. These scales were according to the mapping scales of the existing method in these two areas.

Results

Polygon-Based Feature Mapping

If boundaries are drawn in polygon mode, a parcel should be drawn in a continuous stroke of the pen from start to finish of the boundary. Each lift of the pen implicates the start of a new polygon. If a polygon drawn on digital paper is not closed (the end point being not near enough to the starting point), then the polygon will be closed by the application software in an unpredictable way. Therefore, when drawing parcel boundaries in this mode the operator has to pay close attention to the "closing" of the polygon.

Figure 8.1 presents two cases of drawing boundaries of neighboring parcels. On the left side of the figure, two polygons are drawn as completely closed polygons. The parcels are mapped individually: the result is barely visible gaps and overlaps in the shared boundary. In the right-hand image, the polygon drawn on the right has been inserted by connecting it to the polygon on the left. The result in this case is that the connected (not-closed) polygon is closed in an incorrect way by the software. The used software (Capturx 1.2 for ArcGIS) did not have the right algorithms included to properly auto-complete the parcels adjoining the polygon. To share the boundary between the two parcels, post-processing in ArcGIS was required.

The digital pen uses ink (as a ballpoint pen), and everything drawn and written on the map is therefore permanent; it cannot be erased from the field sheet as it would be when using an ordinary pencil. The available option for the digital pen to make corrections is by making additional annotations on the map to indicate any mistakes.

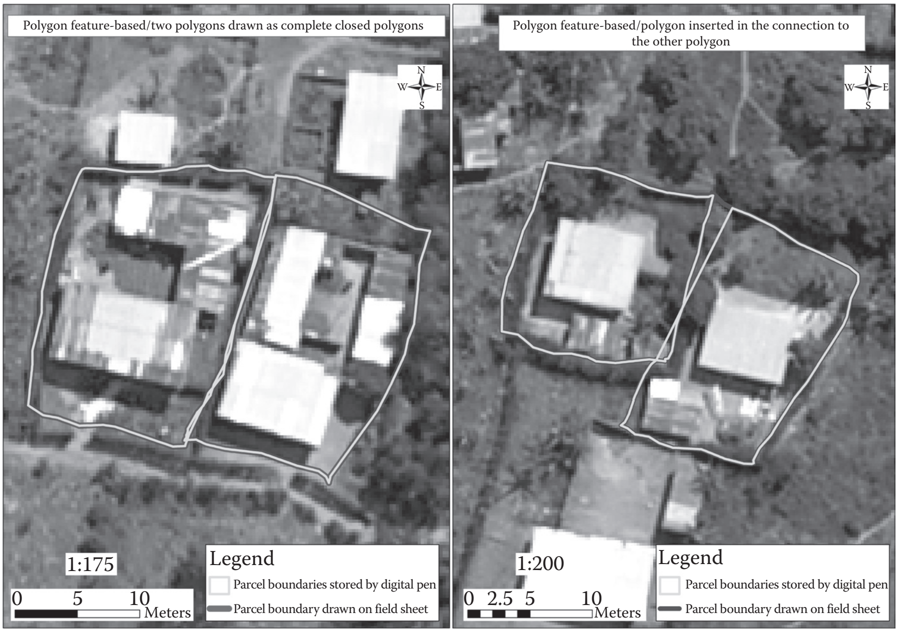

FIGURE 8.1
Polygon feature–based representations of boundaries between neighboring parcels. (From Rugema, D.M., *Evaluation of Digital Pen in Data Capturing for Land Administration Purposes in Rwanda*, Faculty of Geo-Information and Earth Observation-ITC, University of Twente, Enschede, The Netherlands, 2011.)

Polygon-based feature mapping requires objects to be collected as complete polygons. As the object of observation in the field is a boundary, a line feature, it was deemed a better option to build parcel boundaries out of individual line segments. As polygons would be created anyway through (automated) post-processing when all boundaries in the perimeter are drawn, there is no need to draw these polygons in the field.

Line-Based Feature Mapping

Demarcation in the field implies observation of the boundary in the field to draw it on a map as a representation of how it appears on the ground, and how it connects to other boundaries. When a boundary perimeter has been mapped, a para-surveyor issues a unique consecutive number to a parcel. With the digital pen, using a line-based mapping mode, it is possible to draw a single line segment, move the pen from the map, assess its quality, check the following boundary on the ground, and continue this exercise until the completion of the perimeter.

When mapping line segments, the operator must make sure the segments start close enough (tolerance set by software) to connecting/existing lines.

If the lines are overlapping, these overlaps can create small new polygons that do not represent any parcel existing on the ground. Figure 8.2 shows those kinds of errors.

The errors shown in Figure 8.2 (right) are usually not visible on paper. They become visible after uploading data from the digital pen into a GIS and zooming in to a submeter scale. Figure 8.2 shows the connection of four parcels existing on the ground (left image). When the line features were converted to polygon features, this only applied to one parcel. The other three parcels could not be formed because of the gaps between the connecting lines. In addition, however, four new "ghost polygons" were created connected to those four parcels. These extra polygons are very small; they are only visible on a screen at a higher scale than the one used in data collection. In reality, these nonexistent polygons must be tracked and edited out in post-processing. These kinds of extra polygons happen by mistake when the digital pen touches the digital paper unintentionally or is slightly moved on starting or finishing a line segment. The main reason for these problems is the streaming digitization mode of the digital pen. When drawing in streaming mode without the option of point mode digitization, the precision by which the operator can draw parcel boundaries on digital paper becomes

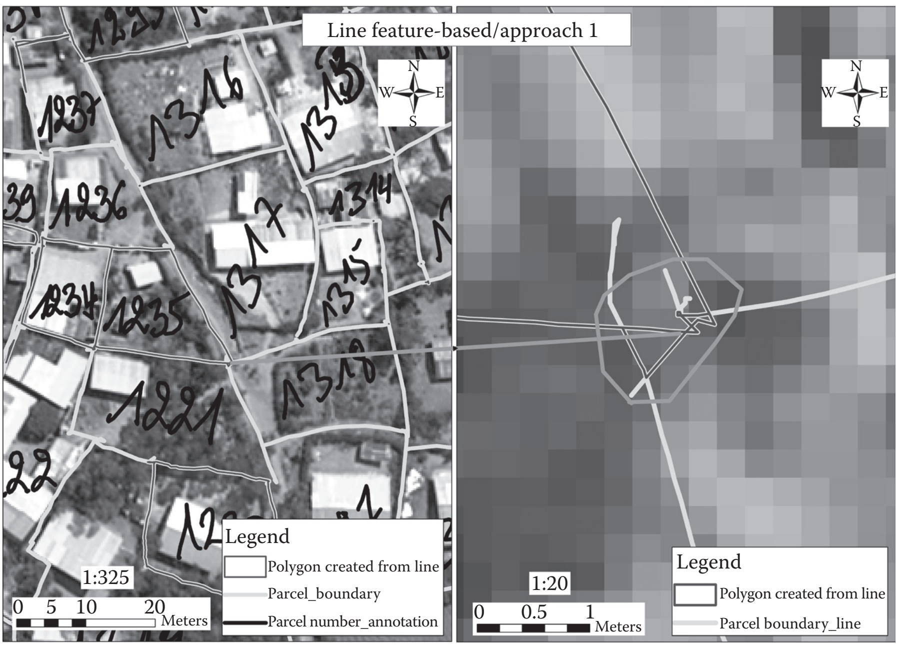

FIGURE 8.2
Errors in a line-based feature approach. (From Rugema, D.M., *Evaluation of Digital Pen in Data Capturing for Land Administration Purposes in Rwanda,* Faculty of Geo-Information and Earth Observation-ITC, University of Twente, Enschede, The Netherlands, 2011.)

less; thus, the control over the mapped coordinates becomes less. This causes a redundancy of vertices (vector coordinates) for parcel boundaries at every vertex; each turn of the pen on paper (sometimes representing field distances ranging up to around 0.1 m) is recorded as part of the boundary. Manual checking of errors and making corrections are time consuming and difficult. Fortunately, much of the errors and redundancy can be automatically removed in post-processing by setting tolerances for line segments. According to the errors occurring with this approach, and the time it takes to correct these errors, a point-based approach was tested as well to assess the way in which the digital pen can capture cadastral data.

Point-Based Feature Mapping

The quality of line-based mapping depends much on the steady hand of the operator, particularly when drawing relatively long lines on paper. With point mode digitization, parcel boundaries can be drawn with control over where the digital pen makes its mark on the map, thus with better control of resulting coordinates (vertices). During this test, point features were marked at the corner points (change of vector angle) of a parcel boundary. The resulting point map would, however, be difficult to interpret in the field. Therefore, each parcel boundary line would also be drawn on the map as markup (annotation).

In ArcGIS, the digitization of parcel boundaries was done by creating a polygon feature class and snapping to the collected points uploaded from the digital pen. Annotated parcel IDs (Figure 8.2, left) were then used to complete the attribute data that uniquely identify each parcel. The output then required manual post-processing to close any incomplete parcel polygons. This requires careful "snapping" of the points to give two neighboring parcels the same vertices for their line of division. With the use of tailored software for the digital pen, the order of point processing to form unique parcels can be automated and executed to avoid this post-processing step. The digital pen stores sequential steps in mapping through which corresponding IDs can be provided to point features belonging to the same parcel. The additional requirements to enable this are a more elaborate field form to be printed on the digital paper map and a consistent mapping approach by the operator, as only points belonging to one parcel can be mapped at a time and shared points must be indicated separately.

Discussion

The digital pen method as tested in Rwanda is almost similar in process to the actual participatory approach used in Rwanda (Rugema 2011). Local people could therefore easily familiarize themselves with this new method. The essential part is the ability to interpret images for parcel boundary demarcation. With the digital pen method, the main difference is that the boundaries are additionally collected as geo-referenced digital features. The point feature-based mapping approach appears to be the most practical. It creates the least number of errors, and it reduces the amount of post-processing. As a consequence, the digital pen could reduce the time required for cadastral boundary survey. However, the point feature-based approach does require additional tailored software for automated post-processing of parcels' boundaries. Compared to the existing method, the point-based method also gives a similar or more accurate output and in less time. Acquisition of cadastral data directly into a geo-referenced digital format can, based on these tests, be useful to reduce the number of steps required to get the final digital land information. This has an impact on reducing errors and saving time as it will reduce the many steps involved to achieve the final digital outputs in a conventional way.

However, the digital pen has been used in practice for cadastral boundary data acquisition purposes in "low technology, low internet environments" where it eventually mounted into frustration (Glenn K., pers. comm.; Thomson N., pers. comm.). Next to solvable technological issues as experienced in Rwanda, there were reported download problems and compatibility issues with GIS software that were not conducive to easy use and maintenance (Thomson N., pers. comm.). In addition, the main problem with the digital pen seemed to be the time needed to "clean" the data after they were uploaded, particularly the unwanted points, lines, and polygons that did not always close properly (Glenn K., pers. comm.). Although most of these errors are user errors that can be reduced by training, when working with local staff, it underscores the difficulty of dealing with the pen's sensitivity. The issue is that the technology needs to be "plug-and-play" in all aspects (preparation, mapping, and post-processing), which is not the way the technology "comes out of the box." The users reported, "We were losing too much sleep over trying to get it to work so we dropped it" (Thomson N., pers. comm.).

Luckily, many of the experienced problems can be solved by using more tailored software solutions with a dedicated workflow attached to the digital paper maps. Our cases indicate the feasibility of the tool for general boundary mapping in rural areas and as an updating tool for more general land administration issues. Further research is needed to develop the required innovative software to enlarge the domain of application of the tools. We suggest that with little adaptation it can be useful for small-scale mapping (e.g., large farming/plantation areas) as well as in urban areas for both initial data collection and updating of existing databases. More comparative studies are recommended for the digital pen with other data collection methods and to test the digital pen to other evaluation criteria, particularly more user-driven criteria.

Evaluation of the pen should focus on possible improvements based on those field experiences. The digital pen method would be more practical by improving some functionality of the techniques related to this method, particularly in the use of line feature based and/or polygon feature based in the field. The software available for the tools needs to be improved, and further testing has to be done. The options to be added are snapping option and point mode digitization. Another option, for any feature type adopted, would be the possibility of erasing the errors done on a digital printed map and this to be related to the information/data stored digitally into the memory of the digital pen. This would improve the quality of final outputs and the saving of time for office workload. However, a successful large-scale application of this tool in general boundary mapping is required before this innovation can be expected to fill the gap of low-cost high-tech data acquisition in land administration.

Conclusion

In conclusion, we can argue that, even though the technology is not yet perfected, the digital pen method has potential for (general) parcel boundary registration in rural and urban areas. It has the ability to collect large quantities of parcel-related data in a participatory manner while reducing the time and workload of post-processing these data. It can therefore assist the establishment of responsible land administration systems. However, data collection using the digital pen should be optimized according to its functions and purposes. Some recommendations to optimize the pen are using point features to get better geometric accuracy and reducing the post-processing time by adding algorithms and dedicated workflow for post-processing into the software.

The most important contributions of the digital pen method for updating cadastral maps are its functionality and usability to provide geo-referenced digital raster (originally drawn) data. The digital pen can take a role for demarcating preliminary boundaries before (if necessary) conducting higher accuracy measurements. The advent of digital pen technology therefore coincides with the urgent need for new approaches in land administration and land management where conventional approaches prove to be inadequate in rural and traditional environments or where flexibility is needed in relation to the way of data acquisition methodologies and the accuracy of boundary delineation. Rather than having an incomplete and highly accurate cadastral map, it is more important to have a complete cadastral map and to know how accurate that map is.

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