PERFORMANCE EVALUATION OF DIGITAL PEN FOR CAPTURING DATA IN LAND INFORMATION SYSTEMS (LIS)

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March, 2011

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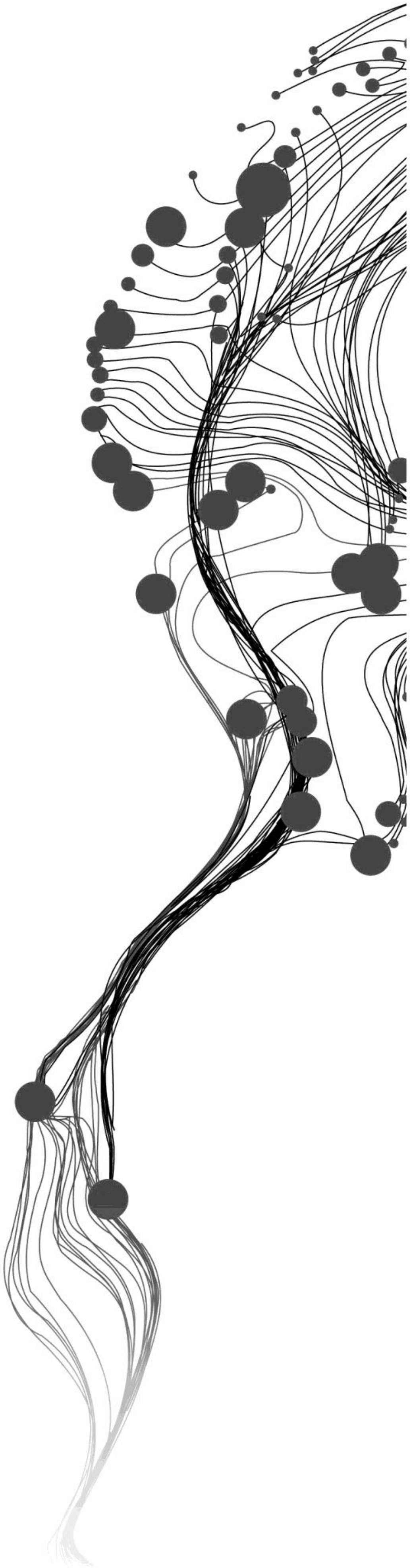

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HENDRO PRASTOWO
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Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.
Specialization: Land Administration

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ABSTRACT

The digital pen has been around for more than one decade for many applications except for an integrated survey and mapping functions (Schneider, 2008). The breakthrough approach of the digital pen technology [1] which has been re-designed for geospatial purposes may open a possibility of contribution to update the data changes for Land Information Systems (LIS). Experiences of using the digital pen for Geographic Information Systems (GIS) data collection describe some claims offering an effective and efficient data collection. The main objective of this research is to evaluate the feasibility of the digital pen for collecting cadastral data in a LIS especially for updating cadastral maps. The main question of this research is: Can the digital pen be used for updating cadastral maps in a LIS?

The performance is evaluated using ***"fit for purpose"*** method adapted from Clegg, et al., (2006). The method aims to evaluate the feasibility of the digital pen to perform its intended purpose: updating cadastral maps. The evaluation consists of 5 criteria: ***usability*** (the familiarity of operation), ***functionality*** (the capability for capturing cadastral data), ***reliability*** (the ruggedness in various environmental conditions), ***accuracy*** (positional accuracy), and ***compatibility*** (the integration of the digital pen data format with other applications). The digital pen has been tested using a cadastral dataset of Enschede and a high resolution (0.10 m) aerial photo. The test consists of component reviews and simulations of updating cadastral maps by drawing cadastral boundary data as polygons, points, lines and drawing attributes (identifiers and remarks) on the aerial photo printed in scale 1:1000 and 1:250.

The result of the evaluation shows that the digital pen is feasible for updating data in a LIS. All the claims proved to be true with some attentions in certain circumstances. Geometric errors, the less accuracy of jagged line, a time consuming post processing, and the difficult integration between spatial and attribute data are the main attentions to be considered to apply the digital pen in a LIS. Extra work for post processing is needed to get better data quality. The significant contribution of the digital pen system is in providing real time and continuous information as soon as the changes in the people/land relationship happen; which is the main concern of updating cadastral maps. Fast and reliable information about the changes cadastral data are often more important than waiting the high accuracy measurement (if necessary). The digital pen system can be applied in preliminary survey such as in subdivision process, identification of boundary dispute and index parcel mapping which need less accurate than cadastral parcel mapping.

[1] The digital pen technology consists of hardware and software technology; it works together with the Anoto digital paper technology as the digital pen system.

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I dedicate my thesis to my lovely family. For my wife Anna Beatrice and my son Marvell Arendra Prastowo: thank you for always cheering me to complete my study. For my parents, brothers and sisters: thank you for your prayer, encouragement and support.

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LIST OF ABBREVIATIONS

AFC	Arizona Fusion Centre
CAD	Computer Aided Design
DCDB	Digital Cadastral Data Bases
DMS	Digital Mapping Services
GIS	Geographic Information System
GPS	Global Positioning System
ICT	Information and Communication Technology
LIS	Land Information System(s)
NASA	National Aeronautics and Space Administration
NLA	National Land Agency
NRC	National Research Council
PC	Personal Computer
PDA	Personal Digital Assistant
RTK	Real Time Kinematics
USA	United States of America
USB	Universal Serial Bus
Y&A	Young and Associates

1. INTRODUCTION

1.1. Background

LIS's are facing challenges to provide reliable information particularly in land administration and generally for planning and development. While in some countries LIS is in sophisticated level of development , in many countries land information infrastructures are in use but with a low coverage (FIG Publications, 2010). Land administration as a domain of land information does not yet serve the people equally. Some people who are living in a formal land administration system may get benefits from it, but some others cannot be part of it or avoid it. Many factors coming from social, economic and cultural become challenges to develop a LIS. Innovations in LIS including data collection are rising to face the challenges and provide appropriate information. Institution, legislation and technology regarding cadastral land surveying should be adapted to the current situation in a particular nation.

Data acquisition technologies for capturing geospatial data are developing rapidly due to provide reliable and timely information. The emergence of various types of innovative equipment provides various options of data collection methods that are considered effective and efficient depend on needed layers and the environment. Nowadays, these technologies are already using the concept of global network reference systems, Global Navigation Satellite System (GNSS), remote sensing, mobile mapping, Geographic Information System (GIS), database system, web-server based approaches, and Information and Communication Technology (ICT) (Sørensen, 2009).

Technology innovations of survey instruments raise new tools for rapid acquisition of measurement data (Craig & Wahl, 2003). Traditional and manual equipment such as tape and theodolite nowadays face a challenge from modern digital and automated instruments. Digital equipment provides some advantages such as accelerating the speed, giving greater levels of productivity, reducing the level of risk of making gross errors in the measurements and reducing the level of manipulative skills that are needed to obtain much higher levels of precision and accuracy (Dale, 1995). The exsiting digital instrument such as total station and Global Positioning System (GPS) receiver have become very familiar in land surveying, moreover, the trend in digital data collection and mobile mapping raise latest technologies such as Pocket Personal Computer (PPC), tablets, notebooks, rugged PC, Handheld Mobile Mapper, smart-phone, and most recently: the digital pen.

Many researchers have studied applications of data collection technology in the GIS environment, including for the LIS data collection in terms of land survey and mapping. In-Su & Linlin (2006) assessed the availability of RTK GPS (Real-Time Kinematics Global Positioning System) under some challenging environmental conditions compared with total station. Raju et al., (2008) presented the use of high resolution image for urban cadastral mapping. Some articles also presented the implementation of data collection technologies to build a LIS; for example in New Zealand (Haanen, Bevin, & Sutherland, 2002), Finland (Tella, 2006) and other developed and developing countries (Bishop et al., 2000).

The digital pen and paper technology have been applied in data collection technology including for GIS applications. Based on the literatures found; there are only few reviews of digital pen in GIS/LIS context available due to the limited use of this technology in GIS/LIS. Sylverberg et al., (2007) initiated a study of the performance of digital pen in geospatial context by assessing the ability of digital pen to recognize soldier's handwriting on the map. This study revealed that hand-drawn symbols written on the military map can be recognized by The Kartago System which combines mobile computer system, GPS and ICT (mobile phones, Bluetooth and GPRS/3G). Bell (2008) reviewed the technology of digital pen and some applications using the digital pen for GIS. Schneider (2008, 2009) who is the Adapx's Chief Executive Officer; one of the digital pen manufacturer; claimed several benefits of using the digital pen in geospatial data collection such as speed-up workflows, increase operational efficiencies and saving cost. Other articles mostly come from commercial company and "grey literatures", say, no peer-review articles on it. Further scientifically research is needed to review the performance of digital pen. This research proposes to study the feasibility of digital pen for a LIS data collection using a scientific method.

1.2. Justification

Geospatial data for GIS applications has similar characteristic with geospatial data for LIS applications, the difference is that LIS has cadastral data as a primary component. Cadastral data is parcel-based information with its legal consequences (Toms, Williamson, & Grant, 1987). This data consists of spatial data and administrative/attributes data. Cadastral data is used to construct the cadastral map. Chicocinski (1999) stated the main component of a computerized LIS is a digital cadastral map. Recent Geo-ICT developments have influenced the development of LIS and Geo-Spatial Data Infrastructures (GSDI) (Lemmen & Oosterom, 2002). In the future, LIS will not only serve the need of cadastral information but also wider information as an integrated part of GIS.

Cadastral data dynamically change due to formal/informal land transaction related to population growth, and use, conflict, environmental change and disaster. Cadastral maps have to be updated according to the changes. Updating parcel-based maps in a LIS should be distinguished from updating maps in a GIS in terms of accuracy and type of information. Cadastral data collection should be supported with the adequate capability to capture the type of cadastral data by considering the methods, tools and human resources.

The history of digital pen and paper technology has emerged since 1998 (Schreiner, 2008). The digital pen has been around for more than one decade for many applications except for an integrated survey and mapping functions (Schneider, 2008). The breakthrough approach of the digital pen technology which has been re-designed for geospatial purposes may open a possibility of contribution to update cadastral data changes in a LIS. To evaluate the performance and disclosing the contribution of the digital pen in LIS, a research has been done through systematic observation, measurement, experiment, formulation, and testing.

1.3. Problem Statement

The digital pen has capability to directly record data from paper into digital format. The digital pen technology has been combined with GIS/CAD (Computer-Aided-Design) software for geospatial data collections. One of the provider of digital pen, Adapx claims that the digital pen allows a faster GIS data collection (Schneider, 2009). Furthermore, Adapx claimed that data collection with this pen is cheaper, easier, more accurate, and efficient, among others. The claims are exposed in GIS experiences but not yet studied based on experiences within the context of LIS. No literatures have been found regarding to cadastral applications of the digital pen technology. There is insufficient information for decision makers to use the digital pen or not use it in cadastral applications.

1.4. Research Objective

The main objective of this research is to evaluate the feasibility of the digital pen for collecting cadastral data in a LIS. Cadastral data collections in this research are limited for updating cadastral maps as one of the activities in the LIS data maintenance.

1.5. Research Questions

The main question of this research is: Can the digital pen be used for updating cadastral maps in a LIS? Sub-questions have been developed by breaking down the main research objective; they are:

1. To describe the use of digital pen for geospatial data collection:
    a. What applications are using the digital pen for geospatial data collection?
    b. What are claims of using the digital pen in those applications?
2. To evaluate the performance of digital pen for capturing and processing geospatial data:
    a. How can the digital pen deal with spatial data for updating cadastral maps?
    b. How is the possibility to capture attribute data?
3. To describe the contributions of digital pen for updating cadastral maps:
    a. What are the capabilities of digital pen that make it suitable for updating cadastral maps?
    b. How can the digital pen be optimized to be used for LIS data collections?

1.6. Conceptual Research Framework

The formulation of the conceptual research framework is based on some concepts: the definition of performance in terms of survey equipment, the updating cadastral data in LIS's and the digital data collection method to collect and maintain cadastral data.

1.6.1. Concept of Performance

Some journals were selected as sources to define the concept of performance. The diverse literatures introduce some point of views of the use of survey equipment for capturing data. Different instruments use different concepts and parameters to measure their performance depend on their purposes: land survey, mapping and navigation. The concepts used by authors in selected journals always combine the "performance" with a process to measure it, such as "investigation", "evaluation", "analysis" and "assessment". This research adapted the concept of performance from Clegg et al., (2006) who has evaluated the performance of tablet PC and PDA using " fit for purpose" method (see Chapter 4.1 for details). This evaluation was adopted to evaluate the digital pen with some modifications depends on the claims in the GIS context and characteristics of the digital pen.

1.6.2. Change of Cadastral Data

The changes of land information contents are growing rapidly and more complexes due to the development of user requirements and purposes. Changes in land parcel boundaries and its associated information have to be updated as soon as they are agreed; the consequence is "a cadastral map must be up to date at all times" (Dale, 1995).

1.6.3. Digital data collection

The rapid development of ICT is open a possibility to establish a real time digital surveying. The availability of network computer connection allows surveyor to extract and submit data online to the database system. In 1996, Land Information New Zealand (LINZ) introduced e-cadaster to automate all surveys and title processes in the digital form to provide mainstream land information (Haanen, et al., 2002). The automated features in e-cadaster included a real time digital surveying which allows cadastral survey information which has already processed and validated directly in the field to be transferred automatically as an up to date data to the database system.

Innovation of technology and method to provide an up to date land information has raise up applications of digital collection method for building a modern digital cadastral database (Sørensen, 2009). "Stand alone" or a combination of modern equipment such as GPS, Total Station, Laptop, PDA, Mobile GIS, Mobile PC, Tablet PC, Smartphone and the digital pen nowadays have a potential to optimize the digital data collection.

1.6.4. Formulation of Conceptual Research Framework

The concepts of the performance, change of cadastral data and digital data collection using the digital pen bring out a conceptual research framework for executing this research. The concept is started by the claims that using the digital pen on digital data collections has many benefits. The claims are described the good performance of the digital pen in GIS context but not yet in LIS context. GIS and LIS have similar characteristics as geospatial information systems. The difference is that LIS has parcels as the basic information. The performance of the digital pen in LIS (parcel-based) context is evaluated using the fit for purpose method. The result of the performance evaluation is used to assess the feasibility of the digital pen in LIS context, especially for updating cadastral maps. The conceptual research framework is drawn as a diagram below:

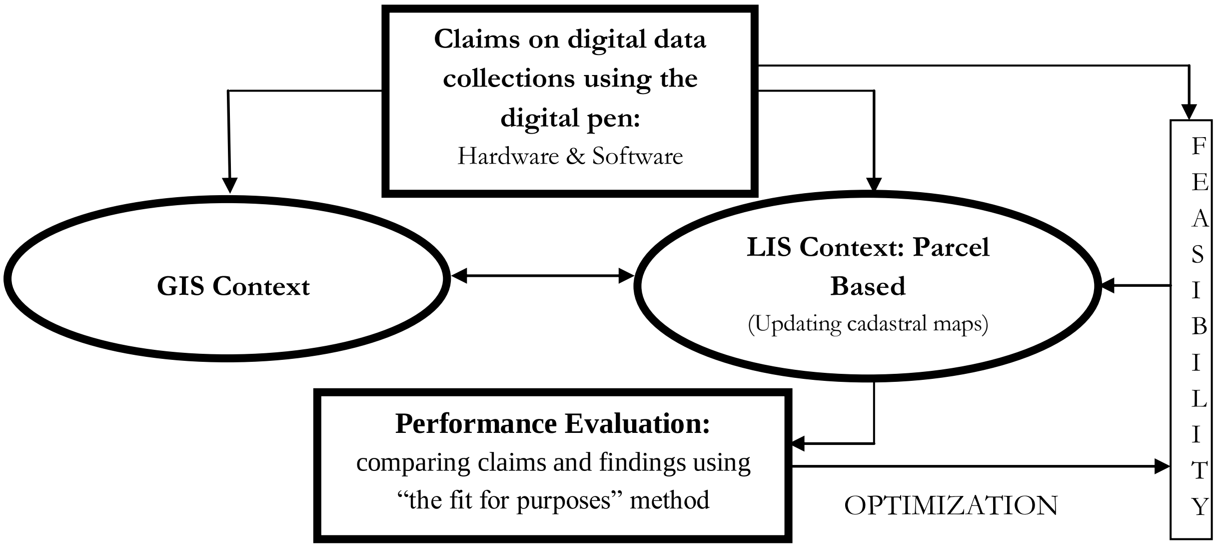

Figure 1. Conceptual Research Framework.

1.7. Research Methodology

This research has applied qualitative and quantitative data observation and analysis. Qualitative observation is checked out by quantitative analysis, in other side quantitative observation may need rational analysis that need a verification using qualitative analysis (Sechrest & Sidani, 1995). Qualitative data based on user opinions, experiences of digital pen implementation, component reviews and a test of hardware and software while quantitative data mostly obtained from the test of hardware and software. The stages of research have been designed to obtain the objectives according to the conceptual research framework.

The research methodology comes up with the specifications and claims on the use of the digital pen for GIS data collection as the main issues. Two stages have been used to collect data: exploring the use of the digital pen; and field test. First, literature reviews and web browsing have been used as main sources to explore how the digital pen is used in the GIS context. Applications for GIS have been chosen because the equipment is not yet widely used especially in the LIS context. The information is useful to study how it also can work in the LIS. The findings of explorations have been used for describing the use of the digital pen and the claims on it. Second, the field test is performed in the neighbourhood of Enschede, The Netherlands. Activities in this stage consist of component reviews and simulations. Component reviews bring out some findings about the detail parts of hardware and software of the digital pen system. Simulations have been done by capturing cadastral data represented by polygon, point, line and attributes (identifier and remarks) on the field map. The simulations were followed by data processing consisting of downloading data from the pen to the computer and updating the cadastral database. Simulations and data downloading bring out some findings about the performance of the digital pen system operations. The performance based on the findings from the field test has been evaluated using the fit for purpose method. The results of the evaluation have been compared with the claims to assess the feasibility of the digital pen in LIS context. This assesment has delivered outcomes to describe what kind of contributions of the digital pen are useful for updating cadastral maps and recommendations on how to optimize the capability of the digital pen for LIS data collection. The stages of the research are composed as a research methodology diagram as shown in Figure 2 below:

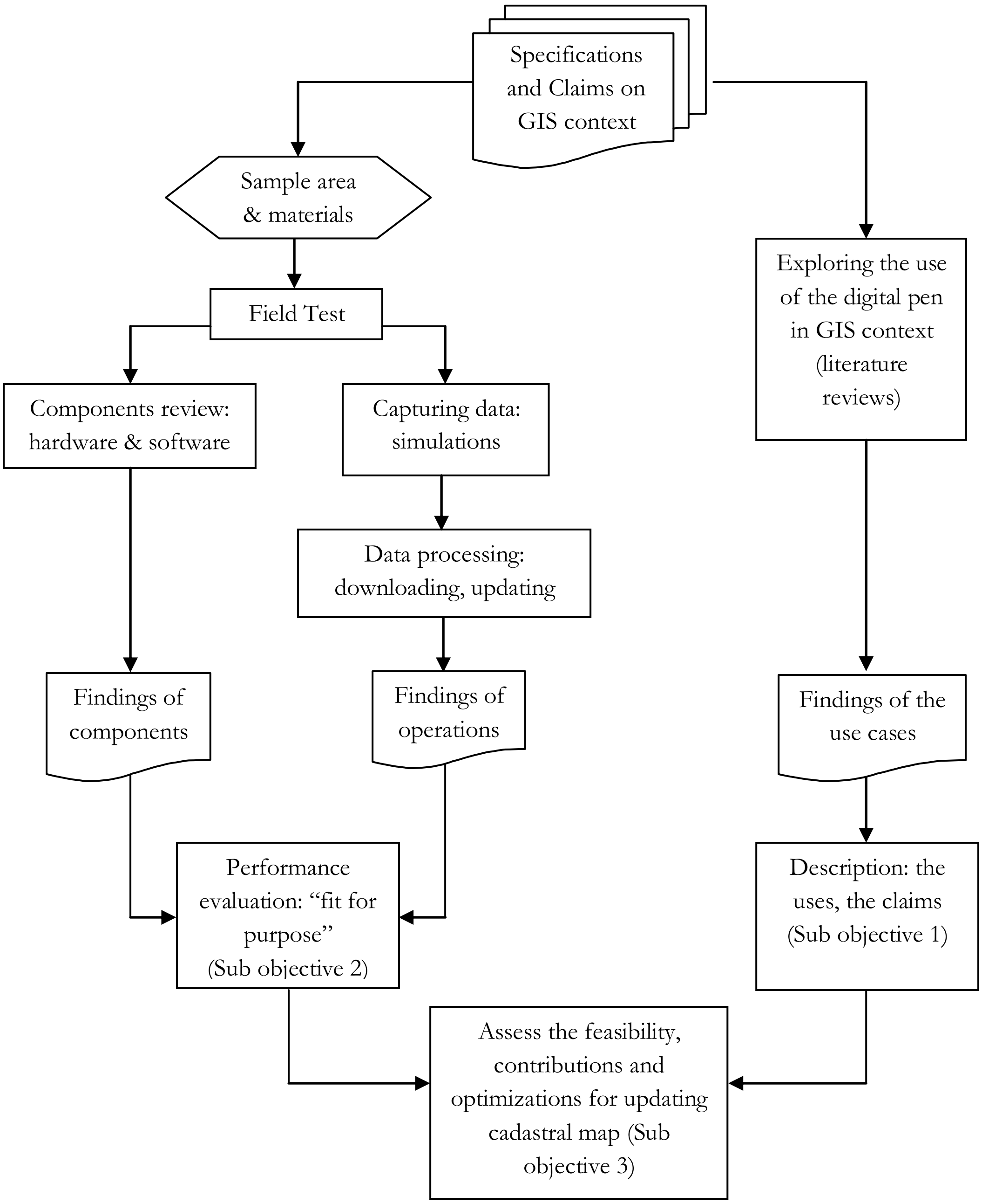

Figure 2. Research Methodology.

1.8. Thesis Structure

The thesis consists of 7 (seven) chapters as follows:

Chapter 1: Introduction

This chapter consists of the introduction, the background of the research, research problems, research objectives, research questions, the conceptual research framework, the reserach methodology and the overview of the thesis structure.

Chapter 2: How Cadastral Maps Are Updated

This chapter is a literature review consists of three parts. The first part is an overview about cadastral data in LIS's, the second part is an overview about cadastral map maintenance; and third is an overview about digital data collection methods for updating cadastral maps.

Chapter 3: The Digital Pen System

This chapter is a literature review consists of three parts. The first part is the development of the digital pen and the digital paper technology. The second part is the use of digital pen for geospatial data collections in several disciplinary fields. The third part is claims on the use of the digital pen.

Chapter 4: Methodology of the Performance Evaluation

This chapter consists of seven parts. The first part is the method for the evaluation. The method has been applied through a field test. The second part is a components review of the digital pen consisting hardware and software. The third part is preparations of the field test simulations. The fourth part is the test of capturing data on the photo maps. The fifth part is data processing after data capturing. The sixth part is the test of reliability. The last part is the test of accuracy.

Chapter 5: Findings from the Field Test

This chapter presents findings from the field test field consist of components review, capturing data, data processing, test of reliability and test of accuracy.

Chapter 6: Performance Evaluation

This chapter consists of two parts. The first part is the evaluation of the digital pen using the defined criteria of performance (the fit for purposes). The evaluation describes the criteria matching with the claims. The second part is contributions of the digital pen for updating cadastral maps; and optimization of the digital pen for LIS data collections.

Chapter 7: Conclusions and Recommendations

This chapter provides the conclusions based on the reflection on the research objectives and revisiting the research questions; and the recommendations consist of further researches needed to explore the capabilities of the digital pen system.

2. HOW CADASTRAL MAPS ARE UPDATED

This chapter is intended to provide some literatures about updating cadastral data changes in cadastral maps. The first session presents some definitions and roles of cadastral data in LIS's. The second session presents the need for updating cadastral maps. Cadastral data is commonly depicted in cadastral maps. Updating cadastral data changes should concern on updating cadastral map. The last session lists several technologies and applications of digital data collection for updating cadastral maps.

2.1. Cadastral Data in LIS's

The roles of cadastral data for the LIS development are not a new concept. Toms et al., (1987) stated that cadastral data can be fitted into the context of LIS by two general types of land-related data. First is the "environmental data" that describes natural phenomena such as vegetation, slope, water body, land cover and so forth. Secondly is "parcel-based data" that consist of any information about parcel as "a smallest registered unit of land".

According to Williamson et al., (1990) the core of LIS is parcel-based information. He described the Digital Cadastral Data Bases (DCDB) which was introduced in 1990's as a spatial reference for the LIS in Australia and New Zealand. DCDB was adopted in some states using different terms such as Geographical Data Base (GDB) in New South Wales, MAPNET in Northern Territory, Western Australia Land Information System (WALIS) in Western Australia and State Digital Cadastral Map Base (SDCMB) in Victoria. They have a common objective to capture and create a digital database of cadastral for the LIS development. The output of DCDB is a geographical index to visualize cadastral parcel, so a high accuracy is not considered as important as the relative spatial relationship.

Chicocinski (1999) stated that a LIS is constructed by the link of two types of data: spatial and attribute data. Spatial data have a geometric characteristic which are represented by point, line and polygon. Attribute data is descriptive information about features in quantitative or qualitative value. The system can be maintained properly if data are computerized, thus mean all data is in digital format. He took a sample of the evolution of cadastral from "classical" to "modern" which emerged in Poland at 1991 by converting the existing cadastral from analogue to digital form and creating the construction of LIS, more generally GIS. Chicocinski described that in Poland, the modern cadastral which is a computerized system has to include "real estate data" to determine its cadastral identifier, location, boundary route, land use and classification, technical fitting (main connections), land purpose for planning and attributes of real estate (its surface and values). The main role of the modern cadastral is the ability to integrate with other information resources in the frame of LIS/GIS.

Bishop et al., (2000) defined a LIS is "a GIS which utilizes land parcels as the link to the non-graphic database attributes". According to Bishop, the development of Bangkok Land Information System (BLIS) used cadastral maps which is an output of the land registration in Thailand; which has been overlaid with large scale rectified photomaps. The land parcel-based map was linked with database attribute from partner organizations (such as electricity, water and telephone) who share the same parcel-based land information (type of building, the owners, location). LIS could be meant as a "using cadastral data in a GIS" environment (DIBLM & FGDC- Cadastral Subcommittee, 2010). In order to fulfil the requirement of parcel-based information, the cadastral data set managed using a GIS should concern on the legal consequences (delineation of boundary, rights, responsibilities and restrictions).

Zevenbergen (2002) described the relation between spatial data and descriptive data in cadastre. The link between those data is arranged through "parcel identifier". He stated that "every parcel is defined by a unique parcel identifier". The identifier takes a role as reference for indexing and identifying the parcel in the map and their administrative records in the database. The changes of a parcel boundary have consequences for updating the map and the parcel identifier. The design of parcel identifier is different among countries depends on their previous or existing cadastral system, time and cost effectiveness and cultural reason (UN/ECE/WPLA, 1996).

Nowadays, the classic definition of cadastral data which is consisting of land parcel registration has been expanded to integrate with the other geospatial information. Started in 1980's when USA was introducing a multi-purpose cadastre concept, the cadastre layer has been connected with other geographic information such as building and facilities, cultural resources, government unit and housing (NRC, 2007). The variety of cadastral data will be dynamically expanded and should be able to be overlaid with other geographic database to provide extensive information.

2.2. Cadastral Map Maintenance

2.2.1. Cadastral Map

Cadastral maps support a significant data in a LIS. Dale (1995) stated that a cadastral map does not only show boundaries of parcels but also additional detail information of resources associated with them. Cadastral maps which are based on large-scale maps can be adapted to general uses; besides as parcel map; such as utilities (pipeline, electricity and telecommunication), roads, canal and ports, land use and classifying land, disaster mitigation, administrative purposes (tax based area), analysis and interpretation of census data and spatial planning.

Level of LIS developments varies in different countries (UN/ECE/WPLA, 1996). Most countries which have a history of formal land administration have already applied a computerized system or are in the process the LIS development. Countries which are building land administration system from the scratch - or almost- have to implement the possibility of optimal solution to deal with the very beginning development without any restrictions to use the existing system. Therefore, the all components of the LIS have to be designed properly regarding to the legislation, time, cost and technology issues, including data collection management for establishing cadastral maps.

Different countries applied different types of land registration system such as deed or title registration, fix or general boundary and systematic or sporadic (Zevenbergen, 2002). Those differences influenced on the type of cadastral maps as a component of cadastral system and the LIS development. Zevenbergen referred to Henssen's classification of cadastral maps based on title registrations. Group of countries (English, German/Swiss and Torrens) has their own standard for cadastral map: English Group uses the large scale topographic map, German/Swiss Group uses a parcel based cadastral map and Torrens Group uses an isolated survey plan. The fix boundary system requires higher accuracy of cadastral map rather than the general boundary system. The systematic system requires a larger coverage of cadastral map rather than the sporadic system. Therefore cadastral map is designed based on the different level of coverage area, level of accuracy and level of information. Konecny (2009) stated that cadastral map may serve as a high accuracy of cadastral map or as an index cadastral "to identify the parcel but not its accuracy".

Cadastral maps serve broader purposes in their development. Colombia and India are examples of countries implementing cadastral map for broader purposes, in addition to several other countries (The World Bank, GLTN, FIG, & FAO, 2010). In Colombia, cadastral maps also provide the base property of tax: building, usage and ownership; as cadastral belongs to the finance sector. In India, a particular cadastral map named a (village) cadastral map serves for a level-micro planning (natural resources) and impact assessment (disaster mitigation).

Boundaries of parcel as a main element of parcel-based mapping are established using various data collection technology methods (see also Chapter 2.3). Parcel boundaries survey and mapping system are now developing from a survey by a land surveyor (government, private or company) (UN/ECE/WPLA, 1996) to participatory mapping by communities (The World Bank, et al., 2010). Innovations of cadastral survey and mapping are being developed to generate cadastral maps in accordance with the desired information. As a result, cadastral maps can be represented in different digital formats (graphic, numeric, CAD, GIS) and different level of accuracy in accordance with its purposes.

A modern cadastre is normally built based on digital maps and registers (Dale, 1995). Cadastral maps in digital format support a computerized LIS. According to Dale, several advantages of computerization of maps and registers to build a computerized LIS are effective and efficient data analysis, reduce space of storage, avoid duplication of records and provide a backup data in case of disaster. UN/ECE/WPLA (1996) give an example a project for computerization of cadastral map in Hungary as a key factor to modernize land registration. The existing paper-based maps are converted into digital cadastral maps to provide an accurate large-scale map in a national mapping base which can be rapidly maintained and updated.

The format and the level of accuracy of digital cadastral maps for developing a LIS depends on the various data sources and technologies available in the country concerned. Bishop et al., (2000) took a sample in Thailand as a developing country, the choices to use technologies or the method of GIS/LIS development commonly based on personal interests, vendor promotions, demonstrations from some conferences/seminar or visited develop countries. The difference of format (GIS or CAD), data sources, accuracy and graphic quality of various maps led to confusions among the end users. The problem has been eliminated by composing "base map compatibility level" (see Table 1) that distinguished the map scale with the application. They determined that the most suitable scale map for a base map of LIS in the urban area is 1:1000; if the area has excellent hardcopy of cadastral maps overlaid on large scale rectified photomaps.

Scale	Meters/mm	Resolution	Application
1: 10,000	10	Some roads may disappear	GIS
1: 4,000	4	Some houses may disappear	LIS
1: 1,000	1	No problem in general	GIS and LIS
1: 250	0.25	Too many map sheets	CAD, engineering design

Table 1. "Base map compatibility level" (Adapted from (Bishop, et al., 2000)).

Scale map issues related to the purposes of cadastral map (Dale, 1995). Utilities of map presenting different purposes may be defined in large scale, medium scale and small scale. Each scale has advantages depending on the applications. Each nation may determine series of map according to their requirements. This issues affected in the accuracy level. Cadastral map is considered as a large scale map which has to show the various accuracy levels of parcel boundaries. The Land Administration Guidelines from Economic Commission for Europe (1996) reported that the requirements of geometric accuracy of parcel boundaries in some countries are "very precise" but in some other countries are "far less demanding ". These guidelines recommend that high geometric position requirement is not often a compulsory but the possibility for applying low cost surveying and mapping methods should be always studied. Therefore, the definition of geometric positional accuracy is not only related to the centimetre or millimetre issues but is more regarding the purpose of cadastral map to serve reliable land information.

Positional accuracy is a great concern in the data quality of LIS/GIS in addition to other accuracy issues such as temporal and attribute accuracy, lineage, completeness, and logical consistency (Huisman & de By, 2009). Information about accuracy issues in the metadata becomes consideration to determine the quality of LIS/GIS desired. Positional accuracy in cadastral survey and mapping is corresponding with the errors (Craig & Wahl, 2003). The errors are originating from several sources such as the human, the instrument and the systematic errors. Skills of surveyor in survey and mapping affect the accuracy of observation. The survey instrument offers different level of accuracies depends on the technology and the method applied. Data processing such as adjustment method and mapping technique provide different result of accuracy. One source of error may lead to another error which is called error propagation. Cadastral survey and mapping contains the combination of errors and influence the quality of cadastral dataset. By recognizing the errors, the map can be used in accordance with the tolerable level of accuracy and type of requirement.

2.2.2. Change of Cadastral Map

Cadastral data dynamically change due to population growth, land transaction, land use, conflict, environmental change and disaster. This condition should be coupled with the adequate ability to collect and update data, both the ability of the methods, tools and human resources. The National Research Council (NRC) of United States of America (USA) reported that the change of cadastral data occurs since there are numerous transactions that change the boundaries and its attributes (NRC, 2007). According to the report, cadastral map should be updated regularly due to change of cadastral data caused by "new subdivisions, annexations, corrections and other routine modifications". NRC reported that the local government in USA maintains these updating to support the local business processes that require current and accurate information.

According to Zevenbergen (2002), the updating of the existing parcel registration is considered a subsystem of the dynamic land registration model. He described 2 (two) varieties of updating: first is transfer of right and second is subdivision or consolidation. The first variety deals with the change due to a transfer of right without change of property unit. The second variety deals with the changes of boundaries of the property unit and usually including the updating of cadastral map. The transfer of the right is the most common case of updating compared with subdivision or consolidation. However, the subdivision and consolidation is also an important process because it is accompanied by the formation of a new property with the change of spatial and attribute data attached on it.

In most cases, the new boundaries as results of subdivision have to be determined by geodetic survey, but in a rare exception cases, an (aerial) photograph can be used to do this in the office as long as the existing topographic features are visible (Zevenbergen, 2002). Take a sample in The Netherlands; the measurement and registration of cadastral boundaries has 2 (two) aims: to enable splitting for creating and registering a new parcel, and to reconstruct boundaries between properties with sufficient accuracy (Lemmens, Lemmen, & Wubbe, 2007). For the second aim, the reconstruction of a boundary in the field is not based on the cadastral map but based on the original survey boundary taken from terrestrial measurement (Zevenbergen, 2002). Therefore, photogrammetric measurement (ortho-image and oblique-image) is not suited for terrestrial measurement but suitable enough for splitting and creating parcel formation in case of subdivision (Lemmens, et al., 2007).

Navratil et al., (2004) stated that the changes of cadastral data have to be documented properly. Cadastral documents become representations that describing cadastral data. They divided the cadastral document into 3 (three) categories:

1. Legal changes which consist of 3 (three) types: transfer of right, establishment of right and deletion of rights.
2. Changes of technical data, for example the change of number of areas after subdivision and the change of land use.
3. Changes of additional data, neither legal nor technical data, such as postal code.

Heo, Kim, &Kang (2006) have studied the dynamic change of cadastral data. They have a specific definition of spatial and attribute data change. They defined the change of cadastral data into 2 (two) categories:

1. Spatial Data Change; in a parcel-based LIS means changes of parcel boundaries. The typical changes are:
    a. Natural changes: land movement caused by nature (e.g. landslide, earthquake, volcanism)
    b. Boundary relocation: moving of physical objects considered as boundaries such as for resolving legal conflict
    c. Parcel evolution: subdivision and consolidation
    d. Surveying observation: boundary changes affected by change of reference points.
2. Attribute Data Change; caused by legal and administrative actions such as transaction, public purposes and mortgage.

These changes imply the need for updating cadastral maps. According to their investigation, some requirements for a temporal parcel-based LIS which deals with change of cadastral data are: automatic updating of cadastral maps, spatial data consistency checking, blunder detection and identification of spatial discrepancy.

Updating cadastral data in term of updating parcel boundaries related with the system to identify a parcel: "graphic cadastre" and "numeric cadastre" (Zevenbergen, 2002). In the graphic cadastre, the updating has to be based on the notes and sketch of original survey, and then it should be depicted in the cadastral map. In the numeric cadastre, the updating is based on "the set of coordinates from the boundary point represented a parcel".

Type of cadastral data and cadastral map affected to the updating process. The main purpose of updating is to inform the changes in the field into the database. The equipment and methodology of updating should be compatible with the existing cadastral map and the database. The updating process has to concern on how to provide streamlining and correct information of changes with a certain level of information to maintain the quality of information on the database ((Dale, 1995); (Haanen, et al., 2002); (NRC, 2007)).

2.3. Digital Data Collection for Updating Cadastral Maps

A modern LIS applies a modern information technology in data collection, storage, data analysis and dissemination of information. This has to be built using a computerized system that has digital databases and ICT to provide reliable and timely information for the user. In some countries such as USA, Netherlands, Canada and Australia have developed a modern LIS to maintain their cadastral data. However, the common problems for building a LIS in developing countries is the availability of digital data which are up to date in order to have an efficient GIS/LIS operational (Bishop, et al., 2000).

Digital data format allows effective and efficient data management including data sharing and data access. Cadastral maps in digital format can be rapidly maintained and updated. Therefore, analogue format in the paper based (both spatial and textual) should be converted into digital format to meet with computerized system requirements. Analogue format has weaknesses such as large of storage space, lack of updating, difficulties in sharing, weak of security, vulnerable to fraud, possibility to disappear, and slow of access.

A step forward to obtain digital data in the field is linking between field data and office database. Dale (1995) mentioned some advantages of automatic data collection: reducing human errors occurring in writing and transcribing data, and facilitating the transfer of data to computer systems. Australia has introduced the digital data collection in 1990's. Digital surveying had been integrated in the DCDB project for updating the cadastral information directly to eliminate digitization or numeric input (Williamson & Hesse, 1990). New Zealand, for example, has applied automatic data collection through the Landonline program which has aims to automate the nation's survey and title system (Haanen, et al., 2002). Cadastral survey information can be validated and transferred electronically through the system for updating geodatabase.

Data collection technologies for digital cadastral mapping commonly can be obtained from several methods:

1. Terrestrial survey (total station, GPS, PDA, tablets PC)
2. Photogrammetry (aerial or space imagery)
3. Scanning and Digitisation (vectorization)
4. Radar (Radio Detection and Ranging)
5. LiDAR (Light Detection and Ranging)

Those different technologies are applicable for different nations but depend on their laws, traditions, infrastructures and factors influenced to the adaptation of the methods (Gustafson, 2005). The type of cadastral data and the purposes of the cadastral map also influences the technology used. Digitization and numeric input are common methods to convert paper-based maps into a digital format. Paper maps are scanned and digitized using vectorization method, textual data may be converted by manual input using keyboard. Improvement of accuracy or the completions of the cadastral map are separate processes. Radar and LiDAR equipments are still considered costly. Recent technology of terrestrial survey to obtain a high spatial accuracy is time consuming and costly, therefore the use of photogrammetric methods is considered more rapid and cost effective (Konecny, 2009). Photogrammetric methods have been used in several countries to accelerate the land registration process. Aerial photos or satellite images combined with other data collection technologies served as a base map are offering effective cadastral mapping processes ((Konecny, 2009); (Raju, et al., 2008); (The World Bank, et al., 2010)).

An attempt to utilize satellite images combined with ordinary pens for recording cadastral data changes emerged in Indonesia in 2005. After the tsunami in 2004 in Aceh, the government had a responsibility to update all land records and cadastral maps which had been destroyed through adjudication. The main information sources about the post-disaster situation has been are mostly provided by communities. A new approach has been applied called Community Driven Adjudication (CDA) or also known as Community Base Mapping (CBM); combining local spatial knowledge and geo spatial technology to reconstruct land administration systems in Aceh (Haroen, Achmad, & Rusmawar, 2006).

Before the adjudication, the community makes a "community agreement" regarding the boundaries of the parcels, the ownership and the sketching of all land parcels (basic map). Parties involved in this process are local community, government, donors and NGOs (Non-Governmental Organizations) as a facilitator. The agreement becomes the reference for the National Land Agency (NLA) [2] on the adjudication activities. NLA provided the necessary materials such as administrative and legal forms as well as the basic map based on the satellite imaging. Quickbird panchromatic (0, 61 m resolution) and Ikonos panchromatic (1 m resolution) have been used in the CDA. For the image processing, Ground Control Points (GCP's) have been obtained from GPS measurements; and the Digital ElevationModel (DEM) has been obtained from topographic maps scale 1:25000 combined with terrestrial surveying. The images were

[2] NLA is the English version of Badan Pertanahan Nasional (BPN), an institution which is responsible for land registration in Indonesia.

plotted in scale 1:2500 on A0-size inkjet glossy papers. Community aided by facilitator identified and demarcated village boundary and parcel boundaries on the top of base map using a pen. Parcel identifier and the owner were simply added inside the parcel or listed on the backside of the map. The identification might took place in the "meunasah" (kind of mosque in Aceh) or in the adjudication base camp. The agreed base map together with other requirements for community agreement was submitted to NLA. Besides as a reference for the field survey, the base map was also used for work planning and work evaluations.

The World Bank study (2010) described the use of photogrammetric method combined with ordinary pens for cadastral purposes in Namibia, Ethiopia and Rwanda. In Namibia, aerial photographs have been applied for updating cadastral maps digitized from handheld GPS for accelerating communal land registration (Kapitango & Meijs, 2010). Based on the concept of the general boundary system, the accuracy to identify the location of boundaries is considered to be sufficient to avoid overlapping claims and to ensure that the right person is allocated to the right parcel. In Ethiopia, Quickbird satellite imagery has been tested as a base map for establishing a parcel index map (Lemmen & Zevenbergen, 2010). The test found that satellite images can support the data collection for land registration by participatory approach, producing field evidences from the field and relatively easy to process. In Rwanda, satellite images and/or aerial photos have being used for demarcating parcel boundaries (Sagashya & English, 2010). The method was suitable when applied in the general boundary principle where "boundaries incorporated as social rather than technical boundaries".

Photogrammetric innovation offers various low-cost data sources, from a low-cost satellite image and Small Format Aerial Photo (SFAP) to free-cost geospatial information provided by Google Earth (Google), Bing Map (Microsoft) or World Wind (NASA- National Aeronautics and Space Administration). Google Map, for example, has covered a whole area in the world with satellite imagery including a high resolution satellite images from Digital Globe. Those data source might be combined with other free-data sources such as a free Digital Terrain Model (DTM) from NASA or from Shuttle Radar Topography Mission (SRTM) for geo-processing. A base map produced by photogrammetry might be combined with other data collection technologies to meet with the requirements. Cadastral data acquisition can be based on free available imageries. The geometric accuracy of boundary points can always be improved later. Cadastral maps based on the free imageries are mostly relevant to object identifications.

Issues considered the need of a high accuracy of photogrammetric products in cadastral maps is always rising. Nevertheless the possibility of photogrammetry to increase the image resolution and the innovation of the method combination provides significant contributions for "standard-sized land parcel (spatial units)" survey and mapping (Lemmen & Zevenbergen, 2010).

3. THE DIGITAL PEN SYSTEM

This chapter is intended to provide some literatures about the digital pen systems for geospatial data collections. The first and second session introduces the digital pen system consisting of the digital pen technology (from Adapx) and the digital paper technology (from Anoto). The third session describes some use cases of the digital pen in GIS contexts. Based on the use cases, some claims have been identified in the third session. The last session presents a classification of claims according to the criteria for the evaluation.

3.1. The Digital Pen Technology

A ballpoint pen is known as a useful tool to create a note in a piece of paper in human daily life. In cadastral applications, the pen and paper method have been combined with photogrammetric methods in cadastral surveying and mapping (The World Bank, et al., 2010). Boundary demarcation using an ordinary pen drawing on the top of an aerial photo or satellite images becomes an alternative approach for an effective and efficient data collection in terms of simple, fast, cheap, error avoiding and participative.

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

Schreiner (2008) listed several companies which have developed the digital pen-paper technology that basically can be used for collecting spatial data, but they did not integrate it with a geospatial software platform for data processing. In the technologies from those companies, the geospatial data drawings are recognized as handwriting without a georeference system. The data is also not yet compatible with the geodatabase format such as GIS or CAD.

In the 2008's, a company based in Seattle, USA named Adapx developed a digital pen technology which can be used in many applications including geospatial data collections. The digital pen for geospatial data collection has capability to directly record spatial data (points, polygons, lines) and attribute data in a digital format. With this capability, data can be processed with both CAD and GIS software to build a database of LIS simultaneously with field data collections. The Adapx collaborated with ESRI to develop a digital pen technology integrated with ArcGIS called Capturx for ArcGIS Desktop. The digital pen technology from Adapx consists of 2 (two) components: a digital pen called Penx and a Capturx software as an extension of ArcGIS version 9.x. The combination of Adapx components allows a direct georeferencing of field drawings in ArcGIS.

The Penx is an electronic pen equipped by a lithium ion battery, an integrated digital sensor (optical lens and filter assembly), an advanced image microprocessor, internal memory, mobile communication device for wireless connection (Bluetooth) and pen cartridge (Adapx, 2010b). Figure 3 shows the main components of the digital pen (Penx). The additional specifications of the Penx as published by Adapx are (Adapx, 2010b):

1. Compatible with "Fisher" pressurized ink pen cartridges, filled with "Rite in the Rain" proprietary ink, which is enable to write in any writing position and in any weather condition.
2. Built in lithium-ion rechargeable battery which can stay charged for up to 10 days of typical use; operation time 4 hours.
3. Charging time approximately 2.5 hours (150 min), from 0% to 100% via cradle and USB adapter.
4. Weight 30 gram; dimensions 153 x 19 x 17 mm without cap; 157 x 21 x 18 mm with cap.
5. Data Communication: USB 1.1 and USB 2.0; standard Bluetooth 1.2.
6. RoHS (Restriction of Hazardous Substances) compliant with European Union directive 2002/95/EC.
7. Working from 0° to 40° Celsius at relative humidity levels of 10-85%.
8. Can be stored between -20° to 45° Celsius at relative humidity.
9. Pen can be used in inclement weather and rain, but is not submersible (underwater).

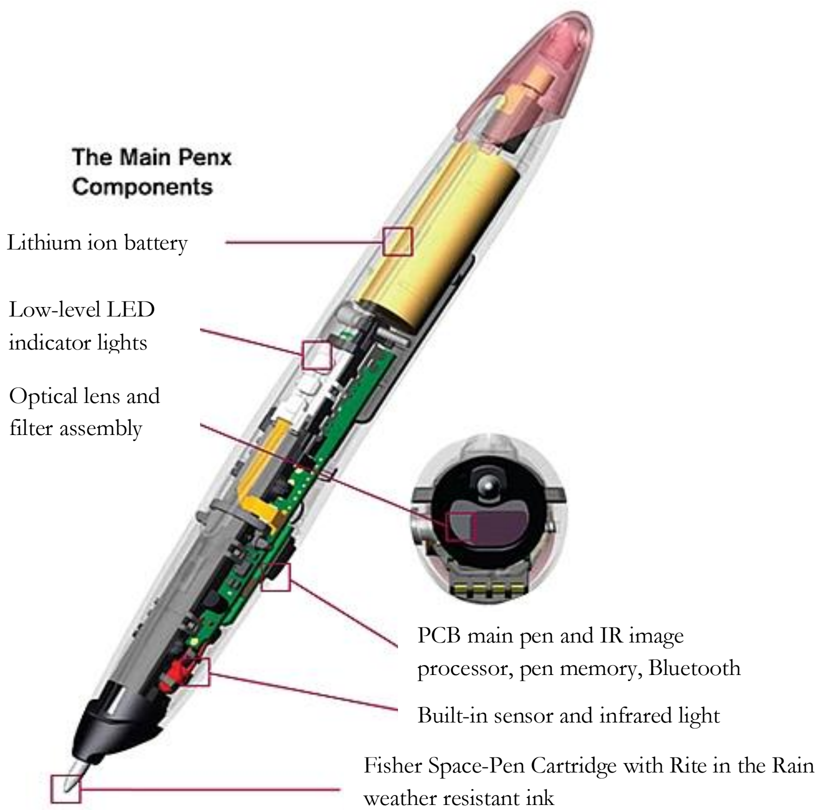

Figure 3. The main component of Penx (Source: Bell (2008)).

Penx works in the same way as scanner. Moreover, each stroke of the pen in the paper consists of writing (drawing), scanning and digitizing at the same time. The digital sensor automatically scan the movement of the pen in conjunction with the patterns at a rate of 75 snapshots per second (Roe, 2009). The "accuracy" defined by Adapx in terms of limit of resolution that the digital pen can detect is around 1.0 mm which is the total summary of 2 (two) conditions (Adapx, 2010d):

1. The errors affected by the Anoto pattern average resolution is 0.3 mm,
2. The maximum errors in calculating the location of the digital pen and the dot pattern is 0.7 mm (varying depends on the angle of the digital pen against the paper; the pen has a field of view of 7 mm^2).

3.2. The Digital Paper Technology

An ordinary paper becomes "digital" when it is watermarked with the Anoto pattern[3] (Schneider, 2008). The pattern consists of numerous tiny black dots (100 micrometers in diameter) arranged in near each intersection of grids with a spacing of approximately 0.3 mm (Livescribe, 2010a). Figure 4 shows the arrangement of the dots configuring the Anoto pattern.

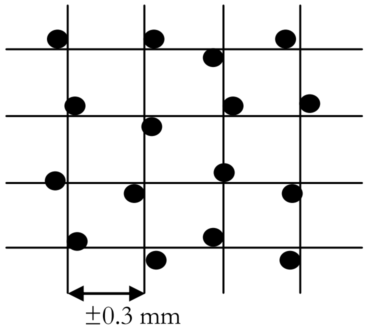

Figure 4. The Anoto dot pattern (copyright by Anoto).

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 colour ink that reflects infrared light in order to be recognized by pen's sensor. The pattern can be printed in the different types of paper which meets with Anoto's pattern enabling requirements (Adapx, 2010c), which are:

1. Opacity at least 88%, this aims to block the pen so it does not see another print (on the backside of the paper if double-side printed or on the following page),
2. Colour must have high reflection in the Infra-Red wavelengths 800– 950 nm,
3. Surface roughness between 100– 400 ml/min (Bendtsen scale[4]),
4. Uncoated paper with weights more than $60g/m^2$.

3.3. Use Cases of Digital Pen in GIS Context

In the 2008's, Adapx started to promote the digital pen technology for GIS (i.e. Capturx) in one integrated package. The intensive publications about the digital pen and its use cases by the digital pen's provider aim to attract users who need an alternative method for spatial data collections. Based on the literature searching, most publications of Capturx for the GIS data collection are online publications coming from Adapx. Even, some other publications in GIS magazines, online news and online reviews are basically similar with the publication from Adapx.

The use cases of the digital pen illustrate the capability of the pen to record features in a GIS context. Although GIS and LIS have different type of purposes, the use cases are useful to test the capability of digital pen in the LIS context because GIS and LIS have the similarities in terms of recorded features, which are:

1. Record spatial and attribute data,
2. Geometric characteristics of features (spatial) are represented as point, line and polygon,
3. Information about features (attributes) is described in quantitative or qualitative value.

[3] More information about the Anoto pattern can be found at http://www.anoto.com/the-paper-3.aspx.

[4] Bendtsen scale is measured using the Bendtsen surface-roughness tester. The roughness of paper is assessed by measuring the flow of air which passes between the edge of a measuring head and the surface of the material under specified conditions (SCAN, 2002).

The use cases are grouped into 4 (four) main applications which are engineering services, GIS survey and mapping services, emergency responses and facilities management. Among those cases, most of them are applied in the USA.

3.3.1. Engineering Services

Digital pen has been used in engineering for civil constructions and environmental projects. Geospatial data management in engineering works is including data collection on site, data processing in back office and inspection for updating data.

Bell (2008) reviewed the digital pen for planning for downtown Las Cruces, USA. The planning aimed to open a main street so that all commercial buildings will have frontages on the main street. Any information from stakeholders (utilities, fire department etc.) is drawn on the map. Engineers can check the information in the exact location for establishing the planning for the new road. The result can be reviewed by the stakeholders in the same drawing as shown in the Figure 5.

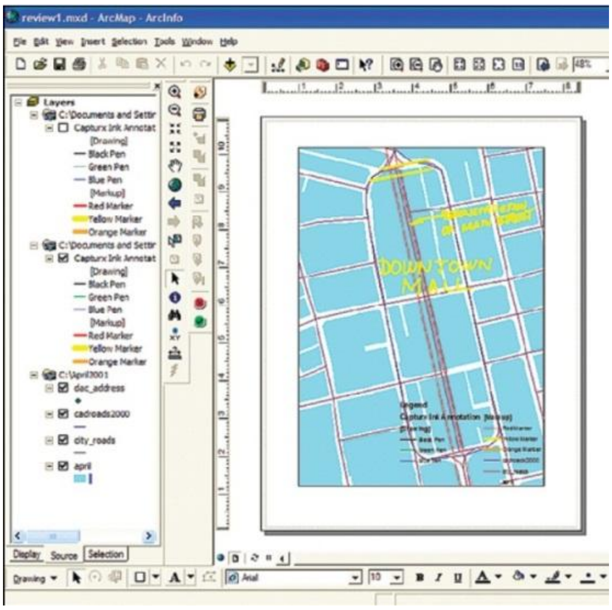

Figure 5. A plan mapping use the digital pen reviewed in ArcGIS (Source: Bell (2008)).

Schneider (2009) stated that the main requirements of geospatial data software for engineering are streamlining data access from project site to project office and compatibility of data with engineering data. He took a sample of Thiess Company who used digital pen for transportation projects in Australia. Staff members used the digital pen technology from Adapx for planning purposes. They marked-up geographic features (such as a design of plantation trees within the road corridors) on a base plan map drawing necessary information. Data were automatically stored in the pen and continuously uploaded into the geodatabase.

Another case described in the Adapx publication (2010a) is using the digital pen for a water reservoir development plan by Freese & Nichols, Inc. During the work, the staff worked on zoning and land use overlaying in the planning phase, checking for soil type and also taking inventory data such as trees surrounding the water reservoir. The staff only needed to mark up, draw and to make inventory of the geographic features on the map and automatically converted into digital format.

3.3.2. GIS Survey and Mapping Services

The main challenge of the digital pen in GIS mapping services is for updating digital maps (Adapx, 2010a). The application for updating maps is started by marking up (on a paper map or an image) changes of spatial data and annotations in the field. The rest of works such as editing and manipulating would be done in the back office operation.

The Natural Resources Conservation Services of United States Department of Agriculture (NRCS) has been used the digital pen for a soil survey (Price, 2010). The aims of the survey was to maintain (adding, deleting, changing and updating) the spatial and attribute data soil survey. The surveyor draws features that can be point, lines, polygon and annotations on the map. The data collected are new features, reshaped features or edges, polygons cut, polygons merge and added or changed annotations. Figure 6 shows a sample when the surveyor cut the polygon number 144 then add a new symbol for the new polygon number 145. All of the data were edited in ArcMap. The spatial data were directly updated into a database using an editing toolbar; however, annotations/symbols should be updated manually by entering the data into the attribute tables.

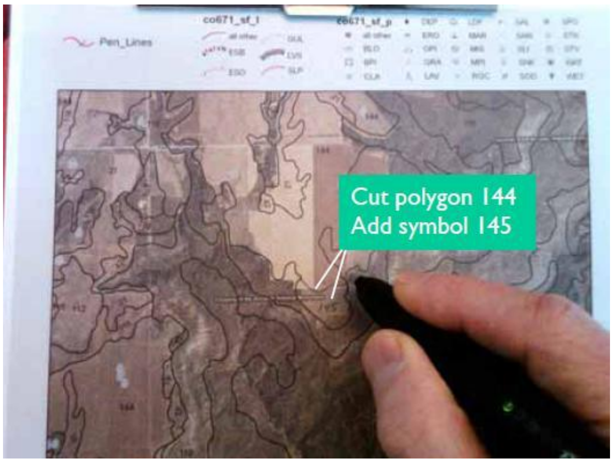

Figure 6. Using the digital pen for a soil survey (Source: (Price, 2010)).

Bell (2008) described experiences of two companies: Young and Associates (Y&A) and Digital Mapping Services (DMS) in data collections using the digital pen. Y&A was using the digital pen for a land development surveying as well as for oil and gas surveying, while DMS using the digital pen for the GIS mapping part. These companies mainly use the digital pen for updating existing GIS maps such as urban sign maintenance, sketching a pipeline routing, adding information on aerial photos which did not provide enough details; and updating out of date maps.

3.3.3. Emergency Response

An access to quality (up to date, complete) geospatial information is useful for preventing incidents and preparing emergency responses (Adapx, 2010d). The information is mainly about critical infrastructures and key resources

The Arizona Fusion Center (AFC) in Phoenix, USA is using the digital pen for automated geodatabase updates based in a GIS (Adapx, 2010a). During some incidents (crowd managements, natural disasters, emergencies), AFC needs up to date information about conditions in the field such as critical infrastructures around the site, building and access surrounding. The information will be shared with other agencies to help coordinate emergency planning and operations.

The City of Nashua, USA used the digital pen as a part of the training exercise to test the response to terrorist attacks (Marino, 2009). During the exercise, several agencies (the police, the fire department, Red Cross and other county organizations) capturing any change of information related to terrorism threats almost as fast as it happened in the field. Information captured on the map such as the location of explosive devices, fires, terrorists, roadblocks or checkpoints could be automatically added into geodatabase. All agencies involved in the exercise could immediately access the information through ArcGIS for simulation and making decision such as where to places barricades or what areas needed to be evacuated.

The City of Boise, USA is using the digital pen to provide the most recent information about routes, conditions and infrastructures to support emergency responses (Adapx, 2010a). The information was stored in the GIS and needed to be updated frequently. Fire brigade; for example; using the digital pen for updating the information such as fixing incorrect placement of fire hydrants and waterways on the map.
The Santa Barbara City Fire Department, USA is using the digital pen for collecting geospatial data in pre-fire surveys, fire operations and post fire assessments (Hoose, 2010). In pre-fire surveys, the team collects data about areas or structures that are defensible, indefensible or stand alone, geographical data such as hazard areas, water resources and safety zones to protect citizen, properties and crews. In fire operations, the team collects data about fire spreads and track crew's location. In post-fire assessment, the team collects and documents the destruction to produce a structure damage assessment map.

The Port of Seattle is using the digital pen for continually updating changes and modification of emergency facilities within the airport (Adapx, 2010d). The GIS department of the port has to provide up to date map of facilities especially for emergency response such as more than 1000 fire extinguishers and more than 200 portable defibrillators (electrical equipment to shock the victim of heart attack) spread in 35 floors. The map aims to help emergency team to determine the correct location of emergency facilities.

3.3.4. Facilities Management

The main purpose of digital pen in facilities management is to automate facilities data collection (Adapx, 2010d). The automatic data collection provides a streamlined data. Sharing information can be immediately accessed. This data is used for planning, inspecting, updating assets and maintenance.

The GIS team from NASA is using the digital pen for collecting geospatial data in their research centre campus (Adapx, 2010a). The ArcGIS database of the building interior details was often out of date because of manual data input. Staffs were collecting features data on maps around the campus. Unfortunately, the publication does not clearly mention certain information about type of features collected.

The Surface Water Management Division of Public Works in Snohomish County, Washington is using the digital pen for managing up to date information of drainage systems, storm water discharges and water bodies maintenance (Adapx, 2010a). All of the data changes are recorded on the paper maps. Unfortunately, the publication does not clearly mention the type of data changes and the map format used.

3.4. Claims on the Use of the Digital Pen

Most of the publications describe that the main purpose of the digital pen is for updating a geodatabase. Sample cases of digital pen in several publications are a kind of repetitions and look like "advertisements". Publications of the use cases of the digital pen promote some claims which are always strongly pointing on its benefit. The claims based on user experiences on the use of digital pen published by Adapx (and its partners) are:

1. Improve the mobility data collection because the pen is handy comfortable and durable,
2. Reduce complicated procedures, so ease and simplify the data collection,
3. Accepted by people who are familiar with the pen and the paper, so no special training required,
4. Allow sharing up to date information by providing streamlined information in ArcGIS format,

5. Collect faster because data can be directly entered into database without a re-entry process so eliminate the gap between data collection and data upload,
6. Reduce errors because features can be recorded digitally without manual entry (as an extra step) which can cause transcription of errors.
7. Improve accuracy because data already georeferenced, and;
8. Provide digital and hardcopy backup.

In their white paper, Adapx compared the digital pen with other electronic equipment such as PCs, tablets and PDA's (Adapx, 2010d). PC and tablet are heavy, expensive, with limited battery life, limited screen view in the bright sun, training required and often resistance of staffs because of change in technology. PDA has a limited screen view and training is required. Adapx claims that the digital pen offers better solutions for those problems by introducing the naturally best known method: pen and paper. The digital pen system treats pen as an intelligent data recording and paper as a computing device. Geo Informatics (2007), reviewed more specific claims of the digital pen which are :
1. The digital pen is a human-centered technology which allows people who are used to collect paper-based data to adapt a digital data collection without an excessive training.
2. The digital format of notes keeps the information safely even if the paper maps are destroyed or lost; (a new map can be re-printed as needed).
3. The digital pen can still recognize the pattern of the map although it is folded, crumpled, wrinkled, wet, or even in pieces: as long as pre-printed dots are discernable.
4. Reduction of possibility of errors, duplication and redundancy, time and cost by providing up to date data and leaving out re-keyed in data from manual to digital format.
5. Filling with "Rite in the Rain" proprietary ink which allows the pen to write in any writing position or weather condition.
6. Holding battery charge for five to seven days and can be recharged any time it's docked (without data loss).
7. Storing up to 50 pages of letter-sized paper at a time.

3.5. Claims in Terms of Fit for Purpose

Based on the previous claims, the digital pen is useful for digital data collections by marking up the geographic features to update the geodatabase in the GIS context. The performance of the digital pen has been evaluated using the fit for purpose method to prove whether the claims are applicable in the LIS context. The method consists of 5 criteria which are usability, functionality, reliability, accuracy; and compatibility (see Chapter 4 for details). For the evaluation purpose, the claims were categorized based on those 5 criteria which are:
1. Usability: the design is simple, comfortable and handy; the digital pen is user friendly because it is accepted by people who familiar with write and work on paper, so no need an excessive training.
2. Functionality: the digital pen is simplifying the process because automatically scan the handwriting and integrate the data into ArcGIS, saving time because no need re-key entered data, and providing real-time and continuous data collection.
3. Reliability: the digital pen deals with various environmental conditions, and provides both analogue and digital backup data.
4. Accuracy: the digital pen is accurate enough both in terms of spatial accuracy; and avoids errors when doing a manual key-entered data.
5. Compatibility: the digital pen is equipped by intelligent software which is compatible with the GIS data format.

4. METHODOLOGY OF THE PERFORMANCE EVALUATION

This chapter provides an overview of the methodology to evaluate the performance of the digital pen[5]. The first session explains the evaluation method and its criteria. The next sessions explains the field test to apply the method; consisting of components reviews, preparations of field test simulations, capturing data, processing data, test of reliability and test of accuracy.

4.1. Evaluation Method

Claims[6] of the effectiveness and efficiency of the digital pen in the GIS context have been tested whether applicable in the LIS context. A field test has been arranged to perform the evaluation. The findings from the field test have been analysed using the fit for purpose method. The method is synthesized from several studies which have evaluated the performance of survey equipment. These studies have various sources (disciplinary), equipment, concept, definition and operational. The synthesis of performance assessment and evaluation is summarized in Table 2:

Source (disciplinary)	Equipment	Concept	Definition	Operational
(Mason, Rüther, & Smit, 1997) (Photogrammetry and Remote Sensing)	Digital Camera	Investigation of the use	Accuracy	Small format mapping in informal area
(Ochieng & Sauer, 2002) (Survey & Mapping)	GPS	Performance Investigation, Evaluation	Accuracy, Integrity, Continuity, Availability	Urban road transportation navigation
(Ruzgiene, 2005) (Geodesy & Cartography)	Non Metric Digital Camera	Performance Investigation, Evaluation	Stability, Accuracy	Modelling, taking stereo images
(Clegg, et al., 2006) (Computer & Geoscience)	Tablet PC and PDA	Performance Evaluation, Assessment	Portability, Performance, Reliability, Operating System, Functionality, Usability, Project set-up, Compatibility, Accuracy, Precision	Mapping geological features
(In-Su & Linlin, 2006) (Survey & Mapping)	GPS-RTK	Performance Assessment	Accuracy	Testing in two different conditions, different season

Table 2. Performance assessment and evaluation in several studies.

[5] The digital pen in this evaluation is the Capturx digital pen system from Adapx.

[6] Claims mean claims as described in chapter 3.5.

The table shows "the pattern" on how the authors evaluate the performance of survey equipment. The pattern delivers to the insight that most of the authors described the performance as "*the capabilities of an instrument for capturing data based on some tests or practical applications in the field and applied a model or a method to evaluate the result"*. The insight can also be adopted to evaluate the digital pen. Authors define the terms of performance and its criteria in various forms based on the purpose of assessment.

Clegg et al., (2006) have been evaluated the performance of tablet PC and PDA which consists of hardware and software for Digital Geological Mapping (DGM). The evaluation uses the fit for purpose method derived from the definitions of a performance evaluation. The method from Clegg et al., have been adopted to evaluate the performance of the digital pen because it has the most comprehensive definitions. 5 (five) criteria of the fit for purpose method by Clegg et al., have been selected with some modifications in accordance to the claims of the use of the digital pen in the GIS context and characteristics of the digital pen. The criteria are:

1. ***Usability***; evaluate the familiarity of operation of the digital pen for the user.
2. ***Functionality***; evaluate the capability of the digital pen to capture types of cadastral data.
3. ***Reliability***; evaluate the ruggedness of the digital pen in various environmental conditions.
4. ***Accuracy***; evaluate the positional accuracy and of the digital pen.
5. ***Compatibility***; evaluate the integration of the data format of the digital pen with other applications.

The field test to evaluate the performance of the digital pen based on those criteria has been arranged consisting of two parts: a component review and simulations.

4.2. Components Review

Equipment selected for a field data collection in cadastral mapping can depend on several conditions such as the cadastral system, regulation, budgeting, environment (topography, climate) and social culture; among others. Characteristics of the components of the digital pen (hardware and software) become a consideration to be applied on these conditions. The first part of the field test is the component review. This review aims to identify the particular parts of hardware and software; and to recognize the characteristics of the component during the test.

a. Penx

A digital pen branded Penx is the main component to be reviewed. In a package of Capturx, this pen is equipped by a docking station base, a docking station insert, USB cable and replacements ink cartridges (see Figure 7). The review of Penx aims to evaluate the functionality and the usability based on its specifications and its principal works. The review is done by comparing the specifications and the works principal of the digital pen with ordinary pens which has been applied in cadastral mapping.

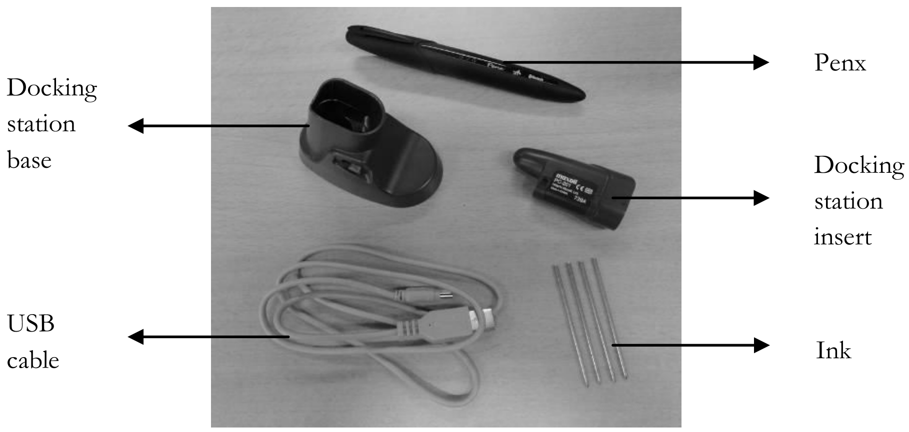

Figure 7. A digital pen set.

b. Digital Paper

The field test used a standard paper for a laser printer and photocopy (bright white paper with opacity 91% and weight 80g/m^2). This kind of paper is commonly used and widely available. The review checked whether the standard paper meets with requirements for enabling the Anoto pattern. The review also explored the impact of Anoto pattern overlaid on the top of the aerial photo printed on standard paper.

4.2.1. Software

Capturx for ArcGIS Desktop version 1.1 with a single user license has been used in this field test. The Capturx for ArcGIS Desktop package is an extension of ArcGIS version 9.x. This software is equipped with Adapx PenxCPL as software for the pen management. The Adapx PenxCPL is software which has main functions to manage settings of Penx and as interface software for bridging connectivity between the Penx and the tablet PC through a USB port. The Capturx for ArcGIS Desktop sticks on ArcGIS 9.3 as an extension with several menus such as create legend, import session, review session and print map. Capturx for ArcGIS Desktop package has a limitation for recording attribute data. This package records attributes data as spatial features (e.g. line/polyline). The review is mainly focus on the roles of Capturx for ArcGIS Desktop in the digital pen systems apart from the roles of ArcGIS as the main software. The roles have been observed based on the main functionalities of Capturx for ArcGIS Desktop for preparing and processing spatial and attribute data.

4.3. Preparation of Field Test Simulations

The second part of the field test is simulations. The preparation aims to ensure that materials and resources are ready to perform simulations as a part of the field test. The preparations consist of two parts: selecting a sample area covered by the existing cadastral dataset and the aerial photo; and processing the materials for making field maps.

4.3.1. Sample Area

The cadastral data changes are simulated in the field test. Attempts have been made to make the simulation as close as possible to the reality as by using existing cadastral dataset from Enschede. The sample areas for the simulations are clustered in a location within one of neighborhoods covered by the existing cadastral map and the aerial photo. The chosen neighborhood is Horstlanden, Stadsweide as seen on Figure 8. This area consists of various landscapes necessary for the simulations including open areas, settlements and networks.

Figure 8. Sample area.

4.3.2. Materials and Resources

The cadastral dataset used for simulations in this field test contain of vector data and raster data (aerial photos). The cadastral dataset illustrates the existing cadastral information, while the aerial photo from a later date serves as a base map for collecting any data changes that occur in the field.

The identification of the cadastral dataset is:

1. Product : National Cadastre Database
2. Scale : 1: 1000
3. Description : Cadastral data of the municipality of Enschede
4. Source : Aerial survey and field survey
5. Year : 2007 (Metadata Entry)
6. Base : Digital topographic data 1:1000
7. Copyright : Topografische Dienst Kadaster
8. Projection system : RijksDriehoekstelsel (RD-stelsel)

The identification of the aerial photo is:

1. Product : Large Format Aerial Photo of Enschede
2. Year : 2008
3. Resolution : 0.10 meters
4. Camera : Digital Aerial Camera, UltraCam D, S/N UCD-SU-1-0037
5. Projection system : RijksDriehoekstelsel (RD-stelsel)

The cadastral dataset of Enschede covers all lands as parcels. For the purpose of the field test, cadastral data were stored in a geodatabase. Spatial boundary data as well as parcels were stored as polygons. Additional tables were created to accommodate the test for capturing point, line and attributes. Both the cadastral dataset and the aerial photo were processed using ArcGIS installed in tablet PC and printed using a laser printer to produce the field maps. The specification of the equipment is shown in Table 3. The specifications of the tablet PC meets with the minimum configuration as required by Capturx. For the printer, there are specific requirements in order to enable the digital pattern to be printed properly. It should has 4-color postscript functionality, carbon-based black ink (yellow, magenta, cyan) and 600x600 dpi (dot per inch) resolution (Adapx, 2010c). Therefore, a black and white printer and an ink jet printer cannot print the digital paper.

Equipment (Tablet PC and Printer)	Minimum Requirements (based on ArcGIS 9.3)	Specifications
Processor	1.6 GHz (higher recommended)	Intel Pentium M 760/ 2.0 GHz
Bus	USB 1.0 and 2.0	USB 2.0
Memory	1 GB (2GB recommended)	1 GB DDR-2 SDRAM
Hard disk	3.2 GB (with 500 MB swap space)	80 GB 5400 RPM (with free space 17 GB)
Drive	CD/DVD ROM	CD/DVD ROM
Display	1024 x 768 pixels	SXGA+ 1400x1050 pixels
Operating System	Microsoft Windows XP Service Pack 2, Net 2.0	Microsoft Windows XP Service Pack 3 Tablet PC Edition Version 2005
Printer	Post Script Level 2, 600x600 dpi resolution, postscript functionality, carbon-based ink	Xerox WC7435 laser printer 2400x1200 dpi resolution, postscript functionality, carbon-based ink

Table 3. Specifications of the tablet PC and the printer.

The field map layout has been designed using ArGIS and Capturx (to enable the Capturx functionalities). The layout of the map aims to present a layer as a visual representation of map that covers an area of interest. The layout setting consists of map body, map elements and map information. As a map element, the legend has a special attention in the layout design because plays an important role to enable the Capturx functionality. Legend refers to features that belong to a layer. It shows the number of layers in the map layout and in the database. Therefore, a certain legend in the map is a reference for updating a certain layer in the database. In the field, the user has to mark up a certain legend before drawing features relating to a certain layer. The detail steps to produce field maps with Capturx functionalities are described in Appendix 1. The aerial photo was printed in A3 paper size in scale 1: 1000 and 1:250 (blow up for detail identification). A3 paper is sufficient regarding to the dimension, the coverage and the availability in the market. Figure 9 shows the design of a field map with the legend created using Capturx functionalities.

Figure 9. A field map for printed in scale 1:1000.

4.4. Test of Capturing Data

This section presents the methodology of the field test simulations for capturing data. Capability of the digital pen for capturing cadastral data was tested to record both change of spatial data (parcel boundaries) and attribute data (identifiers and remarks). Besides parcel boundaries, additional geographic features representing point and line were also collected to accommodate the broader content of information in the cadastral map. The test for capturing data has been arranged as simulations; therefore the data collection and data processing have been performed in the office.

4.4.1. Capturing Polygon

An individual parcel as a unit of land is determined its boundaries and its neighbour relationship. The United Nation Economic Commission for Europe (UNECE) defined parcel as "a closed polygon in the surface of the Earth in unique ownership and with homogenous real property rights" (UN/ECE/WPLA, 2004). In GIS terms, a parcel can be represented as an area which has two model approaches: "polygon-by-polygon representations" and "a boundary model" (Huisman & de By, 2009). The disadvantage of the first model is data duplication because the line that makes up a boundary between parcels is stored twice. The second model which is also called "a topological data model" avoids the data duplication. This model stores a boundary of a parcel once as non-looping arcs/lines/polyline and indicates the spatial relationship between parcels such as which parcel is on the left and which parcel is on the right of a line.

This first test used the polygon-by-polygon representation model to store changes of parcel boundaries. However, to maintain the spatial relationship between parcels and its owners, ArcGIS 9.3 provided functions for topological operations and editing. Changes of parcel boundaries in this field test were simulated based on the 2 of 4 definitions of spatial data change by Heo et al., (see Chapter 2.2.2.), which are boundary relocation and parcel evolution. Those changes are the most common cases to be updated. The 2 other definitions (natural changes and changes in reference systems) were excluded because they occur in specific circumstances such as disasters and change of Geodetic Control Points.

a) Boundary relocation

Boundary relocation caused by deliberate boundaries displacement caused by people. The difference between physical object considered as parcel boundary and the legal boundary may cause a conflict. One of the solutions to solve this problem is boundary relocation based on the legal decision. The new location of boundaries would change the geometric information of parcels involved.

The boundary relocation in this simulation is adapted from a case in Namibia which was updating cadastral maps digitized from handheld GPS (Kapitango & Meijs, 2010). The map should be updated because previous measurements using handheld GPS contain some weakness such as: insufficient waypoints are taken along boundaries and confusing between waypoints for boundary and features in the parcel. This results in differences between physical boundary and legal boundary. All parcels were mapped on large scale orthophotos using an ordinary pen. The analogue orthopotos then were scanned and digitized for updating the cadastral map. In this field test, the simulation aims to update the discrepancy between the legal boundary in the cadastral dataset of Enschede and the physical boundary represented on the aerial photo. In this simulation each parcel was mapped as a polygon using the digital pen on the field map. Boundaries could be recognized on the field map using features such as roads, fences, vegetations and natural depressions.

b) Parcel evolution

Subdivision and consolidation are types of parcel evolution. Consolidation is a merger of two or more parcels. Subdivision is an establishment of new smaller parcels of land within larger original surveyed parcels. This test simulated subdivisions process creating new parcels as polygons.

The subdivision simulations are adapted from the process in The Netherlands described by Lemmens, et al., (2007). Boundary measurement of subdivision process in The Netherlands has 2 (two) main stages: first, buyer and seller carry out "a boundary addressing *(aanwijzing)* " in the presence of a cadastral land surveyor; second, the surveyor measures the boundaries in the field using a terrestrial measurement. Aerial photos can be used as a base map for the boundary addressing process to determine preliminary boundaries. The accuracy of this measurement is in many cases not sufficient for the boundary reconstruction but accurate enough for the parcel formation. The information of preliminary boundaries is stored for updating the cadastral map and archived in the register of Kadaster. Figure 10 shows a sample of a subdivision process using a polygon to determine new boundaries. In this simulation, boundaries of parcels changed because of a parcel subdivision. A surveyor did a boundary addressing to determine preliminary boundaries and parcel formation. Without taking an actual measurement, new boundaries of parcels were identified on the field map by drawing as polygons using the digital pen.

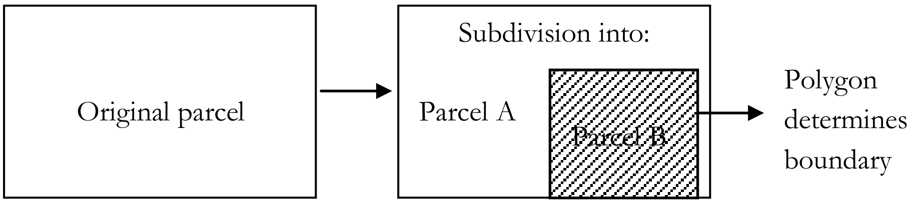

Figure 10. Boundary determination using polygon based.

The pen has been traced along the boundaries of a parcel on the field map to draw a closed polygon. The polygons did not share boundaries with neighbouring parcels. The drawing method for recording parcels as polygons was by free-hand and a ruler. With the free-hand, a surveyor had to make a line as straight as possible to avoid overlaps. A ruler aimed to increase the accuracy by helping the surveyor to make a straight line following the boundary.

4.4.2. Capturing Point

Parcels represented by points depend on the purpose of the spatial information compared to the scale applied to the map. In large scale cadastral maps, a point might serve to identify a boundary point forming a parcel. In smaller scale maps, a point can serve to mark the parcel location.

The test for capturing parcels using points has been simulated also for cadastral data changes called boundary relocation and parcel evolution. The main features to be identified were boundary corner points which are recognizable on the field map. The points were marked using the digital pen. In this case, a point is also used by its neighbouring parcels. Figure 11 shows an example of using points to construct two parcels based on 7 boundary corner points.

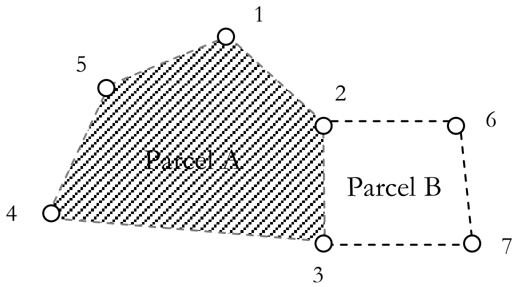

Figure 11. Boundary determination using point based.

The cadastral dataset of Enschede did not contain a table to store point features. Spatial data (e.g. parcels) were stored in the polygon table. However, for evaluating the performance of digital pen to capture points, the boundary points were stored in the point table (see Appendix 1). Construction of parcels using boundary corner points would be compiled later on in the editing process using digitizing methods. The table has also stored other point features as additional data such as electric poles and individual trees.

The simulation used 2 (two) methods of marking: using dots and symbols. The first method was applied for boundary marking. The digital pen marks a single dot (•) and a bold dot (●). The manual imprint was also required to make parcels visible on the field map. This imprint was created by connecting boundary corner points using lines recorded in Capturx Ink Annotation layer[7]. The second method was applied for additional data. The digital pen marks point using symbols which are circle (O), square (□), cross (X) and tick (√) as shown in Figure 12.

[7] Capturx Ink Annotation is a default layer provided by Capturx for marking annotations (see also Appendix 1).

Figure 12. Marking features using various symbols.

4.4.3. Capturing Line

Another representation of a parcel is the boundary model. Van Oosterom and Lemmen (2001) represented a parcel as a minimal bounding rectangle as type “Bounding Box (Bbox)”. The Bbox is indicated by lines which cover boundaries of a complete perimeter of a parcel. This approach is called “the boundary based approach”. The list of boundaries is stored topologically in a table, so that the area features can be obtained. The approach allows classifying the boundaries based on the administrative cadastral and political subdivision in cadastral zones.

The test for capturing parcels using line has been simulated also for cadastral data changes called boundary relocation and parcel evolution (e.g. subdivision). In the simulation of the boundary relocation, the digital pen traced the boundaries along a parcel on the field map to draw boundaries per-line segment formatting a Bbox. In the simulation of the subdivision, preliminary boundaries and a parcel formation are identified by lines. Figure 13 shows an example of the subdivision process using a line. Lines share boundary with neighbouring parcel. The drawing methods for recording parcels and other features as lines are by free hand and a ruler as well as in the test for capturing polygons.

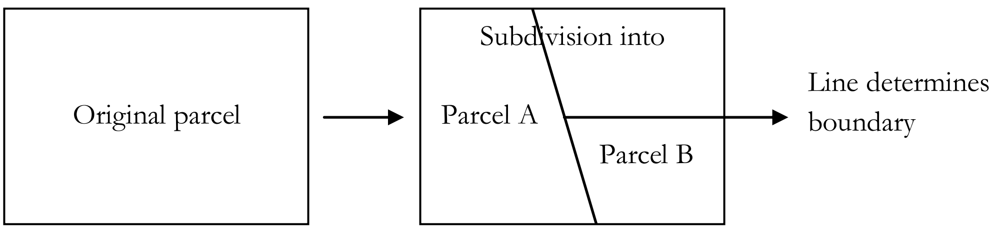

Figure 13. Boundary determination using line based.

The cadastral data set of Enschede covers all segments of land parcels. For example, a road is considered as a two-dimensional parcel. All of spatial data were stored as polygons. However, for evaluating the performance of the digital pen in capturing lines, boundaries were stored in the line table (see Appendix 1). Other additional features representing lines such as railways and network utilities were also recorded in the line table.

4.4.4. Capturing Attribute

A cadastral map should provide the relationship between the spatial data with corresponding registers and other attribute data stored together in a digital cadastral database (Dale, 1995). Spatial data is linked with attribute data which are the descriptive data about parcel; such as subject, right, encumbrances of a parcel (parcel registration) and building, address, postal code, land use (additional data). The link between spatial data and attribute data is arranged through a parcel identifier. Parcel identifiers of cadastral objects or parcels of Enschede is a derived attribute called *object_id* which is a combination of the *cadastral_municipality_code*, *section* and *parcel_id* attributes.

Updating cadastral maps should concern on updating of both spatial and attribute data. In this test, a simulation for capturing attributes data has not been performed for all fields represented in cadastral dataset tables. Some fields such as identifier, name of owner and number of registration were taken as samples. Following a change of parcel boundaries, the identifier of the parcels has to be updated. All necessary information related to the changes was noted as remarks. However, the limitation of the Capturx for ArcGIS Desktop package (see Chapter 4.2.2) has a consequence that the identifier and remarks could only be captured as well as spatial data (e.g. line/polyline). The identifier was marked on the layer identifier (see Appendix 1); while remarks were marked on the layer Capturx Ink Annotation. Both of layers recorded handwriting as line features.

4.5. Data processing

Updating map using the digital pen is not only about data collection in the field but also about data processing in the office. Even though data collected from the field can be automatically synchronized with ArcGIS geodatabase (as claimed by the vendor); as other pattern recognition method applications; the "raw data" collected from the field may contain errors. The input data has to be edited to fulfil the requirement of cadastral data such as clean-up and topology, otherwise the data may be uploaded in ArcGIS but have no meaning for the geodatabase.

Penx uses OCR (Optical Character Recognition) technology for recording the data. This technology (based on a pattern recognition for vectorization) may cause errors such as overshoots, undershoots, dangling nodes and duplications (Huisman & de By, 2009). Those errors have to be edited in order to improve the quality of geometric data. This editing process aims to maintain the geometric of features as well as the existing spatial relationship between those features.

Data processing started with the downloading data from the pen into the tablet PC (see Appendix 2). Then the uploading data was activated in the ArcGIS for reviewing and editing. The Capturx extension only provides basic functionalities to review and decides to accept or reject the changes. All data captured from the field test were stored in determined tables in the geodatabase.

4.6. Test of Reliability

One of the claims on the digital pen regarding to its reliability is suitable to extreme conditions. The reliability of the digital pen is the whole system including the pen and the paper. The test of reliability has been adapted from a stress testing of hardware[8]. Because of the price of the equipment package, the physical test for the pen ruggedness was restricted only based on its specifications(e.g. no check if the pen is waterproof, no try to drop the pen, no try to damage the pen). However, an alternative was available by testing the paper condition instead the pen because the field condition affected both the pen and the paper. In this test, a paper map was assumed getting wet, dirty and folded. These conditions are

[8] Stress testing aims to determine the stability of the given item under expected stress (more information on http://en.wikipedia.org/wiki/Stress_testing)

commonly happen in data collection because of the weather, human interactions and unintentional acts. Samples of data were marked up on the top of conditioned paper map.

4.7. Test of Accuracy

Quality of geospatial data is a combination of several issues which are positional, temporal and attribute accuracy; lineage, completeness, and logical consistency (Huisman & de By, 2009). Positional accuracy is a great concern in case of cadastral surveying (Craig & Wahl, 2003). The other issues are also important because cadastral data is related to the descriptive information about the parcel with legal consequences.

The main concern of this test is to check the measurement using the digital pen against the existing map. Since the digital pen "works" on the top of image, the term accuracy of measurement using the digital pen is not solely depending on the accuracy of the pen. The accuracy is a combination of the optical accuracy of human eye, the resolution of image, the accuracy of map and the accuracy of the digital pen. This test is not about to test the accuracy of the image and the map but mainly to test the accuracy of the pen working with the human eye. Two notions of accuracy are used: accuracy of drawing against the aerial photos printed on the digital paper (raster format) and accuracy of drawing against the existing cadastral map (vector format). Two approaches have been applied to test the accuracy of the digital pen based on type of geometric features: a point-based approach a line-based approach.

4.7.1. Point Based Approach

Positional accuracy consists of horizontal and vertical accuracy. The geometry of parcel is commonly represented by horizontal position (planimetric coordinates system). Federal Geographic Data Committee (1998) defined that horizontal accuracy can be tested by "comparing the planimetric coordinates from *the well-defined point* in the dataset with the coordinates of the same points from an independent source of higher accuracy".

The test for positional accuracy is adapted from a point-based method assessment (Seo & O'Hara, 2009) by comparing coordinates of the well-defined points identified in the field and the same points earlier collected. Figure 14 shows the positional discrepancies resulted from of the point based assessment. The values of discrepancies are calculated using a statistical analysis.

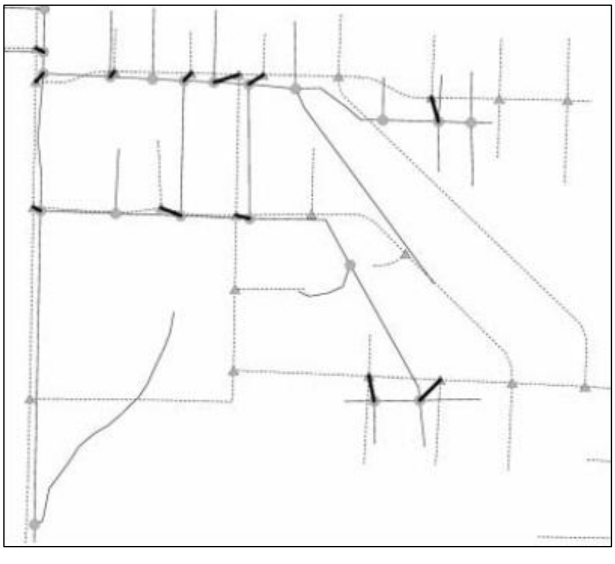

Figure 14. Positional discrepancies (bold lines) in the point-based assessment method (Source:(Seo & O'Hara, 2009)).

13 points have been selected as the well-defined points distributed over a dense urban settlement. Various objects have been selected as marker of the points, such as wall, fence, bush/vegetation and roof. Coordinates of those points are determined on the aerial photo in ArcGIS. Points captured by the digital pen are matched with points on the aerial photo. The matches are verified using statistical analysis to identify the value of positional discrepancies.

4.7.2. Line Based Approach

Linear features represented as polygons and lines also contain series of points such as intersections (Goodchild & Hunter, 1997). Although boundaries represented by polygons and lines captured by digital pen contains series of points but they suffer from geometric errors and jagged lines (see also Chapter 5.2.1 and Chapter 5.2.3). Therefore, a point based approach is not applicable because handwriting generates and presents the boundaries as series of points which cannot properly define intersections as boundary corner points. Using the line based approach is more suitable to judge the accuracy of handwriting. The line based approach is adapted from the principal to distinguish geographic objects in the space (Huisman & de By, 2009).

The test keeps the originality of raw data resulting from handwriting method. 4 parcels (2 big size parcels and 2 small size parcels) are drawn as polygon in map scale 1:1000 using the digital. The polygon approach is chosen representing line segments and for calculating area. Size of parcels is representing difficulties of drawing. The raw data has been compared with the aerial photo and the cadastral data set. The comparison has been verified using a visual inspection to check the accuracy of spatial information about objects provided from the updated cadastral map. The accuracy of spatial information is inspected based on the location (where is it?), the shape (what form is it?) and the size (how big is it?).

5. FINDINGS FROM THE FIELD TEST

This chapter presents some findings from the field test. The first sessions describes the findings coming from the components review of the digital pen systems. The next sessions describe the findings coming from the field test for capturing data, processing data, test of reliability and test of accuracy.

5.1. Components Review

5.1.1. Hardware

a. Penx

Penx is similarly designed as an ordinary pen consisting of body, ink cartridge, point nib and cap. The point nib works in principal the same as a ballpoint. Compared with an ordinary pen (for example a ballpoint) and a technical drawing pen (for example a fountain pen[9] such as Rapidograph), the Penx's body is thicker, heavier but has a similar length. This is because the Penx has electronic components besides an ink cartridge inside the body. Figure 15 shows the Penx compared with ordinary pens. The Penx works similarly as an ordinary pen in handwritings.

Figure 15. Penx compared with other ordinary pens.

In a conventional technical drawing, the line thickness reflects the accuracy of the pen. The thickness depends on the nib size of the pen. There is no information about the nib size of the digital pen. The maximum resolution that the digital pen can detect can be considered as its accuracy (see also Chapter 3.1). Using the term of accuracy in this context, the digital pen has a 1.0 mm accuracy, while ordinary ballpoint pens have up to 0.7 mm accuracy (Wikipedia, 2010a) and technical pens have up to 0.13 mm accuracy (Wikipedia, 2010b).

A package of Penx equipped with ink pen cartridges that can be replaced if it lacks of ink. The original ink for the analogue drawing is dark blue. The battery can be automatically recharged while it is connected to

[9] A fountain pen does not contain a ball on its nib, so it requires little or no pressure to write (for more information visit http://en.wikipedia.org/wiki/Fountain_pen).

the any power sources designed to recharge power through USB cable (this has been tested using several USB ports in PC's and laptops). As an electronic device, the pen has some limitation regarding environmental conditions (Adapx, 2010c). The storage should concern on the normal temperature, moisture, dry and clean area. The use should avoid roughly handling (knock, drop, shake). Cleaning and maintenance should avoid any chemicals that are not recommended for electronic devices.

b. Digital Paper

An ordinary paper has been used in this test to make a digital paper. Although the tiny patterns were printed in the black colour but they were smoothly and slightly visible. The printed patterns appear as a light grey layer covering the image; thereby reducing the quality of the image. The comparison between photo printed in the digital paper and the ordinary paper is shown in Figure 16. The photo printed on the digital paper generated less accuracy in terms of detailed identifications compared with the photo printed on an ordinary paper.

Figure 16. Comparison between the aerial photo printed in the ordinary paper (left) and the digital paper (right).

5.1.2. Software

Adapx PenxCPL and Capturx for ArcGIS Desktop are a software package for the digital pen technology from Adapx (see also Chapter 3.1). Both of the software are only working under Windows (XP or newer version) operating system from Microsoft and ArcGIS (version 9.x) from ESRI. After installation, they are grouped in one folder requiring 9 MB of hard disk space. Adapx PenxCPL created a new display named Pen Manager while Capturx for ArcGIS Desktop stick on ArcGIS.

Pen Manager has basic functions to monitor the status of Penx and to manage connections between the pen and the computer. The software provides information about the status of battery, memory space and data on the pen; and setting of connection. The Pen Manager only works if the pen is connected. The software automatically detected the pen if it is connected into the computer machine via USB cable.

Capturx for ArcGIS Desktop cannot be considered as stand-alone mapping software. It is designed as an extension of ArcGIS to provide a full range of GIS functionality. The buttons of the Capturx toolbar are simple, only for 2 (two) functions: map design and data review. The map design consists of two basic steps: add annotation layers to enable the digital paper functionality and to print. The data review consists of several options: import a new session for the current map, open a session dialog box, select/de-select features, select changes and accept/reject changes (see also Appendix 2). Furthermore, data manipulations (e.g. clean up, topology) are fully processed using ArcGIS functionalites.

5.2. Capturing Data

In this part, the findings of capturing data are clearly visible after downloading data. The download process can be via Pen Manager or directly on the Capturx toolbar. Both of them were working properly. When the pen was connected into the tablet PC, sometimes a prompt directly informed that files have to be downloaded, but sometimes it should be "caught" by activating Pen Manager. This condition was happen when the pen was connected at the first time. After the data was downloaded into ArcGIS, a session is ready to be reviewed (see also Appendix 2).

5.2.1. Capturing Polygon

Creating a parcel as a polygon was done by first touching a parcel legend and then tracing boundaries as a closed polygon. Once the digital pen touched the parcel legend, the pen could be used to draw many parcels on the field map until it was switched to another legend. During the tracing of boundaries for drawing a parcel, the pen had to continuously touch the map until the polygon was closed or nearly closed. If during the tracing the pen was lifted or was vibrating, the pen automatically stopped the recording and at that moment the polygon was automatically closed. Since the type of layer was a polygon, every feature drawn on the map was recorded as a closed polygon. Incompleteness in tracing the boundaries caused an incomplete parcel in spite of a closed polygon. Figure 17 shows if the boundaries (blue lines) were not recorded completely, the parcels (yellow) also were not recorded completely.

Figure 17. Incomplete parcels (yellow) caused by incompleteness of recording the boundaries (blue).

The accuracy of delineating parcel boundaries depends on the quality of image and optical accuracy of human eye. Since the spatial resolution of the aerial photo was considered to be sufficient to represent features in the field, challenges were rising on the drawing. The pixel size representing 10 cm on the ground could clearly be recognized when it was blown up into photo scale 1:1000 and 1:250. Tracing the boundaries was easier using the map in large scale, but drawing using the pen in order to capture data in a high accuracy still had to be done very carefully. Two methods of drawing; by free-hand and ruler; generated different results as seen on Figure 18.

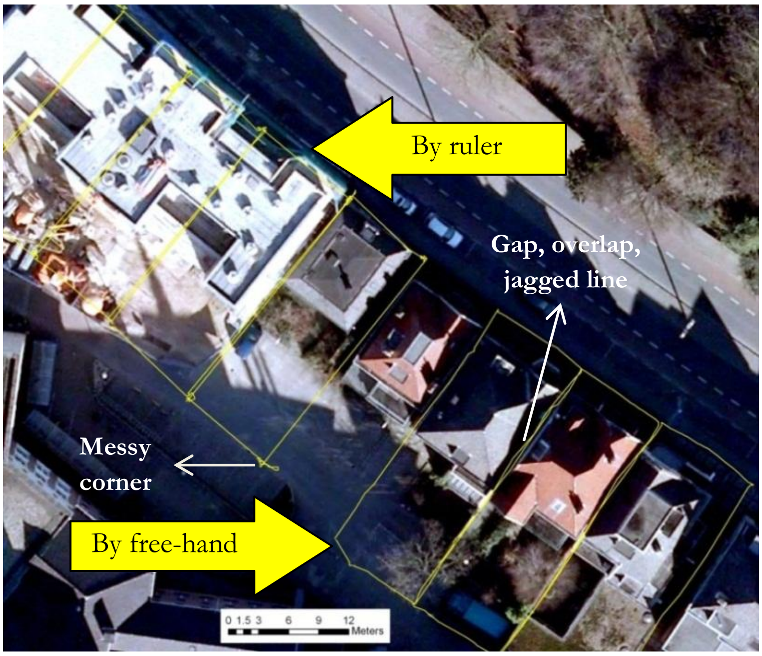

Figure 18. Result of two methods of drawing polygon (by free-hand and by ruler).

a. Free-Hand

Although the boundary could be recognized easily but the drawing by free hand to make a straight line along the boundaries was difficult. As handwriting, the result of drawing is jagged lines. Each drawn parcel is represented as an individual polygon. During the drawing, it is difficult to avoid overlaps and gaps between parcels. Tracing the boundaries had to be very carefully especially in the adjacent boundary. A pad [10] was helpful for tracing a line along the boundary. Smooth surface of the pad make the drawing was easier to be addressed but still difficult to make a straight line. The problems of curly lines affected on an adjacent boundary. Overlaps and gaps between parcels could not be avoided. However, all parcels drawn by this method could be successfully generated as complete polygons. The use of the large scale field map (1:250) could improve the accuracy of drawing and reduce gaps and overlaps.

a. Ruler

The other method was using a (metal) ruler. A straight line on the boundary could be drawn more accurate, gaps and overlaps could be reduced, but making a complete polygon was a hard work. The difficulties happen in drawing a continuous line while keep touching the ruler's edge. In most cases when the nib turned around in the corner, it made a "messy corner" (messy intersection) as seen on Figure 18. The location of the corner point in a messy corner is difficult to be determined. The ruler also became an obstacle when covering the sensor in the pen. The pen always vibrated during the drawing process. Therefore, the entire parcels drawn by this method were generated as incomplete polygons. An attempt for a solution was made by putting the pen's sensor opposite to the ruler's edge. This solution was working, but it needs a high concentration, especially when it had to turn around in the corner. The obstruction can also be reduced using a transparent ruler but a complete polygon still could only be obtained with much difficulty and needs advanced skills. Using a larger scale map (1:250) was more difficult because when a polygon was larger, continuous strokes needed to trace the boundaries was longer.

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[10] A pad means a smooth flat cushion; placed beneath the field map during the drawing.

5.2.2. Capturing Point

Boundary corner points are the main feature to identify parcels as points. In both the simulations of boundary relocation and in parcel subdivision, recognizable boundary corner points were identified on the field map. Adjacent parcels share boundary corner points. The digital pen only need to markup once for every boundary corner point to be used between neighbouring parcels. Since the type of feature of parcel in the cadastral database was set as a polygon, the recording of boundary corner points was applied on the layer point to generate the type of feature as points.

The digital pen has been used to make two types of mark-up in the boundary corner points: a single dot (•) and a bold dot (●). The single dot aimed to increase the accuracy of mark-up on the identified corner. Using the single dot, the point was not clearly visible (on the field map) and often no traces of ink were visible due to the tiny size of the dot. Moreover, on areas with low level of brightness, the manual ink colour (dark blue) could be seen only vague (see also Figure 12). This problem could be avoided by adding lines in drawing to connect the points. The lines constructed parcel boundaries on the layer Capturx Ink Annotation as "imaginer lines" only. Figure 19 shows the dots (red) marked the boundary corners and the lines (green) connected the points. The bold dot aimed to increase the manual visibility of the dot. As a finding of the test, it was found that in the point mode; only the first point of each stroke was digitally recorded, although the analogue imprint showed in many strokes (as illustrated in Figure 20). Therefore, to keep the accuracy, the first stroke was started from the centre of an identified corner then continuously furthers outward the centre. Although the single dot and the bold dot generated different mark-up visibility in the drawing but they have the same result as a vector in digital recording.

Figure 19. Boundary corners to identify parcel are marked using points (red) and connected using "imaginer lines "(green).

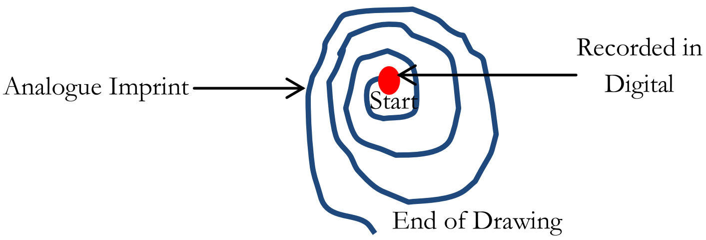

Figure 20. An illustration of drawing a point using a bold dot in the point mode.

Besides recording boundaries, the test also recorded other point features such as electricity poles and individual trees. In the test 4 (four) different symbols have been drawn: “circle” (O), “square” (□) “cross” (X) and “tick” (√). These symbols are commonly used to mark point features. A special attention was given to “cross” because a cross was formed from two strokes thus mean recorded two points at one object. Figure 21 illustrates different results of drawing the symbols in the point mode. Considering that the level of accuracy needed by non-boundary features was lower than for boundaries, all of the symbols; except the “cross”; were accurate enough to identify points. Key attention was to properly adjust the size of those symbols with the size of features identified. However, for the boundary corner points, a dot was a better choice. The use of the large scale field map (1:250) could improve the accuracy of drawing. The first stroke could be defined easier on the identified boundary corner points.

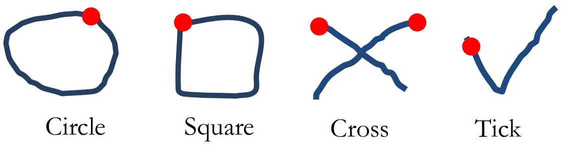

Figure 21. An illustration of drawing symbols (blue lines) in analogue imprint and the results in the digital record (red points).

5.2.3. Capturing Line

The principal work of marking up parcel boundaries as lines was similar with the drawing process applied to polygons. Once the pen was touched the line feature class in the legend, then the pen could be used to draw many boundaries as lines on the field map until it was switched to select another legend. Since feature type of parcel in the cadastral database was set as a polygon, boundaries captured as lines cannot directly be added to the parcel layer. Lines were stored on the line layer to generate parcel boundaries as “a bounding box”. The slight difference for tracing the boundaries between polygon and line is that for drawing lines, the pen has not to continuously touching the map. There were 2 (two) options for tracing boundaries: per-segment of boundary or once for a Bbox. The first option generated several lines constructing a Bbox which had more possibility of undershoot and overshoot. The second option generated polyline constructing a Bbox.

The representation of parcel as a bounding box eliminated the overlaps and the gaps between adjacent parcels. The pen only marked a boundary of a parcel once. The line would be “shared” with the neighbouring parcels. The use of the large scale field map (1:250) could improve the accuracy of drawing, including minimizing overshoots and undershoots.

As experienced on capturing features as polygon; two methods of drawing: by free-hand and a ruler; brought the same consequences. Figure 22 shows the result of drawing parcel boundaries as lines using free-hand and the ruler. In case of marking a boundary, making a straight line was still the most challenging with the free-hand method. The ruler also raised a problem regarding obstructions to the sensor in the digital pen. However, compared with making a polygon, the possibility to put the pen’s nib against the rule’s edge was easier because there was no restriction to make a continuous stroke on the field map. The pen could be lifted and turned over to adjust the nib position whenever needed. But in case of making polyline instead of line, serious attention was still needed to draw continuously and to avoid messy corners. In case of marking non- boundary features such as railways or electricity network, using a ruler was very helpful because they do not have a lot of angles so that the line is simpler.

Figure 22. Results of two methods of drawing lines (by free-hand and by ruler).

5.2.4. Capturing Attribute

The test of capturing attribute recorded 2 (two) concerned kinds of attribute: identifiers and notes/remarks. The identifier aimed to link between spatial and attribute while the remark aimed to collect additional information. Figure 23 shows an example of recording attributes. A parcel identifier was updated by adding a new identifier for a new parcel (parcel number 02012). Remarks for the process were added on the papers: the title, the date, the identifier, the number of the registration and the owners, amongst others

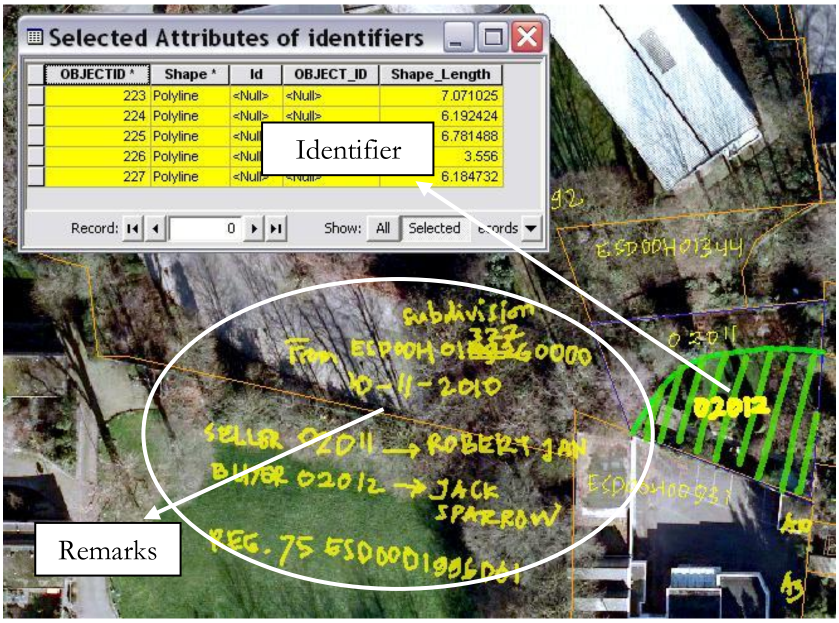

Figure 23. Capturing identifiers and remarks

Capturx software recognizes each stroke of the pen as a vector. The lines/polylines were stored in the table with a unique "id" for each stroke. Handwriting such as a parcel identifier is represented in many strokes. Capturx does not have capabilities to convert handwriting into a single identifier. Therefore, a parcel identifier is extracted as many objects in the identifier table (see the table in Figure 23). The table had no meaning in terms of automatic updates in the geodatabase. The recorded identifier could help as a reference to visualize the changes of attributes; the real updating had to be done manually later on. Handwriting as notes/remarks has the same characteristics as identifiers. The remarks are saved in the annotation layer as additional information. The remarks were helpful to provide information about the updating process; both analogue and digital; so the data analyst had no confusion to understand the changes.

5.3. Data processing

The main data processing functionalities of Capturx for ArcGIS Desktop are a review session and accept/reject changes. During the review session, besides the review function which are *select the changes, accept all changes* and *reject all changes*, the editing function of ArcGIS was activated automatically. The accepted changes are then used for updating the database. The updating could be done by adding raw data to the database. Figure 24 shows the updating result. The brown lines are the old parcels and the green lines are the new parcels. The editing processes (such as parcel construction, clean up and topology) to reconstruct geometry is based on functions of ArcGIS.

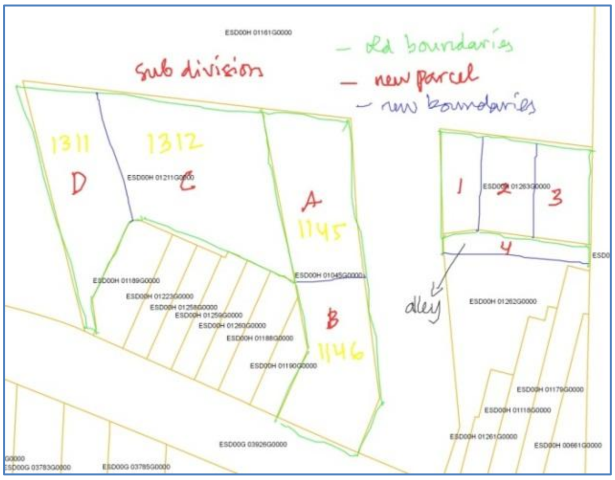

Figure 24. Result of the updating by "accepting changes" into the cadastral dataset

Updating attributes, which was also very important, had to be performed manually. The new geometric information of a parcel was created but not the attribute value such as the identifier. A parcel table had to be opened and the identifier had to be added or changed by typing manually. Notes/remarks related to the subject, object and right also had to be added or changed manually. The limitation of the capability in attribute updating caused inefficient steps for updating many attribute values.

5.4. Test of Reliability

The quality of field data collected by the digital pen is determined by both the pen and the quality of the digital paper. Besides its ruggedness, it was found that the ability of the pen to record the data depends on the availability of discernable dot pattern on the digital paper. The quality of the digital paper in this test was affected by outdoor environment. The digital paper was put on conditions which had a low average temperature (below 10° Celsius), a high average humidity (above 60%), rain and dirt. It became dirty, crumpled and wrinkled. However, the pen generally still worked to capture data as long as the pattern could be recognized. Only on the part with serious damages made the pen vibrating and capturing data failed. Serious damages usually can be identified by thick dirt covering the patterns and a fade of colour image. When the paper was folded, the pen did not work properly in the area which had a tight fold. As long as the folding did not ruin the pattern, the pen still could work properly.

The same features can be drawn many times and could still be recognized. For example a legend has to be marked every time before marking up the features in a layer. If there were many features to be drawn several times in a layer, the legend represented the layer would be full covered by ink strokes. However, it was found that the mark-up on the legend which was already full covered by ink after several mark-up was still recognizable by the pen, as long as the pen touched or nearly touched the legend.

5.5. Test of Accuracy

5.5.1. Point Based Approach

The findings are depicted the accuracy of drawings against the raster (aerial photos). 13 well-defined points have been used for matching. The result is presented as comparisons of positional discrepancies between coordinates of 13 points on the photo printed in scale 1:1000 and 1:250 (see Table 4). Patterns printed in the digital paper reduce the quality of image, making the identification is more difficult for a small object. The simple statistic calculation shows that the pen and the human eye "digitize" more accurate on a large scale map. In the photo printed on scale 1:1000 the RMSE radial is around 0.41 m. In map scale 1:250, the RMSE radial significantly reaches less than 0.12 m. Details discrepancy values of each point are presented in Appendix 3.

Map Scale	**Δx (m) (in absolute value)**				**Δy (m) (in absolute value)**				**Radial RMSE**
	min	max	mean	RMSEx	min	max	mean	RMSEy	RMSEr
1: 1000	0.019	0.366	0.149	0.187027	0.044	0.810	0.288	0.366267	0.411255
1: 250	0.010	0.283	0.055	0.088178	0.000	0.156	0.054	0.076145	0.116504

Table 4. Comparison of positional discrepancy between 13 points in different map scales.

5.5.2. Line Based Approach

The findings are depicted as the drawn boundaries (both the free hand and the ruler aided) compared with the existing cadastral map. While tracing the boundary using the digital pen, the user directly see the imprints on the field map but does not yet known the result in the digital format. On the aerial photo printed in a field map scale 1:1000, the imprints look somewhat neat along the boundaries, especially if aided by the ruler. However, the result on the digital format shows the shape of the real lines recorded. The sensitivity of sensor (75 snapshots per second) is able to record details of the pen movements. When the drawing results are zoomed, the lines/polygons captured by freehand are really jagged and not exactly on the boundary. The ruler may increase the accuracy in term of drawing straight line/polygon, but its position did not vary much compared with lines drawn by freehand. Figure 25 shows the drawing results using the free hand (yellow) and the ruler (green) compared with the existing cadastral map.

The line-based approach concerns on object identifications based on the location (where is it?), the shape (what form is it?) and the size (how big is it?). Discrepancies between the drawing and the existing cadastral map are found when parcels are zoomed. In terms of location, shape and size, these discrepancies do not cause significant differences for parcel identifications. A relative position, shape and size of a parcel in the drawing can be identified and can be distinguished easily among its neighbouring parcels in the cadastral map. These discrepancies caused significant difference in parcel area calculations. A comparison between areas calculated in the drawing and areas calculated in the existing cadastral map is presented in Table 5. The area differences between in the drawing and in the existing cadastral map can be up to 21% while drawing using a ruler and up to 12% while drawing using free-hand.

Figure 25. Comparison between the drawing (yellow by free hand, green by ruler), the existing cadastral map (red) and the aerial photo.

	Area Existing	**Area by Ruler**		**Area by Freehand**	
OBJECT_ID	Shape Area	Shape Area	Diff (%)	Shape Area	Diff (%)
ESD00H01086G0000	626.81	629.86	0.49%	650.75	3.82%
ESD00H01172G0000	60.72	55.67	8.31%	60.89	0.27%
ESD00H01173G0000	728.52	727.59	0.13%	723.77	0.65%
ESD00H00770G0000	80.82	63.67	21.22%	70.56	12.69%

Table 5. Comparison of size (area) between drawing using freehand and ruler in different size of parcels.

The positional accuracy in this test shows estimated values of discrepancies between of original data captured using the digital pen and the existing data (raster and vector). It was found that in terms of positional accuracy, using a point mode is more accurate than a line/polygon mode. The positional accuracy of points drawn using the digital pen could be stated in terms of RMSE, whereas the positional accuracy of lines or polygons should be stated in terms of identification purposes.

6. PERFORMANCE EVALUATION

This chapter presents results of the performance evaluation of the digital pen based on the fit for purpose method. Findings from the fields test are categorized into 5 criteria. In each criterion, findings are compared with claims of the use of the digital pen in GIS context. Comparisons are discussed in accordance with the literature review in Chapter 2 and Chapter 3. The result of the performance evaluation shows the feasibility of the digital pen for updating cadastral maps. Based on this feasibility, the digital pen can contribute in some applications of cadastral data updating.

6.1. Fit for Purposes Evaluation

There are 5 (five) criteria in the fit for purpose method: functionality, usability, accuracy, reliability and compatibility. Those criteria are used to evaluate the performance of the digital pen in this chapter.

6.1.1. Usability

The usability concerns familiarity with the tools to operate. The familiarity depends on subjective issues: background and experience of the user using the tools. Design and customization of hardware and software of the digital pen are the main considerations to evaluate its familiarity.

Case studies in Namibia, Rwanda and Ethiopia; for example; revealed that people are comfortable to use an ordinary pen for parcel demarcation in the field (The World Bank, et al., 2010). The design of the digital pen (Penx) is similar to the ordinary pen used in Namibia, Rwanda and Ethiopia. The paper used is the same as the ordinary paper (photocopy paper). The combination of the digital pen and the paper is handy and portable. The pen is handy for collecting cadastral data either in the field or in the office. Cadastral survey in rural and remote area needs a portable equipment to keep moving from place to place. The size and weight of the digital pen is not significantly different with an ordinary pen. The digital pen is easy to carry during tracing boundaries in the field. The prior splitting and parcel formation as an integral part of the transaction as proposed in The Netherland was using photogrammetric method (Lemmens, et al., 2007). The proposed principle is also applicable using the digital pen for broader purposes. Using the portable digital pen by users such as notaries; does not need GIS software equipments to make a georeferenced drawing. Parcel identification and preliminary boundaries demarcation can be performed on the top of images in the office during a transaction. The image can be sent it to the cadastral office as attachment for archiving or planning for a field survey.

People are used to use pen-paper interactions in their daily works. Writing or drawing on the paper is very familiar method to record and review information. However, collecting spatial data which have geometric characteristic is not as simple as collecting information in handwriting, especially in cadastral data, which deals with boundaries with a specific accuracy requirement. A research of using the digital pen to make NATO hand-drawn symbol revealed that the users need a minimal training to draw difficult symbols (Sylverberg, et al., 2007). The principal works for drawing NATO symbols using the digital pen is similar with the principal works for drawing cadastral features requiring the handwriting should be recognized by the algorithm of the mapping software. Although using of the digital pen does not need a special training in term of writing or drawing on the paper, in terms of drawing spatial data in cadastral applications, the user needs specific skills on how to draw a polygon, line and point in a correct way. As long as basic skills on working with the pen-paper based method is mastered, the training to draw spatial features on the paper map is considered simpler compared with the training using PC or PDA which is requiring computer skills.

Apart from the data collection, the data processing as a part of updating cadastral maps requires skills on the GIS data processing. Cadastral surveyors, notaries or other skilled persons on cadastral mapping can learn both of data collection and data processing. Moreover, in case the user is only mastering basic skills on drawing using the digital pen, the data processing still can be handled by GIS operators in the back office.

Because the digital pen (Penx) has no keyboard, button or screen, the customization of the digital pen is not necessary. As an ordinary pen, the pen can be used soon after the cap is removed. The user has not to be bothered with complicated settings and customizations. An attention for customizations is in the software operation (map preparation and data processing using Capturx for ArcGIS Desktop and ArcGIS). The map preparation is an important part to customize the map because type of data, design of layout and selection of legend/symbol contributes to the quality of data. For example the user cannot input a particular data if the legend is not available since he/she cannot add/customize the legend on the printed map. Customizations for software operations fully depend on the skill to operate ArcGIS. In case the responsibility of data collection is in a different section with data processing, customizations of software operation can be handled by GIS operators in the back office.

The ability to print a digital paper on an ordinary paper (photocopy paper) extends the usability. Photocopy paper is widely available. Sometimes people need a specific skill to draw on the specific paper (glossy paper, transparency etc). The ordinary paper needs no special treatment and is easy to use. Selection of amount, dimension and size of paper is flexible for particular purposes.

Overall, in terms of usability, is feasible for updating cadastral maps. Usability of survey and mapping equipment should encourage the user to continue to use the system (Clegg, et al., 2006). The pen is portable, handy and easy to use. From the point of view of capturing data, drawing using pen on the top of paper is already familiar with our daily works. However, specific skills are needed to draw a polygon, line and point in a correct way. No need customizations/settings for the pen but need customizations/settings for the software. From point of view of data processing, software customizations and data processing in the back office depend on skills of users to operate GIS software. The cadastral map can be printed on proper size of photocopy paper, folded and displayed on the field. User can trace and draw boundaries or write information as using an ordinary pen on the top of ordinary paper.

6.1.2. Functionality

The functionality concerns operations which can be handled by the equipment. Operations of the digital pen for capturing cadastral data (collecting and processing) are the main considerations to evaluate its functionality.

Spatial data in LIS as well as in GIS may use different approaches to represent boundaries of parcels: polygons, lines and points (Huisman & de By, 2009). In terms of data collection, the digital pen can record parcel boundary (and other spatial features) as polygon, point and line. The digital pen technology is equipped with software which automatically converts the raster data captured into vector data in ArcGIS format. The function for data manipulations are supported by ArcGIS which is well known as sophisticated GIS software. The function to capture data digitally in the field is in line with the development of digital data collection for building a modern digital cadastral database (Sørensen, 2009).

Attribute data in cadastral data contains both in qualitative and quantitative information which has legal consequence of related spatial data (Chicocinski, 1999; Toms, et al., 1987). Capturing spatial data is meaningless for cadastral database without attributes. In the modern LIS, changes of cadastral data, both spatial and attributes, has to be recorded digitally in the right format. The digital pen can record the attributes as vector while the attribute should be stored as a table in the cadastral database. In this research, the function of the digital pen for capturing attributes as table is not available due to the limited functionality of Capturx for ArcGIS Desktop package. At this moment the attributes have to be entered manually into a table. However, this limitation will not become a disadvantage to use the digital pen (in general) because actually the software for capturing attribute as table is available. Goldliner, for example, software from Vicrea[11] offers an integration of spatial and attributes during the data collection. In their presentation[12], they have been demonstrated that attributes can be captured as a table and can be automatically linked with spatial data in the geodatabase.

Using the digital pen is proven simplifying the process of updating cadastral maps and saving time in terms of input data compared with similar data collections using an ordinary pen and paper (in Namibia, Rwanda and Ethiopia). Scanning, georeferencing and digitizing (except for point features) process can be eliminated since the field data is automatically converted into digital vector format. Although the digital pen can simplify the data collection process, there remains 2 two issues of attention for the field data collection:

1. The type of data; draw boundary as a complete polygon is more difficult and taking extra time compared with draw point which is the fast way.
2. The method of drawing; draw polygon/line using the aid of ruler is slower compared to use freehand; sometimes the user needs several times to redraw an incomplete polygon or unrecorded line caused by obstructions of the pen sensor caused by the ruler.

Without re-entering data (just collect-plug-play), the data collection becomes efficient. The digital format data leads to real-time and continuous (streamlined) data collection. In terms of updating the cadastral map, the changes of cadastral data can be reviewed on the geodatabase as soon as data are observed. Sharing information between stakeholders is ready to be performed in real time. The digital pen can be combined with electronic technologies such as Bluetooth and mobile phones for more efficient data transfer and data sharing. These capabilities are valid if the data does not require high accuracy which consumes time for post processing (see also Chapter 6.1.4). Capabilities of the digital pen (in general) in terms of data transfers and data sharing still can be improved. Goldliner from Vicrea, for example, has capabilities to transfers data from the pen to the computer using Bluetooth connection and share the data in Google Earth application.

The function of data processing is necessary to reconstruct the geometric conditions which aim to maintain the relation between geometric features in the geodatabase (Fradkin & Doytsher, 2002). Raw data from the digital pen has geometrical errors, especially because the "digitation" based on handwriting which has less precision than digitation using computer (e.g. tablet, on screen). The geometric errors have to be cleaned to reconstruct the geometric features and to improve the quality of geometry. In terms of spatial data processing, the editing of raw data captured using the digital pen consumes time. Lines and polygons contain many geometric errors while in case of the boundary is captured as points, re-digitizing is needed to reconstruct the parcel. In terms of attribute data processing, the digital pen system has no capability to record attribute data as table, the updating of attributes has to be done manually. The updating process will take a long time and error prone. The extra time for post processing may result in a disadvantage of the use of the digital pen.

[11] Vicrea is a company based in The Netherland, specializing in geographic information services.

[12] The demonstration of the Goldliner has been organized in the Vicrea office, Amersfoort. Due to some limitations (time, resources, etc), Goldliner is not tested in this research.

Overall, in term of functionality, the digital pen is feasible for updating cadastral maps. Generally the digital pen (Capturx) can record all of the type of geometric features (spatial) but has limited for the attributes. The proper choice on geometric features and drawing methods regarding to the purpose (high or less accuracy) can simplify the process and can save the time in terms of data collection, but not in terms of data processing. The post processing is necessary to improve the quality of geometric data. Data from the field can be reviewed and be shared as soon as the changes are observed. This capabilities support the need of streamlining (real time and continuous) information for updating cadastral maps (Dale, 1995; Haanen, et al., 2002; NRC, 2007).

6.1.3. Reliability

Term of reliability of survey and mapping equipment is specified as the ruggedness to perform tasks in various environmental conditions. Using equipment in the different types of weather, climate and terrains allows the possibility of loss/failure of data recording. The reliability relates to the user confidence to rely on the system in terms of capability to collect and stored/backup data. The ruggedness of digital pen is focused on two factors: the pen (Penx) and the digital paper.

The reliability on the pen is focused on the given specifications due to the limitation (the price is expensive) to test the pen. Although the pen is designed as rugged equipment, since it containing electronic elements, the handling should be more careful compared to an ordinary pen, especially in outdoor data collections. The user awareness to treat the pen as an electronic device is a key to perform during the data collection. This statement is also suggested by the vendor in the guideline of Capturx care and maintenance (Adapx, 2010c). Information to the user for avoiding wet, drop, shake and improper storage are important to keep the durability of the pen components. The ruggedness of digital data collection highly depends on the electricity as the main power source of battery (Clegg, et al., 2006). The digital pen is equipped with USB connection which allows flexibility for recharging the battery. In an area which has limited electricity, the pen can survive for mapping task because it is equipped with long last battery which is rechargeable by any electronic devices having the suitable USB port.

The performance of the digital pen also highly depends on the quality of the digital paper. This quality is determined by the quality of the Anoto pattern printed on the paper. The pattern is durable. Whatever the condition of the paper, as long as the patterns are not ruined, the pen still can recognize them. This capability is related to the situation of survey for updating of cadastral maps in the field. Cadastral surveying for all day in various weather conditions, where many people are touching the paper for identifying and discussing boundaries, paper is folded for a clear view, many strokes on the paper, etc; are examples of daily situations in field surveys. Although this kind of situation make the paper is shabby but the patterns are still recognizable.

Survey and mapping using the digital pen provides both analogue and digital data. Although a modern LIS is normally built based on digital maps and registers (Dale, 1995), the analogue data may be necessary as legal source documents, backup and accepted as evidence. Digital data captured by the pen are directly compatible with the digital cadastral database. Analogue imprint of drawing on the image can be considered as an original data attached on the survey documents. If the data is illegally manipulated, the backup in analogue can be used as evidence.

Overall, in terms of reliability, the digital pen is feasible for updating cadastral maps. The digital pen and digital paper have no crucial problems for cadastral survey both in indoor and outdoor environments. However, the pen should be treated properly as an electronic device to reduce the risks of damage. The Anoto pattern printed on the ordinary paper is not easily damaged although it becomes shabby. User can rely on the data availability because the backup data is simultaneously stored in both analogue and digital format.

6.1.4. Accuracy

At the beginning, a high geometric accuracy of parcel boundary is one of the requirement of cadastral map (Dale, 1995). In fact, the requirements of high geometric position requirements are not often a compulsory but the possibility for applying low cost surveying and mapping methods is more important to develop a LIS according to the cadastral system, technology, time and cost (UN/ECE/WPLA, 1996). Each level of accuracy of cadastral map may serve different purposes. Accuracy for purpose is the most suitable terms to illustrate the accuracy level of the digital pen. Accuracy of handwriting has to be considered depending on the natural capability of human to digitize on the top of image. In general, digitizing using handwriting has a less geometric accuracy compared with digitizing using computer (e.g. tablet, on screen) in stated of “cm” or “mm” accuracy. However, in certain type of information, effective and efficient cadastral mapping is more important rather than necessity to gain a high accuracy level. The accuracy of digital pen has to be distinguished based on its geometric type which are point, polygon and lines. Different geometric types offer different accuracies and purposes.

Patterns printed on the digital paper reduce the quality of image. The original geometric accuracy of the image still remains but the real visualization on the image gets a lower quality. The smallest object that can be distinguished by the human eye is about 0.2 mm (Engelkirk & Duben-Engelkirk, 2010). The “accuracy” of the digital pen to detect a location of object in is about 1 mm see also (Chapter 3.1) This means that the smallest object that can be recognized by the eye in the image might be not be recorded very accurate by the pen. High resolution of images printed in a large scale delivers better support to the identification. Unlike the computer digitizing, digital zooming option for better identifications is not available in the digital pen system. The zooming is available by using large scale maps. Zooming into a map scale 1:250 gives better interpretation but it takes many map sheets and the map may only cover a few objects. Using high resolution of image is considered more effective and efficient rather than using a very large scale of map. This consideration is in line with the possibility of better resolution of photogrammetric method for better accuracy of cadastral maps (Lemmen & Zevenbergen, 2010).

In terms of positional accuracy, drawing parcel boundaries using points is more accurate compared to drawing lines/polygon. In a point mode, the digital pen can provide RMSE less than 0.5 m horizontal accuracy (against the raster), and better in higher scale maps. The eye and the hand are more focused to accurately mark a point in the boundary corner rather than tracings series of points along the boundaries, especially when tracing using free-hand. Points were connected on the map using line feature and re-digitized in ArcGIS. The higher positional accuracy has consequences in terms of time in data processing. Extra time is needed for re-digitizing because the points and line originating from the pen have no capability for snapping. Lines as guidance are automatically provided in digital format which guides to a faster digitation. The positional accuracy for non-boundary features is considered more than enough to identify the object. By knowing the value of positional accuracy, the digital pen can be applied according to the purposes. As an example, the pen may be not accurate enough for updating cadastral maps that require high accuracy but it may be acceptable as a starting point or an intermediate solution for the cadastral mapping (better than nothing).

The nature of jagged line generated by handwriting is always difficult to match with a line generated by computer. While the user is drawing features on the top of analogue map, he/she cannot see the results in the digital format at the same time until the drawing is downloaded. Especially on a small scale map, the drawing/mark up seems to match with the traced object on the image, but in fact, jagged lines and displacements always happen. Using a ruler is helpful to draw a straight line but not significantly increases the positional accuracy. The digital pen software actually can be modified to automatically capture straight lines without the help of a ruler to improve its accuracy. Goldliner from Vicrea, for example, has an algorithm to automatically smoothing jagged lines as straight lines.

It is difficult to measure the exact value of the positional accuracy of jagged lines, but the accuracy of jagged lines captured by the digital pen is sufficient enough to identify the location, the shape and the size of a parcel and to distinguish it to other parcels. Parcel boundaries drawn using the digital pen are automatically georeferenced. The relative position of a parcel among its neighbouring parcels can be located easily in the cadastral map. The shape of a parcel in the drawing seems similar to the parcel in the cadastral map. In term of size, it can be seen that parcel are bigger, smaller or similar compared each other. In terms of calculating a parcel area, the size cannot serve as an exact measurement because it still has positional discrepancies and geometric errors.

The accuracy in terms of errors caused by manual data entry is avoided by eliminating scanning, georeferencing and digitizing (except point features). Error propagation arising from low quality of scanning, low accuracy of manual georeferencing and misinterpretation of manual re-digitations is eliminated. The data is represented as the original data taken from the field.

Overall, in terms of accuracy, the digital pen is feasible for updating cadastral maps (depending on the purposes requiring high or low geometric accuracy). A high geometric accuracy is not a compulsory for cadastral mapping (UN/ECE/WPLA, 1996). Fast and correct information is often more important than nothing. For mapping purposes requiring a better positional accuracy, drawing features as points is the best method instead of drawing as polygons/lines. For identification purposes, drawing features as lines/polygons is sufficient to identify the location, the size and the shape of parcel and its properties. Error propagations of manual process during scanning, georeferencing (and re-digitizing) are eliminated. The accuracy applicable for parcel boundary is also sufficient for non-parcel boundary data such as other properties inside/around the parcel which requires less accuracy than parcel boundary. The further development of the digital pen technology delivers the possibility to improve its positional accuracy.

6.1.5. Compatibility

Using combination of different technologies of data collection is an alternative to perform an effective and efficient cadastral survey and mapping. Combining different equipment needs the compatibility to convert and exchange data with other equipment to perform in a standard data format.

Originally, the digital pen is capturing data in raster format. The digital pen software (Capturx) has a capability to automatically convert raster into ArcGIS vector data format. The issue of compatibility of data format mostly depends on the ArcGIS specifications. Vector and raster data format supported by ArcGIS is widely used in cadastral survey and mapping applications. Data conversion and export/import capability is able to provide format data for other CAD and GIS based applications e.g. AutoCAD and the open GIS software. The compatibility with (Arc) GIS data format provides options to simultaneously update the existing cadastral map and the GIS/LIS geodatabase.

Since Capturx for ArcGIS Desktop works on Windows and ArcGIS platform, existing cadastral geodatabases in non-ESRI environment needs to be imported into ArcGIS in order to enable the digital pen system to function. It is common for survey and mapping company to bundle hardware with specific licensed software in a branded package. Capturx has a limitation on its software development. It is understandable that Capturx as a commercial software has a limitation in its license policy for software the development. However, technology of the digital pen (in general) actually still can be further developed. The trend of using open source software for supporting the GIS operations is widely increasing. Compared with other digital pen manufacturers such as Livescribe which opens the software development for their digital pen technology, Capturx has a policy to limit the software development into their licensed partner. Livescribe provides Software Development Kit (SDK) based on Java language program for their registered users (Livescribe, 2010b). The users are allowed to create, publish, share and sell their innovative applications to make the Livescribe digital pen system. The development of the digital pen software is also being done by Vicrea with their Goldliner. Vicrea is improving functionalities of their digital pen system to meet with various purposes of geospatial data collections.

Overall, in terms of compatibility of the digital pen is feasible for updating cadastral maps. As a scanner, the digital pen captures drawn data as raster. The digital pen can automatically converted the raster into the GIS/LIS data format which exchangeable with other survey and mapping applications. Generally, the digital pen technologies still can be further developed, both in limited license and in open source platforms.

The summary of the performance evaluation presented in Table 6. The evaluation shows that the claims are proven to be true with some attentions.

Criteria	Claims (GIS Context)	Performance Evaluation (LIS Context)	
		Feasibility	Attentions
Usability	• Simple, comfortable and handy	• Yes, portable design as ordinary pens	• Additional skills needed for drawing points, lines and polygons in a correct way.
	• User friendly	• Yes, people are used to interact with pen-paper	
	• No need an excessive training	• Yes, no need customizations, working similar to ordinary pen-paper method.	
Functionality	• Simplifying the process	• Yes, eliminate scanning, georeferencing and digitizing	• Extra time needed for post processing. • Attributes has to be updated manually.
	• Saving time	• Yes, collect-plug-play, no need manual re-entering data.	
	• Providing real time and continuous data collection	• Yes, data changes can be reviewed and shared as soon as data are observed.	
Reliability	• Deal with various condition	• Yes, applicable in indoor and outdoor, patterns are not easily damage	• Should be treated as an electronic device to reduce the risks of damage.
	• Provide digital and manual backup	• Yes, on paper map (analogue) and cadastral database (digital)	
Accuracy	• Accurate enough in spatial	• Yes, data captured are already georeferenced	• Depends on the purpose (e.g. accurate mapping, identifications) • Depends on the quality of image and the accuracy of eye.
	• Avoid errors happen in manual data entry	• Yes, eliminate error propagations from scanning, georeferencing, digitizing	
Compatibility	• Compatible with the GIS data format	• Yes, automatically convert raster into vector data • Supported various data format (GIS/CAD)	• Based on Windows and ESRI (no open source). • Limited software development.

Table 6. Summary of the performance evaluation.

6.2. Contributions of Digital Pen for Updating Cadastral Maps

The use of an ordinary pen and paper combined with the aerial photos/satellite images has being used for the land registration purposes. Cadastral maps should be regularly updated to maintain the registration data. Moreover, cadastral maps serve broader purposes in their development such as for administrative purposes, taxation, planning, disaster mitigation, land use classifications, statistical and analysis, amongst others. Fast, correct and reliable information about cadastral data changes are often more important than waiting the high accuracy measurement. More advantages are provided by the digital pen in addition to some limitations that require attentions. The digital pen system is possible to improve the map quality collected using the traditional pen and paper system. Furthermore, the digital pen can contribute as an alternative data collection method and/or supporting other data methods to perform cadastral maps updating.

Contributions of the digital pen for updating cadastral maps are in line with the feasibility of the digital pen for cadastral data collections. The significant contribution of digital pen is providing real time and continuous information as soon as the changes in the people/land relationship are observed; which is the main concern of updating cadastral maps. The real time and continuous data supports the automatic data collections. The digital pen is able to transfer the GIS data format to a computer system as soon as it was connected to the system (real time) and anytime when it was connected to the system (continuous).

In case of high accurate cadastral maps are not yet available, the digital pen system becomes a starting point for effective and efficient data collections. The digital pen can contribute by producing less accurate maps quickly before the higher accuracy measurement is performed (if necessary). The digital pen can be used to perform an index mapping for updating cadastral maps in area which high accurate measurement is not effective and efficient. Data from the field index mapping are automatically georeferenced in the digital format. The updated maps can be used for planning (utility networks, infrastructure developments), secure land tenure (preventing land grabbing, recognizing customary lands, slum area mapping, and participatory mapping) and disaster mitigations, amongs others.

The digital pen system can contribute as an intermediate data collection before the high accurate measurements are performed. It can be applied in preliminary surveys such as in identification of boundary dispute, subdivision and consolidation process; which need less accurate than cadastral parcel mapping. When the boundary relocation happens because of boundary dispute, for example, the boundary can be drawn and discussed both in analogue and digital format simultaneously. The manual imprint of the agreement can be used as evidence and the digital format can be stored in the cadastral database. When subdivision and consolidation happens, new parcels as results of parcel splitting (subdivision) and parcel formation (consolidation) can be enacted immediately. The manual imprint can be used as evidence to avoid illegal changes/frauds. The digital format can be used for estimating the parcel area and for planning accurate measurements.

The digital pen can be improved to serve wider and better contributions in geospatial data collections in LIS. The raw data captured by the digital pen have geometric errors. Before geometric reconstructions are performed, the integration of raw data captured using the digital with the cadastral database is limited on the visualisation/reviewing without any spatial relationship functions. However, the post processing using ArcGIS can improve the quality of data. By data manipulations (e.g. editing, clean up, topology) it is possible to improve the accuracy of the map and enable the spatial and attribute relationship functions.

In line with some limitations of the digital pen[13], the use of the digital pen can be optimized by using it appropriately according to the requirements. For example, to get a better geometric accuracy, it is better to

[13] The digital pen means the Capturx digital pen system from Adapx.

draw features using point with a consequence of re-digitize to connect the point (with extra time for post processing). The limitations can be eliminated by improving the software capabilities (as done by Vicrea). For example, the algorithm of the software can be improved to reduce the post processing time by adding several functionalities (e.g. automatic smoothing jagged lines, automatic snapping, automatic data transfer, erase the drawing, and automatically link spatial and attributes data).

The digital pen system is possible to be combined with other data collection methods to optimize its contribution for wider purposes. The combinations propose wider contributions for cadastral survey and mapping, both in initial data collections and in data maintenance/updating. In one hand, areas mapped using ineffective and inefficient methods can be supplemented with data from the digital pen systems using high-resolution images from photogrammetry methods. In the other hand, areas mapped using the digital pen can be supplemented or upgraded its accuracy by other data collection methods. Because of data captured using the digital pen system pen are ready in GIS/CAD format, the data can be used to complement the other data from other methods.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1. Reflections on Research Objectives

The main objective of this research is to evaluate the feasibility of the digital pen for collecting cadastral data in a LIS, especially for updating cadastral maps. Evaluation using the fit for purpose method revealed that the digital pen is feasible to capture cadastral data for updating cadastral maps in terms of its usability, functionality, reliability, accuracy and compatibility. The advantages of the digital pen claimed in GIS context are proven to be true when applied in LIS context with some attentions regarding to the characteristic of cadastral data. Geometric errors, the less accuracy of jagged lines, time consuming post processing, and the difficult integration between spatial and attribute data are the important attentions to apply the digital pen in LIS context. The attentions could be qualified as disadvantages but they should not become obstacles because the capabilities of the digital pen system still can be improved by software developments.

7.2. Revisiting Research Questions

The detailed conclusions and the recommendations are drawn by answering the research questions. The main research question is: Can the digital pen be used for updating cadastral maps in a LIS? The answer is yes, the digital pen system can be used for updating cadastral maps. The sub-questions derived from the sub-objectives are answered based on the literature reviews and the performance evaluation.

What applications are using the digital pen for geospatial data collection?

The development of the digital pen from "a handwriting digitalization tool" into "geospatial data collection system" offers a new alternative in GIS survey equipment. An example of a digital pen system called Capturx is developed by Adapx which integrates the digital pen technology into ArcGIS. Capturx has being applied in engineering services, GIS survey and mapping, emergency responses and facility managements. The applications are performed in the GIS circumstances to update the map digitally.

What are claims of using the digital pen in those applications?

Several use cases based on user experiences brings out claims that the digital pen system provides an effective and efficient data collection method. Based on criteria to evaluate the performance of survey equipment (the fit for purpose), the claims are categorized into 5 criteria:

1. Usability: the design is simple, comfortable and handy; the digital pen is user friendly because it is accepted by people who familiar with write and work on paper, so no need an excessive training.
2. Functionality: the digital pen is simplifying the process because automatically scan the handwriting and integrate the data into ArcGIS, saving time because no need re-key entered data, and providing real-time and continuous data collection.
3. Reliability: the digital pen deals with various environmental conditions, and provides both analogue and digital backup data.
4. Accuracy: the digital pen is accurate enough both in terms of spatial accuracy; and avoids errors when doing a manual key-entered data.
5. Compatibility: the digital pen is equipped by intelligent software which is compatible with the GIS data format.

How can the digital pen deal with spatial data for updating cadastral maps?
Using the principal of Anoto pen and paper technology, the digital pen system accommodates capturing boundaries and other additional cadastral features as points, lines and polygons. The system has the capability to automatically convert raster format drawn by the pen into vector format compatible with ArcGIS. The main considerations to use the digital pen for capturing spatial data are the method of drawing (using freehand or ruler) and the type of parcel representation (point, line or polygon). The considerations affect the accuracy and time for post processing. Using the ruler is not an effective solution to improve the spatial accuracy. The better solution is to improve the functionality of the software for smoothing jagged lines automatically (as done by Vicrea). Capturx software takes roles to download and add the spatial data into the geodatabase in the GIS format for reviewing; while the processing and editing data are fully supported by ArcGIS function.

How is the possibility to capture attribute data?
Capturx from Adapx cannot record attribute data in geodatabase (table) format. The attributes are recorded as vector. However, the facts show that basically the digital pen is possible to record attribute data. Goldliner, for example, a digital pen system from Vicrea, has capabilities to automatically link spatial and attribute data during the data collection. The issue of limitation of capturing data is not about the technology but mostly about the license policy of software development.

What are the capabilities of digital pen that make it suitable for updating cadastral maps?
The digital pen is suitable for updating cadastral maps by providing real time and continuous information as soon as the changes in the people/land relationship are observed; which is the main concern of updating cadastral maps. The process and time between data collection and data processing can be reduced. While capturing data using the digital pen on an analogue map, the digital format is also simultaneously captured by the pen. The digital pen system can take roles as a starting point and intermediate step of data collections (better than nothing). The digital pen can contribute to provide maps quickly before conducting the higher accuracy of measurement (if necessary).

How can the digital pen be optimized to be used for LIS data collections?
The digital pen can be optimized by improving its capabilities and combining with other data collection methods. Opportunities to develop the software package are available to reduce post processing steps. Combinations of the digital pen with other data collection methods propose optimum contributions for both in initial data collections and data maintenance. The combinations allow the digital pen and other data collection methods for complementary insufficient data.

7.3. Recommendations

The digital pen is not widely use in cadastral applications. The following researches are recommended to explore the capabilities of the digital pen:

1. Further research of the possibility to develop the software of digital pen are needed so the digital pen can be more innovative; such as can be used based on the open (Operating System, GIS) software, connected with ICT technology (mobile phone, PDA) and combined with audio/video recording.
2. Further research to evaluate the performance of the digital pen compared with other data collection methods/equipment.
3. Further research to assess the effects of different human characteristics (educational level, gender, age etc.) in using the digital pen.

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APPENDIX 1: CREATING FIELD MAP

A file geodatabase (.gdb) was created to store the entire database as a folder in a file system. This file system supports the full information model of the geodatabase such as topology. The geodatabase consists both of the cadastral dataset and the aerial photos.

Cadastral dataset of Enschede is obtained from ITC server using PostgreSQL. The spatial data (parcel) is retrieved into shape files (.shp) using QuantumGIS in order to be transferred into ArcGIS. Due to the huge size of attribute data (subject, object, right), only attribute data are registered in Horstlanden, Stadsweide are selected using SQL (Structured Query Language) commands. The file of the aerial photo of Enschede, is *ITC-Enschede_1ECW_10cm_Lufo2008*, retrieved from ERDAS which is compatible with ArcGIS file format.

Attributes of esd00_subject_HS.csv

name_non_natural_person	type_non_natural_person	street_name_wa	initials	given_names	prefix	place_of_residence_wa
DE GEMEENTE ENSCHEDE	PR	HENGELOSESTR	<Null>	<Null>	<Null>	ENSCHEDE
R.K. WONINGSTICHTING ONS HUIS	PR	EEFTINKSWG	<Null>	<Null>	<Null>	ENSCHEDE
WONINGSTICHTING DE WOONPLAATS	ST	INSTITUTENWG	<Null>	<Null>	<Null>	ENSCHEDE
DE GEMEENTE ENSCHEDE	PR	HENGELOSESTR	<Null>	<Null>	<Null>	ENSCHEDE
<Null>	<Null>	EMMASTR	R.B.	RAIMOND BERNHARD	<Null>	ENSCHEDE
<Null>	<Null>	EMMASTR	J.E.M.	JOHANNA ELISABETH M	<Null>	ENSCHEDE
DE GEMEENTE ENSCHEDE	PR	HENGELOSESTR	<Null>	<Null>	<Null>	ENSCHEDE
DE GEMEENTE ENSCHEDE	PR	HENGELOSESTR	<Null>	<Null>	<Null>	ENSCHEDE
STICHTING JONGEREN HUISVESTING TWENTE	ST	LASONDERSNGL	<Null>	<Null>	<Null>	ENSCHEDE

Figure 1. Sample of attribute table

Based on the geodatabase, several map files are created in accordance with the type of test. Map files are stored in ArcMap documents (.mxd). These files contain a representation of map, graphs and tables; and the geo-reference. Additional tables were also added for collecting points, lines and identifiers. A default table from Capturx (Capturx Ink Annotation) was automatically added to enable the digital paper function.

a. Design Field Maps

Field maps are designed in A3 paper size (landscape). Besides they are designed for 1:1000, the field maps are also prepared for a larger scale 1:250 to test the pen for a better identification. The field test needs more than one sheet to cover samples for every feature. Series of map were created for making several sheets in a same map layout in the map file. The map series are created using Map Book extension for ArcGIS. Because not all of the sheets are printed for the field test, the map series are helpful to determine which map sheets contain necessary features and available to be printed.

b. Printing Field Maps

Capturx needs the Anoto pattern to be printed the digital paper; therefore the pattern should be available in stock. There are 3 (three) sizes of pattern which use the same standard of paper size: A0, A2 and A4. A larger size pattern can be used to print a smaller size of map layout. In this research, the pattern's stock available is for A2; therefore it can be used to print maps in A3 size. To setup the page and the printer, the user can use regular *page and print setup* menu provided by ArcMap. Capturx advises to put the layout 7 mm away from the printer margin to cover all of layout contents. To enable the pattern in the printed map and to execute printing, Capturx provides *a print button* on the Capturx toolbar.

APPENDIX 2: PROCESSING DATA

a. Downloading Data

Setting for downloading data is provided in Adapx PenxCPL menu. The Penx has 2 (two) options to communicate with computer: by USB cable and Bluetooth. Another setting is an option to download the incoming data when pen is docking: auto download, prompt for download or manual download. In this test only the USB connection has been used.

Capturx recognizes a task of data collection as "a session". Cadastral dataset have been made as several map files in ArcMap. Each session refers to a map file. Capturx automatically provides information if there are some session with their related map file. In the field test a surveyor was assumed did several time of data collections for updating a map file; therefore there were several sessions for a map.

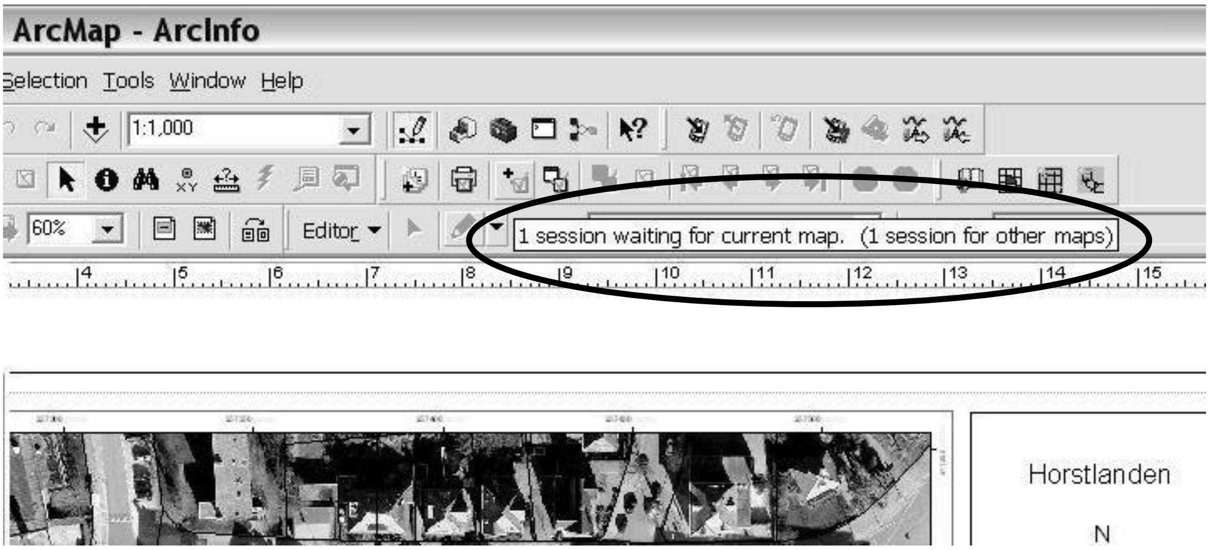

Figure 2. A session

b. Updating Data

Capturx can store parcel boundaries in different tables based on the feature type representation: polygons, points, lines. Boundaries represented as polygons were added automatically in esd00_parcel table as independent polygons. A polygon has no spatial relationship with other polygons. In order to make a new polygon integrated to the database, ArcGIS functions took over the process. A cleaning up process was needed to make a topology. Boundaries as a configuration of boundary corner points could not be stored directly in esd00_parcel table which only stored polygons. Before updating the parcel table, the boundary corner points have to be digitized to configure parcels. Boundaries as lines could not also be stored directly in esd00_parcel. Cleaning up the lines is needed for topological process. Identifiers are stored as vector; therefore they have to be updated by typing manually.

APPENDIX 3: TEST OF ACCURACY

Horizontal Accuracy Statistic Worksheet For Point in Map Scale 1: 1000

A Point number	**B** Point description	**C** x (reference)	**D** x (test)	**E** diff in x	**F** absolute	**G** (diff in x) ²	**H** y (reference)	**I** y (test)	**J** diff in y	**K** absolute	**L** (diff in y) ²	**M** (diff in x)² + (diff in y)²
A01	wall fence	257249,562	257249,661	-0,099	0,099	0,00984064	471110,805	471109,995	0,810	0,810	0,65674816	0,6665888
A02	bush edge	257293,261	257292,925	0,336	0,336	0,11262736	471104,352	471103,771	0,581	0,581	0,33709636	0,44972372
A03	wall fence	257289,544	257289,369	0,175	0,175	0,03059001	471088,307	471088,362	-0,055	0,055	0,00300304	0,03359305
A04	roof	257287,958	257287,591	0,366	0,366	0,13424896	471080,252	471080,361	-0,109	0,109	0,011881	0,14612996
A05	roof	257271,946	257272,182	-0,236	0,236	0,05550736	471082,688	471082,731	-0,044	0,044	0,00192721	0,05743457
A06	roof	257272,343	257272,478	-0,135	0,135	0,01825201	471086,418	471085,991	0,427	0,427	0,18241441	0,20066642
A07	roof	257268,890	257268,922	-0,032	0,032	0,00101761	471087,093	471086,880	0,213	0,213	0,04528384	0,04630145
A08	wall fence	257269,737	257269,515	0,222	0,222	0,04919524	471091,156	471090,733	0,423	0,423	0,17901361	0,22820885
A09	wall fence	257248,115	257248,179	-0,064	0,064	0,004096	471094,713	471094,289	0,424	0,424	0,18020025	0,18429625
A10	wall fence	257249,261	257249,068	0,193	0,193	0,03721041	471105,245	471104,957	0,288	0,288	0,08305924	0,12026965
B01	bush edge	257285,256	257285,221	0,036	0,036	0,00127449	471063,833	471064,062	-0,229	0,229	0,05262436	0,05389885
B02	wall fence	257259,163	257259,143	0,019	0,019	0,00036864	471067,854	471067,915	-0,060	0,060	0,00361201	0,00398065
B03	wall fence	257260,306	257260,329	-0,022	0,022	0,00049729	471084,890	471084,806	0,084	0,084	0,00710649	0,00760378
				min	0,019				min	0,044	sum	2,198696
				max	0,366				max	0,810	average	0,169130462
				mean	0,149				mean	0,288	RMSE	0,41125474

Sum (diff x) ²	0,45472602
Average	0,034978925
RMSEx	0,187026535

Sum (diff y) ²	1,74397
Average	0,1341515
RMSEy	0,366267

Horizontal Accuracy Statistic Worksheet For Point in Map Scale 1: 250

A Point number	B Point description	C x (reference)	D x (test)	E diff in x	F absolute	G (diff in x) ^{2}	H y (reference)	I y (test)	J diff in y	K absolute	L (diff in y) ^{2}	M (diff in x)^2 + (diff in y)^2
A01	wall fence	257249.562	257249.583	-0.0214	0.0214	0.00045796	471110.805	471110.649	0.1559	0.1559	0.02430481	0.02476277
A02	bush edge	257293.261	257293.218	0.043	0.043	0.001849	471104.352	471104.352	0.0001	0.0001	1E-08	0.00184901
A03	wall fence	257289.544	257289.588	-0.0436	0.0436	0.00190096	471088.307	471088.201	0.1056	0.1056	0.01115136	0.01305232
A04	roof	257287.958	257287.884	0.0738	0.0738	0.00544644	471080.252	471080.274	-0.0227	0.0227	0.00051529	0.00596173
A05	roof	257271.946	257271.956	-0.0097	0.0097	9.409E-05	471082.688	471082.645	0.0424	0.0424	0.00179776	0.00189185
A06	roof	257272.343	257272.327	0.0167	0.0167	0.00027889	471086.418	471086.423	-0.0052	0.0052	2.704E-05	0.00030593
A07	roof	257268.890	257268.919	-0.0283	0.0283	0.00080089	471087.093	471087.090	0.0027	0.0027	7.29E-06	0.00080818
A08	wall fence	257269.737	257269.660	0.0773	0.0773	0.00597529	471091.156	471091.165	-0.0092	0.0092	8.464E-05	0.00605993
A09	wall fence	257248.115	257248.398	-0.2826	0.2826	0.07986276	471094.713	471094.795	-0.0819	0.0819	0.00670761	0.08657037
A10	wall fence	257249.261	257249.213	0.0484	0.0484	0.00234256	471105.245	471105.167	0.0782	0.0782	0.00611524	0.0084578
B01	bush edge	257285.256	257285.291	-0.0347	0.0347	0.00120409	471063.833	471063.680	0.1532	0.1532	0.02347024	0.02467433
B02	wall fence	257259.163	257259.140	0.0228	0.0228	0.00051984	471067.854	471067.828	0.0262	0.0262	0.00068644	0.00120628
B03	wall fence	257260.306	257260.325	-0.0186	0.0186	0.00034596	471084.890	471084.868	0.0225	0.0225	0.00050625	0.00085221
				min	0.0097				min	0.0001	sum	0.17645271
				max	0.2826				max	0.1559	average	0.013573285
				mean	0.0554538				mean	0.0542923	RMSE	0.116504444

Sum (diff x) ^{2}	0.10107873
Average	0.007775287
RMSEx	0.088177587

Sum (diff y) ^{2}	0.075374
Average	0.005798
RMSEy	0.0761446