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Geoinformatics

THE UTILIZATION OF GPS IN ORIENTEERING MAPPING IN URBAN HELSINKI AND RURAL KENYA

Mårten Boström

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Orienteering maps are special types of maps. They are designed to give orienteers equal chances to make route-choice decisions. Orienteering maps have traditionally been made using aerial images, LiDAR scanning, old orienteering maps and/or other topographical maps as base material. With one or several as these as the foundation the mapmaker then does the field work in the terrain with pencils after which the material is combined by scanning and superimposing of the data on a Personal Computer. Aerial images and the following stereoscopic evaluation are costly and the field work a tedious procedure so when using these methods, the whole mapmaking process may take up to two years. In this study a GPS-connected tablet-PC running OCAD was used for the whole mapmaking process.

The study areas include urban Pikku-Huopalahti, Helsinki and in the rural Ngangao forest in Kenya. The usability of different GPS receivers and the mapmaking software OCAD were tested in different terrains and conditions, as well as at different locations on the globe in order to get comprehensive results. Up until recently the accuracy achieved with affordable GPS receivers has not been sufficient for detailed mapping, but with recent technological advances the cost of accurate receivers are low enough to make this method of mapmaking advantageous.

The reception of GPS signals is drastically limited by the tree canopy in equatorial indigenous forests, where the canopy may cover up to 100% of the sky view. A high navigation sensitivity (>160dBHz) of the GPS receiver is desired for best GPS reception. The results of comparing GPS reception between receivers in urban terrain also showed variance between the receivers and between differing terrain conditions. The tablet-GPS mapping systems worked well in differing conditions. Even humidity did not cause problems, contradictory to mapping using traditional mapping methods.

The accuracy and productivity of the traditional way of making orienteering maps and the Tablet-GPS method were compared. Utilizing the Tablet-GPS method an orienteering map may be produced faster and with enhanced accuracy of the final map.

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Satellite positioning, GPS, orienteering, mapping, Pikku-Huopalahti, Ngangao, Taita Hills

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Suunnistuskartta on erikoislaatuinen kartta. Se on suunniteltu antamaan suunnistajille tasaveroiset mahdollisuudet reitinvalintojen tekemiseen. Suunnistuskarttoja on perinteisesti tehty hyödyntämällä ilmakuvia, LiDAR dataa, vanhoja suunnistuskarttoja ja/tai toisia topografisia karttoja pohja-aineistoina. Yhtä tai useampaa näistä hyväksi käyttäen kartoittaja suorittaa maastotyön värikynillä paperille. Skannaamalla maastotyökonsepti data siirretään tietokoneelle. Ilmakuvat ja stereokuvatulkinta ovat kalliita toteuttaa ja maastotyö aikaa vievää, joten näitä menetelmiä käyttäen koko kartantekoprosessi saattaa kestää jopa kaksi vuotta. Tässä tutkimuksessa GPS -yhteydellä varustettu tabletti-tietokone, jossa on OCAD asennettuna, käytettiin kaikkien työvaiheiden suorittamiseen.

Tutkimusalueina toimi kaupunkimainen Pikku-Huopalahti, Helsngissä sekä maalaismainen Ngangaon metsä Keniassa. Erilaisten GPS vastaanottimien ja OCAD -kartanpiirto-ohjelman käytettävyys testattiin erilaisissa ympäristöissä sekä eripuolilla maapalloa, jotta tulokset olisivat kokonaisvaltaiset. Viime aikoihin saakka huokeiden GPS vastaanottimen tuottama tarkkuus ei ole ollut riittävä yksityiskohtaisten maastokarttojen tekoon, mutta viimeaikaisten teknillisten edistysten myötä tarkkojen GPS vastaanotinten hinta on madaltunut riittävästi, tehdäkseen GPS -avusteisesta kartoituksesta kannattavaa

Päiväntasaajan seudun alkuperäismetsien latvuspeitto, joka saattaa peittää jopa 100 % taivasnäkyvyydestä, heikentää GPS signaalien vastaanottamista huomattavasti. GPS vastaanottimen korkealla (>160dBHz) navigaatioherkkyydellä saavutetaan paras GPS vastaanotto. GPS vastaanottimet osoittautuivat eriarvoisiksi myös erilaisissa kaupunkiympäristöissä. GPS -yhteydellä varustettu tabletti-tietokone toimi hyvin erilaisissa olosuhteissa. Edes kosteus ei aiheuttanut ongelmia, toisin kuin perinteisiä maastokartoitusmenetelmiä käytettäessä.

Perinteistä maastokartoitusta ja GPS -yhteydellä varustetun tabletti-tietokoneen avulla tehdyn kartan tarkkuutta ja työskentelytehokkuutta vertailtiin. GPS -yhteydellä varustettua tabletti-tietokonetta käytettäessä suunnistuskartta voidaan tuottaa nopeammin ja lopputuotteen tarkkuus on parempi.

Avainsanat − Nyckelord − Keywords
Satelliittipaikannus, GPS, suunnistus, kartoitus, stereokartoitus, Pikku-Huopalahti, Ngangao, Taita Hills

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

ABBREVATIONS

AGPS	**Assisted Global Positioning System**
C/A	**Coarse Acquisition**
CAD	**Computer Aided Design**
DEM	**Digital Elevation Model**
DGPS	**Differential Global Positioning System**
DGNSS	**Differential Global Navigation Satellite System**
DOP	**Dilution of Precision**
ESRI	**Environmental Sciences Research Institute**
GDOP	**Geometric Dilution of Precision**
GNSS	**Global Navigation Satellite System**
GPS	**Global Positioning System**
HDOP	**Height Dilution of Precision**
ISOM	**International Standard for Orienteering Maps**
ISSOM	**International Standard for Sprint Orienteering Maps**
LAS	**Common LiDAR Data Exchange Format**
LiDAR	**Light Detection And Ranging**
MTK	**MediaTek Inc**
PC	**Personal Computer**
P-code	**Precise code**
PDA	**Personal Digital Assistant**
QZSS	**Quasi-Zenith Satellite System**
RDS	**Radio Data System**
RMSE	**Root Mean Square Error**
RTCM	**Radio Technical Commission for Maritime Services**
RTK	**Real Time Kinematic**
WGS84	**World Geodetic System of 1984**

1 Introduction

The increasing complexity of our world, the pressure on natural resources, the degradation of the environment and the security of citizens require accurate maps to display a wide variety of information. To meet these challenges, timely produced maps made using high-quality and reliable information are of importance to governments, companies and citizens. Orienteering maps are good examples of standardized maps, which meet these qualifications and will therefore be used as the focus of this study.

Humans have a need for knowledge about his/her environment. The earliest discovered maps are from thousands of years ago, made in from times from which not many other documents are preserved, which proves the importance of maps. The recording of one's surrounding has evolved and nowadays topographical maps, which aim to depict a truthful picture of the earth, are our best information source of our surroundings.

The development of topographical maps is still an ongoing process as are the mapmaking methods. Field work is a prominent step in the making of any topographical map, but as orienteering maps are of the most detailed widely used maps, the importance of it cannot be stressed too much.

Orienteering maps have traditionally been made using aerial images, LiDAR scanning (Anonymous 2009c), laser distance finders, old orienteering maps and/or other topographical maps as base material (Zentai 2008, Ake et al. 1989, Zentai 2009). With one or several of these as the foundation the mapmaker then does the field work in the terrain with pencils after which the material is combined by scanning and superimposing of the data on a Personal Computer (later PC). Aerial images and the following stereoscopic evaluation are costly and the fieldwork a tedious procedure so when using these traditional methods, the whole mapmaking process may take up to two years (Boström 2005).

This study includes mapping of one flat urban area in Pikku-Huopalahti, Helsinki, Finland and another mountainous rural terrain in Taita Hills, Kenya (Figure 1). The goal with the research is to test the usability of the latest version (10) of OCAD in fieldwork on a Global Positioning System (later GPS) -connected Tablet Personal Computer. The mapping software OCAD is used for the production of the majority of orienteering maps in the world (Zentai 2008). Orienteering maps are drawn with standardized sets of symbols, called ISOM (International Symbols for Orienteering Maps) (Persson 2000) and ISSOM (International Sprint Symbols for Orienteering Maps) (Tveite, Gloor & Zentai 2006). This assures that the symbols found on orienteering maps across the world are identical and by knowing the symbols, one is able to orienteer in any terrain, anywhere in the world.

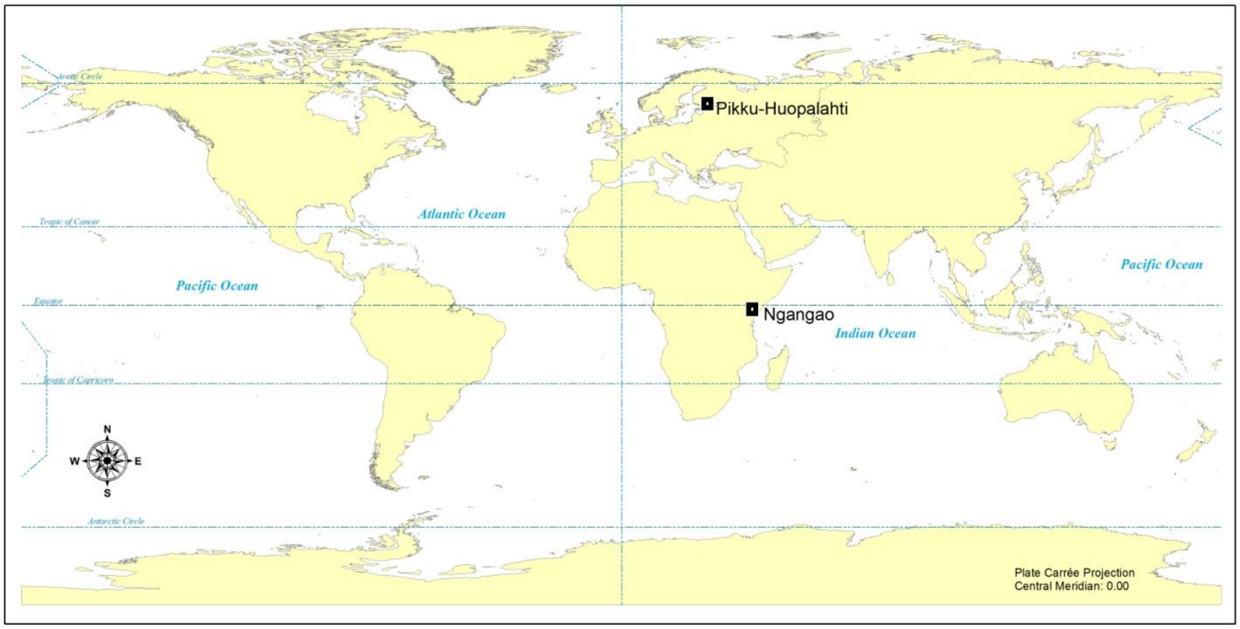


Figure 1. The study areas are located in differing locations on the globe.

An orienteer has to be able to traverse the terrain based on the information gathered about the terrain from an orienteering map in running pace. Precision is therefore important but sometimes also generalization has to be used to satisfy this condition. This study has examined Dilution of Precision (DOP) values from the GPS devices in order to decide if terrain features, buildings and vegetation cover disturb the GPS-signal. Instead of tedious and costly aerial image processing the methods used in this study will rely on the GPS coordinates for spatial accuracy. Not only should this shorten the orienteering mapmaking process, but also significantly cut down the cost of it.

The expectation that the GPS signal will be weak in deep valleys and in thick vegetation (Zentai 2009) will be tested. By testing the usability of a different GPS receivers and OCAD in different terrains and conditions, as well as at different locations on the globe the results of this study should be comprehensive. Up until recently the accuracy achieved with affordable GPS receivers has not been sufficient for detailed mapping, but with recent technological advances the cost of accurate receivers are low enough to make on this method of mapmaking.

The research questions of this study are the following:

1. What kind of a GPS receiver is sufficient for orienteering mapping?

2. Does the GPS -connected Tablet PC system work in all kinds of mapping conditions?

3. Does the GPS -connected Tablet PC system work in all kinds of terrain conditions?

4. Is making orienteering maps using a GPS -connected Tablet PC system time wisely productive and/or more accurate compared to traditional mapping methods?

2 Theoretical and methodological background

The theoretical and methodological background regards the history of mapmaking in Finland and evaluates the positioning systems and how these may be used. A brief introduction of orienteering maps is given and previous research papers on the subject are noticed.

The history of mapping in Finland is quite glorious, with Finland being the first to launch a National Atlas as early as 1899. Since then Finnish mapmakers have been at the cutting edge of mapping development for example in usage of aerial images and the production of large scale topographic maps covering the entire country. Recent improvements in field work technologies and surveying have been noted to change the characteristics of cartography. The accuracy achieved by using global positioning systems is far greater than the methods used earlier, since even centimeter accuracies may be achieved. Digital geographic data may with the newly adopted methods be collected much faster which also creates a challenge, since the amount of data available is ever increasing. This change is recognized as both a technical and a social in character (Vuorela, Burnett & Kalliola 2002).

2.1 Global Navigation Satellite System

The Global Navigation Satellite System (GNNS) includes signals from the US governmental GPS, the European Galileo, the Russian Glonass, the Chinese Compass, the Indian IRNSS and the Japanese QZSS (Rainio 2010). Only GPS and Glonass are operating at present (2010), but the increased signals when using these side-by-side have not yet proved their strength (Poutanen 2009). The potential gain with several satellite systems is that you may see more satellites at once, which gives a better GDOP that in turn results in a better accuracy. In Finland we are so far north that GNSS receivers may pick up satellite signals from the other side of the polar circle (Kaisti 2010). This should improve position accuracy compared to that in the lower latitudes, but there are studies (Poutanen 2009) rejecting this theory. According to Viitala (2009) GPS signals are not accurate enough for detailed mapping in Northern Finland. The Galileo system in operation should however bring changes to this.

2.1.1 Global Positioning System

GPS consists of 24 operational satellites which orbit earth at an altitude of 20 000 meters at a 55 degree orbital plane. One orbit takes 12 hours, so the same satellite flies over the same position on earth twice a day. GPS uses a time-difference-of-arrival model utilizing on-board atomic clocks and the precise position of the satellite to create continuously broadcasted navigation messages. Each satellite is recognized by an individual code so the user on the ground may monitor which satellite's signal he is receiving. Based on the received messages the GPS receiver on earth calculates the position accurate to within a few meters (McNeff 2002).

GPS is a threefold: the satellites, a control network and the user. The control network monitors the state of the satellites correcting possible clock errors, defining their orbits and updating the transmitted information. The satellites broadcast two differing signals, named L1 (1575.42 MHz) and L2 (1227.60 MHz). Incorporated into both these signals is the P-code (Precision) and only into L1 the C/A-code (Coarse Acquisition), which are both used for navigation. The signals from a minimum of four satellites are needed to determine an accurate position. Figure 2 illustrates how each satellite gives an area of possible locations on the surface of the earth and how the true position is narrowed down by increased number of satellites. The locations of three satellites defines the possible location as the dashed area, while the addition of the fourth satellite reduces the possible locations to two points, of which only the other one is located on earth's surface. GPS is provided as a common good by the U.S. Government and is free for users all around the world (Poutanen 1998).

There are several factors that affect the positional accuracy of the GPS-signal. The C/A-signal is available for civilians and is not since the year 2000 being interrupted by the US government (Poutanen 1998). Before this only a weaker P-code which provided less accurate positioning was available for civilians.

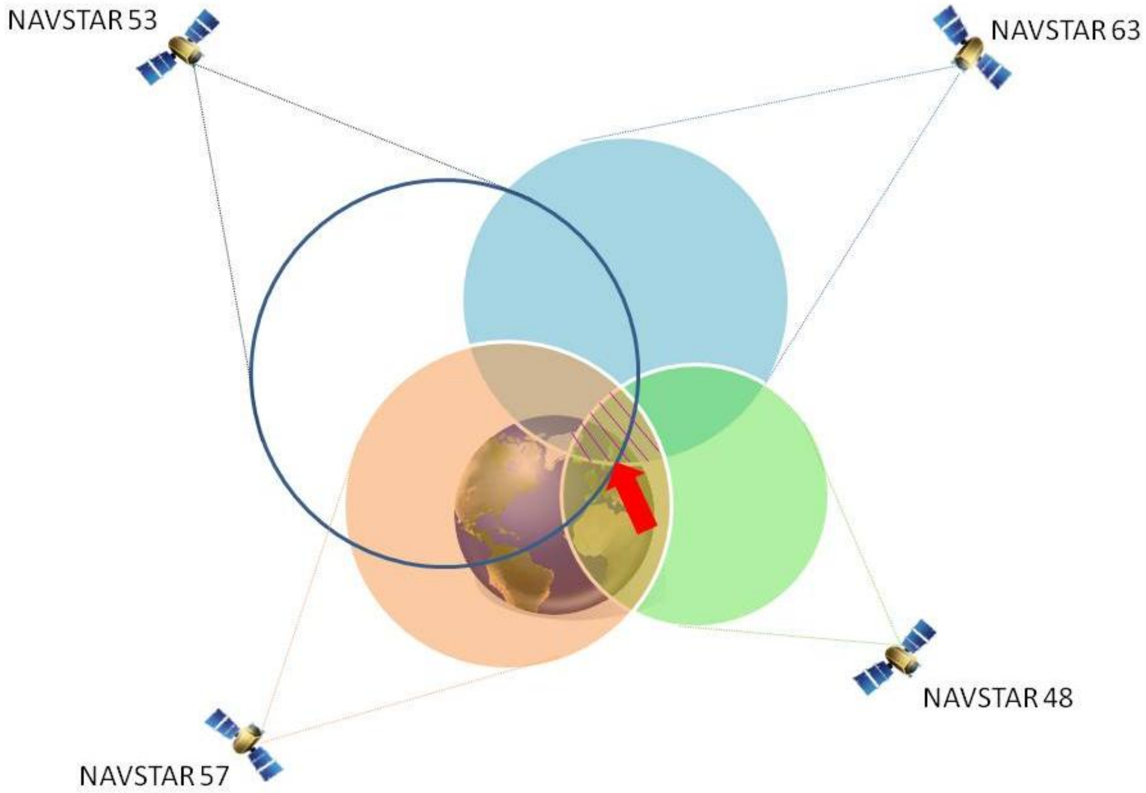


Figure 2. A minimum of four satellites are needed for accurate GPS positioning-

Factors reducing the positional accuracy are clock- and orbit -errors of the satellites and errors in the GPS-receivers. Adding to these are the errors produced by the ever-changing ionosphere and troposphere and the satellites´ location to each other in the sky (satellite geometry). The satellite signals do not permeate solid structures, such as trees, buildings and rock features, but reflects from them. These reflections are called multipath reflections and are considered one of the largest inaccuracy producing factors (Leick cop. 2004.). In this case the same signal arrives to the receiver at two different points of time, thus representing two different positions. Based on Rouvinen, Varjo & Korhonen (1999) the species of trees, the length of the trees, the width of neither the trees nor other tree characteristics significantly affect the spatial accuracy of GPS. This applies if one can acquire signals from at least four satellites. According to Poutanen (2009) the biggest error factor however is the GPS data handler.

2.2 GPS receivers

As the popularity of GPS-use is ever-increasing also the variety of the receivers available for consumers is greater. There are a number of qualities, which needs to be taken into account when choosing an appropriate receiver for mapping purposes. When choosing a GPS to use for mapping one needs to focus on certain aspects when comparing the specs of various products. The positional accuracy is important but the sensitivity is even more critical for acquiring signals in challenging conditions. Positional accuracy is the evaluation of the proximity of the location of the GPS location in relation to the true position on earth’s surface. Sensitivity refers to the receiver’s capabilities of acquiring GPS signals. PDA devices are effortless to use in the terrain, but the limited screen size brings some challenges, as not all information can be fit onto it.

Multipath rejection technology is important to differentiate from correct signals and reflected signals, which is important when mapping nearby buildings and large cliffs. Receivers, which picks up both L1 and L2 GPS signals have increased positional accuracy, since the ionosphere error is corrected (Poutanen 2009). Correlation algorithms follow the signal and calculate if the signal is largely off the normal path (Poutanen 1998), and only the correct position is saved. In order to achieve this improved accuracy, the acquisition and navigational sensitivities on these dual-band receivers are decreased.

GPS accuracy in the order of 2-5 meters would be acceptable for orienteering map making. A 5 meter error in the terrain would introduce 0.5 millimeter error on a 1:10 000 map – less than the size of any of the point symbols and would be hardly noticeable. Accreditation tests of the GPS receivers was conducted in Pikku-Huopalahti to make sure the competency for orienteering mapping is adequate (Stanoikovich, Rizos 2001).

By using a single GPS receiver one can at the moment at the best achieve about 5 meter positional accuracy through GPS, depending on the quality of the GPS receiver. As there are always other error factors involved one might want to consider using an improved GPS signal in order to reduce the raw positional accuracy error acquired from the GPS.

2.2.1 GPS Channels and Antenna

Each GPS channel tracks the movements of one satellite (Viitala 2009). By following a greater number of satellites in the sky the chance of picking up the most appropriate signals is increased. A low channel number is a limitation factor of some GPS receivers.

The antenna is the most critical component in a GPS receiver. The latest silica component of the GPS receiver module is not bigger than 10x10 millimeters and this seems to be the minimum attainable size. The GPS signal strength is measured in dBHz, where the bigger the number the more signals the receiver picks up. There are two critical sensitivity measurements; acquisition and navigation (Kaisti 2010).

2.2.2 Multi-satellite-system usage requirements

Most GPS receivers currently on the market use only the GPS. The addition of the European Galileo and the Russian Glonass includes the use of a larger base pad, which can handle a higher electronic cycle. The needed radio is the same, but the search engine and correlators needs to be extended. This is due to a wider wavelength span that needs to be tracked (Kaisti 2010).

2.2.3 Acquisition and navigation sensitivity

The GPS satellites transmit signals, which are weakened as they pass through the atmosphere. The acquisition sensitivity is the minimum received signal strength that a receiver can work with to initially acquire connection to the satellites. The goal is to get as much information as possible out from the antenna and thus a high sensitivity figure is desired. Acquisition strengths in the area of 54-55 dBHz are achievable with an open sky view. It is expected that a wet deciduous forest would weaken the signal by -15 dBHz. At about 10 dBHz the GPS signal is lost. With a smaller sensitivity figure you lose some information already in the signal you are receiving. Therefore, if one starts out with a receiver which has a weaker acquisition sensitivity one has a higher risk of losing the signal when conditions block some of the signal (Kaisti 2010).

Navigation sensitivity is the minimum signal dBHz level the receiver needs in order to continue navigating. Since the receiver has already downloaded the ephemerides of the satellites it will not need as high signal power as during acquisition (Kaisti 2010, Viitala 2009).

Cold start is the situation when the GPS receiver does not have time, satellites and ephemeris information readily available in it. This situation occurs when the GPS receiver has not been used in a long time (Hurskainen 2005). For cold start a better signal is needed than for the actual navigation and the higher the cold start sensitivity the easier it is to acquire satellite signals in weak conditions.

Cold Start acquisition is where newer receivers usually beat older versions, since they can pick up weaker signals. The signal strength of -148dBHz is needed for the latest GPS receivers to be able to perform a cold start. In cold start the receiver needs to lock to time, satellites and ephemeris. In a hot start the receiver knows time, satellite locations and on-ground positions within a couple seconds (Kaisti 2010).

2.2.4 DGPS

Differential GPS, also known as DGPS, uses a network of fixed, ground-based reference stations (Poutanen 2009). The accurately measured and known base station positions are used for correcting the errors in the signals received from satellites. The improvement of the acquired positional accuracy depends on the conditions and on the size of the error in the uncorrected signal.

The most known Differential Correction Services in Finland are the Digita Oy/Indagon Oy's FOKUS-service, the Finnish Maritime Administration (Merenkulkulaitos) base station service and the Evo Forestry School DGPS-service. All of these utilize Trimble's DGPS-devices. The Evo DGPS signal is a post correction service and therefore not usable in real-time mapping. The FOKUS-service provides real-time correction, but is rather costly. These reference stations provide accurate RTCM-correction data for all satellites at 7 degrees or more above the horizon. This data stream is then broadcasted throughout the nation as a concealed RDS-signal through the Radio Suomi radio frequency (Anonymous 2009a). For professional users the reliability and nationwide accuracy of the FOKUS-service is a clear advantage. For the purpose of this study real-time DGPS would have been the only option, but was not used due to economical restrictions.

2.2.5 AGPS

Assisted GPS (AGPS) utilizes a mobile network or other available network for transferring navigation information to the GPS/mobile phone receiver. The network based AGPS systems have a significant time lapse, and can therefore not be used for real-time mapping. The Mobile Station based systems could be used for real-time mapping applications (Hurskainen 2005).

2.2.6 Other properties

The GPS receiver used for terrain mapping field work should be lightweight, water resistant and have a long battery life for practical reasons to ensure successful field work. A screen is not needed on the GPS-receiver if the device is connected to a laptop and the absence of a screen will provide for extended battery life. Unobstructed online data transfer either through Bluetooth or appropriate cable is of utter importance for successful Tablet GPS field working.

2.3 Orienteering maps

Orienteering maps are detailed topographical maps, which primary use is to give an orienteer an equal chance to navigate in an unknown terrain. Since these maps are the most detailed standardized terrain maps that are abundantly available the use of these maps in other affairs is desirable. The results will be available in orienteering publications across the world in order to educate interested orienteering enthusiasts whether the use of GPS in Orienteering Mapping is practical or not.

Only magnetic north lines are shown on an orienteering map. Another point which differentiates orienteering maps from topographical maps is the fact that absolute positions are not demanded, but only relative positions between features which the orienteer uses to navigate in an unknown terrain. The use of symbols is somewhat relative on an orienteering map, as for example a 0.3 meter high boulder may be drawn if it is located on an open field, while left out if located in a rocky terrain in a dense forest. Both would still comply with the ISOM (Persson 2000) or ISSOM (Tveite, Gloor & Zentai 2006) mapping standards. The general rule is that a feature should be included on the map if it's of use in navigation through that area. Absolute height difference is not significant, while the relative height difference is needed to make route choice decisions (Ake et al. 1989).

When mapping orienteering terrains using traditional methods, data is gathered in the field onto a piece of specially made transparent paper (Boström 2005). Digitizing is a process where paper based spatial information is processed to a format, which is usable on a computer. Scanning and digitizing the information drawn onto this paper is a tedious process, which involves a considerable risk of errors (Fotheringham, Brunsdon & Charlton 2000).

Every map is a generalization of the truth, but even though the map must represent the truth of the physical reality. The map must also be readable by the user in running pace. Unless both of these conditions are satisfied the final product is not of high quality (Harrie, Weibel 2007).

2.3.1 Normal orienteering maps

The International Specification of Orienteering Map 2000 standardizes map language to ensure that the map representation is equal and understandable (Persson 2000). According to ISOM, the scale of an orienteering map should be 1:10,000 or 1:15,000, depending on the course distance and the character of the terrain. 1:10,000 is internationally the most commonly used map scale with a contour interval of 5 meters.

2.3.2 Sprint orienteering maps

The International Specification for Sprint Orienteering Maps (ISSOM) is based on ISOM, but has variations to fulfill the requirement of being usable in any kind of terrain. Detailed maps of a great variety of city centers, parks and forests may be made using ISSOM. Maps drawn in ISSOM are in the scale of 1:4,000 or 1:5,000 with a contour interval of 2 meters or 2.5 meters (Tveite, Gloor & Zentai 2006).

2.4 Previous studies on subject

This subject has not been studied in detail in the past but in the following I present two papers, which touch on the orienteering subject and two which involves topographical GPS mapping.

Leung (2003) has found that GIS is useful for spatial data-acquisition from aerial images and Digital Elevation Models (DEM). He did not however try to integrate GPS into the mapping procedure, but aimed at doing most of the mapping without in-situ data.

New Technologies in Making Orienteering Maps is a paper written by László Zentai. The paper summarizes the development of some recent innovations to orienteering mapping techniques. GPS in orienteering mapping is mentioned in New Technologies in Making Orienteering Maps as a usable new technique, but no research on the subject is accomplished. It is however suggested that the use of GPS will save a minimum of 25% off the fieldwork time and that the accuracy of maps is improved (Zentai 2008).

Schmidt compared an RTK GPS receiver and a DGPS receiver for mapping topographical features with the goal being improving the management of agricultural inputs. The elevation relief of the study areas was within 4 meters of altitude, but according to this study the used devices were successful in recording the topographic features which were agronomically important (Schmidt, Taylor & Gehl 2003).

Haavisto-Hyvärinen & Kutvonen (2007) has noted that the usage of GPS in the fieldwork of geological maps has both made the mapping more effective and the gathered data more accurate.

2.5 Development of orienteering maps

Since the first maps, made by the Egyptians 6000 years ago mapping techniques have evolved towards more and more specific applications. Roman’s mapped large areas for practical needs, such as tax collecting, land divisions and road network recognition. The terrain mapping methods used by the Roman’s were used, which only slight improvements, until the end of the 18th century. At this time triangulation had entered the picture and boosted the production of maps. Especially the military produced a large amount of maps, which were usually in the scale

1:100,000 or 1:50,000. At the end of the 19th century there were maps which were accurate enough for orienteering, but no maps were yet made particularly for orienteering. The sport of orienteering evolved in Scandinavia as a part of military training sometime in the end of the 19th century (Myrvold 2004). Orienteering, such as other sport, aims on giving all competitors an equal chance to success. Luck played a significant role in orienteering and only by securing the maps were of an acknowledged standard could the significance of luck be reduced. At the start maps made especially for orienteering, were of the same scale as the used base material, 1:20,000. The Finnish base map was at the time the International Orienteering Federation was founded, in 1961, the best available terrain map and was thus used as a model when the international standards for orienteering maps was established (Niemelä 1995). Orienteering maps differ from other kinds of topological maps in that they are made solely for orienteering. The book Suunnistuskarttakirja (Ake et al. 1989) gives unambiguous details about all the procedures taken in a traditional mapping procedure.

3 Studied Areas, Datasets, Software and Hardware

3.1 Differing study areas

In order to get a complete understanding of the usage of GPS in orienteering mapping the study needed to compare how different conditions and environments affect the procedure. The two study areas have significant variations in the location on the globe as well as in elevation and terrain features. Ngangao is mostly rural, while Pikku-Huopalahti provided a chance to test the usability of GPS in urban areas.

3.1.1 Ngangao

This majorly indigenous forest around the highest point of an isolated mountainous area in southwestern Kenya (S 3°25’ E 38°20’) is located just south of the Equator. The total area of the forest is 150 hectares and it is situated between 1650 and 1950 meters above mean sea level. The large area of the forest and the deficient base material was a big challenge. This area was chosen as study area in order to test the usability of GPS when the vegetation cover is extremely thick. As seen in Figure 3 the forest, which belongs to the Mwarungu district, has slopes towards different directions. GPS reception was expected to differ between the slopes of different steepness, which presented another good reason for choosing Ngangao as study area.

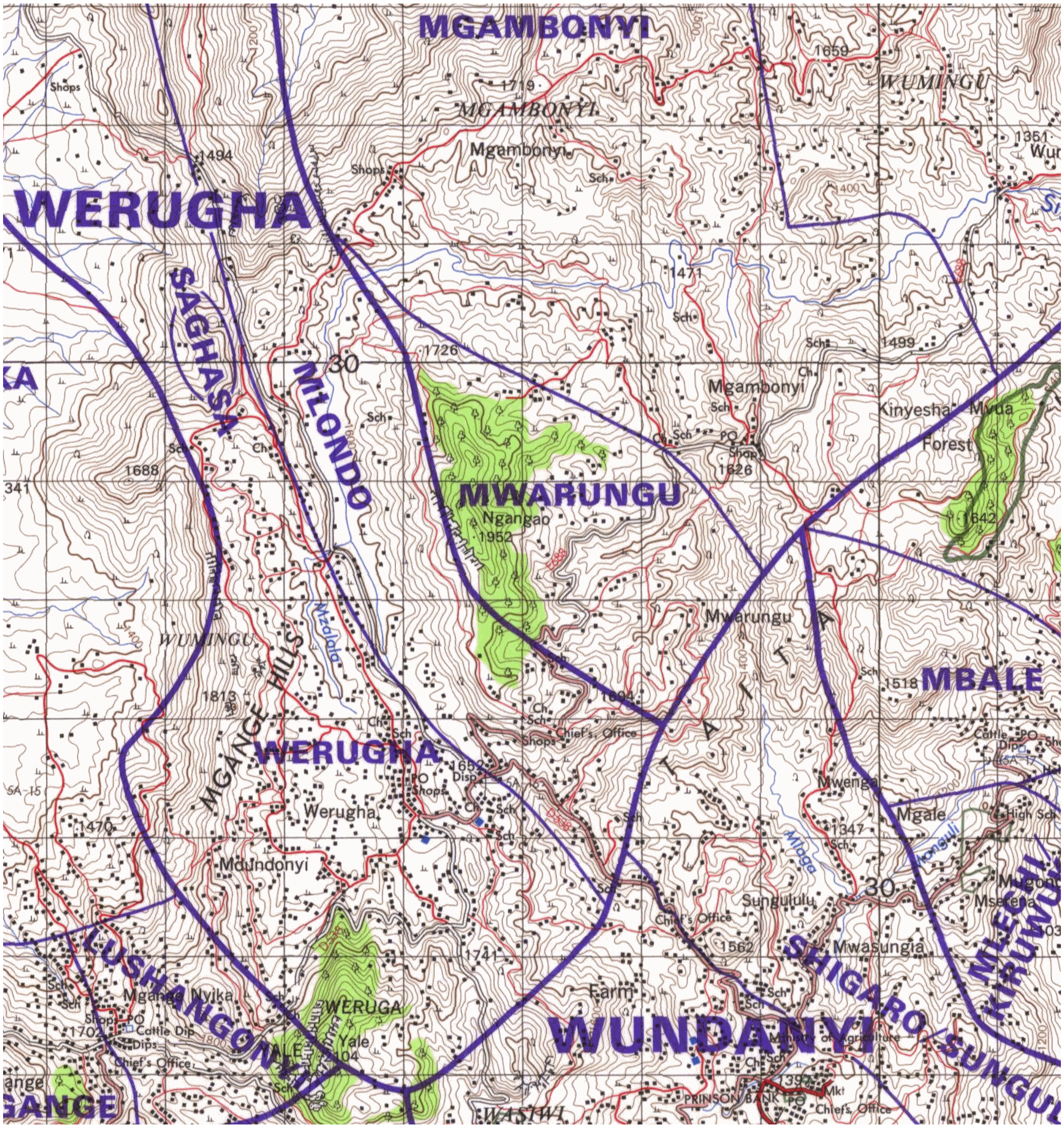


Figure 3. Portion of Survey of Kenya map 189/4 showing Ngangao forest, green area in the Mwarungu district, in the northern part of the Taita Hills (Survey of Kenya 1991)**.**

3.1.2 Pikku-Huopalahti

Pikku-Huopalahti is an urban neighborhood in western Helsinki (N 60°12’ E 24°53.4’). The study area consists of a total of 155 hectares of which roughly half is built up areas and half parklands and forest. The area has only a limited number of streets with regular car traffic on it and is therefore suitable for sprint orienteering (Tveite, Gloor & Zentai 2006). Pikku-Huopalahti is a rather flat area with the highest point being 24 meters above mean sea level and the lowest points at 0 meters as a shallow bay, named Pikku-Huopalahti, of the Finnish Gulf cuts into the southern part of the area.

Pikku-Huopalahti was chosen as study area as a representation of a typical urban sprint terrain area. The area includes of a variety of differing buildings which vary in size and shape, but all provide a challenge for GPS reception. Small patches of forest and larger parklands are scattered all around the study area, but since the canopy cover in these are thin these were not expected to disturb GPS reception. The large open parklands were expected to offer superb GPS reception. There has not been any previous orienteering maps of Pikku-Huopalahti.

3.2 Datasets

I acquired a wide array of datasets from different sources for the study, as good quality base material should be used whenever available. Data mining is a crucial part of preparing for a mapping process since high-quality data may considerably cut down the time required field working.

3.2.1 Remote sensing Data

Ngangao

Orthorectified airborne digital camera image mosaic 25.1.2004. Acquired by Petri Pellikka and processed by Milla Lanne using EnsoMOSAIC in the University of Helsinki TAITA project (Lanne 2007, Pellikka et al. 2009). The resolution was 0.5 meters and the projection Universal Transverse Mercator, zone 37S.

A Land Cover Vector model in ArcGIS shapefile format of roads, rock, fields, pine forest was acquired from the Orthorectified airborne digital camera image mosaic, from the University of Helsinki, Department of Geography and Geosciences (Pellikka et al. 2009). This data was in the projection Universal Transverse Mercator, zone 37S, with 0.5 meter resolution.

A digital elevation model (DEM) which was derived from a 1:50,000 scale topographic map, made in 1989. Planimetric resolution of product was 20 meters interpolated from 50 feet interval contours. DEM was acquired from the University of Helsinki, Department of Geography and Geosciences (Survey of Kenya 1991, Pellikka et al. 2004, Clark 2010).

Google Earth satellite images were used for making the insert localization map. The data is in the WGS84, projected into General Perspective. Resolution data was not available.

Pikku-Huopalahti

The information cards on benchmarks ”Taso- ja korkeuskiintopiste” 90M1003 and 90M1015 were acquired from the Uusimaa District Survey Office. Benchmarks are accurately surveyed points in the terrain, which are used as reference points for nearby detailed terrain mapping.

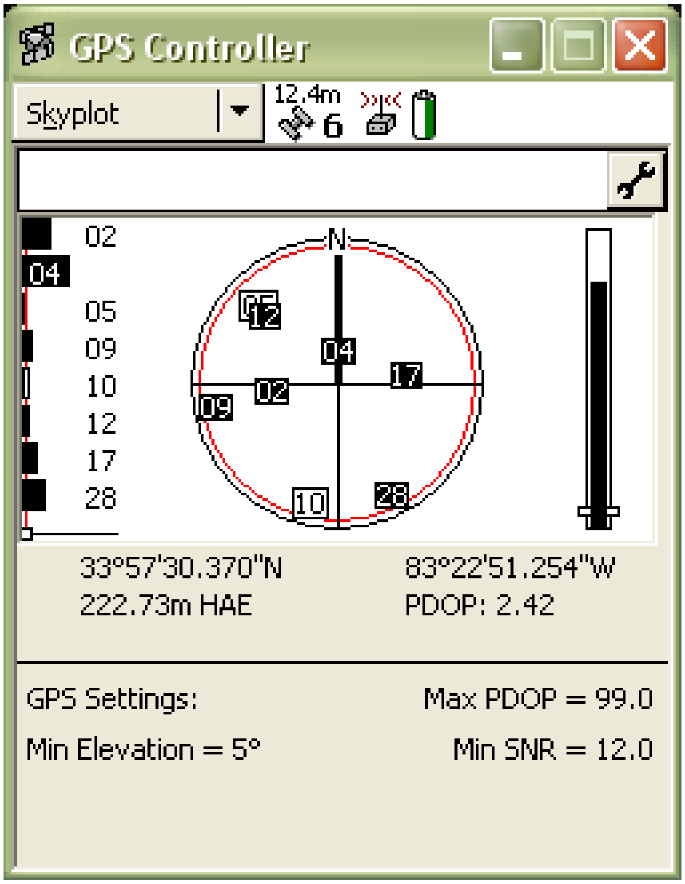
City of Helsinki Cadastral map “Kaupungin kaavakartta”, City of Helsinki, The Real Estate Department. Projected into ETRS TMS35FIN to conform with the WGS84 used in GPS.

Classified LiDAR data, in LAS format, of the majority of the study area was acquired from the University of Helsinki Department of Geography and Geosciences. The elevation RMSE accuracy of the data is 0.15 meters on most surfaces. The LiDAR data is acquired from 2 kilometers and the footprint of a single laser beam is max 0.5 meters (Anonymous 2010b).

The aerial image, which was used in the comparison of mapping methods, was acquired from Karttakeskus. Image acquisition was done 4/2004 and it possesses a 0.5m resolution.

3.2.2 Skyplot

During the planning of each days field work and during the actual field work the Skyplot function of Trimble TerraSync was used in order to evaluate the most feasible field working locations for each time period. The Skyplot window shown in Figure 4 demonstrates which of the numbered satellites are visible to the current location. On the top the total number of satellites from which reception is gathered is shown, as well as the accuracy with the current satellite constellation. To the left in the window the strength of the signal from each satellite is presented, while the figure in the center demonstrates where on the sky the satellite is located. The bar to the right in the window shows the Positional Dilution of Precision (PDOP) visually, while the actual PDOP number is shown on the bottom next to the coordinates and the elevation.



33°57'30.370"N 83°22'51.254"W
222.73m HAE PDOP: 2.42

GPS Settings: Max PDOP = 99.0
Min Elevation = 5° Min SNR = 12.0

Figure 4. Skyplot function available in Trimble TerraSync.

3.3 Software

OCAD is a CAD software specifically designed for mapping purposes and originally for the making of orienteering maps. It is approved by the International Orienteering Federation, which has a mapping committee to further develop and monitor current mapmaking practices. Currently 95% of orienteering maps around the world (Zentai 2008) are produced using OCAD. The versions of the software used in this project were OCAD 10 Student and OCAD 10 Trial.

ArcGIS 9.3 is a widely used GIS software made by ESRI. ArcGIS 9.3 is the world leading GIS software and provides for excellent data analysis and processing.

GPSView is a software, which came along with the iBT747A+ GPS Data Logger. This software gives information about the satellites' location in the sky at a selected point in time, according to which successful GPS-mapping may be planned.

Trimble TerraSync is the software through which Trimble GPS receivers communicate to PCs. It was used in Ngangao for planning fieldwork according to when the conditions were most suitable and for monitoring the Height Dilution of Precision (HDOP) values and skyplot while field working. The aerial image rectification points in Ngangao were recorded using TerraSync.

3.4 Hardware

3.4.1 GPS Receivers

Trimble Pathfinder ProXT is a dual band receiver, which tracks signals from both L1 and L2 in order to maximize position accuracy. By using both L1 and L2 bands the ionosphere error is corrected (Poutanen 2009), but in order to achieve this, the acquisition and navigational sensitivities on this dual-band receiver is decreased. While achieving a better positional accuracy it reduces the navigation sensitivity to about -145-150dBHz. This affects the chances of getting reception in bad signal conditions. RTK receivers like this are idealized for positional accuracy, not for sensitivity. Good positional accuracy and bad sensitivity do not however always go hand in hand (Kaisti 2010).

Trimble's ProXT GPS-receiver has the EVEREST multipath rejection technology incorporated. This feature reduces the multipath signals, which is important when mapping nearby buildings and large cliffs. The real-time accuracy is informed to being below 1m and the weight only 0.53 kilograms (Anonymous 2009b).

Garmin GPSMAP 60CSx is a handheld GPS receiver, which is said to be a high-sensitivity receiver (Anonymous 2010a). The navigation sensitivity of this receiver using a SIRFstar III microcontroller GPS chip is -159dBHz (Chow 2009).

The Magellan eXplorist GPS-receiver (Anonymous) was tested in Ngangao. Since the data conversion into OCAD was unsuccessful it was not useful for the study.

The iBT747A+ GPS Data Logger is a lightweight and small GPS receiver, as shown in Figure 5, which uses either Bluetooth Technology or USB cable for data transfer. The MTK chipset is reported to be "powerful and lean", powerful because rated and perceived sensitivity is on par with SiRFstar III and lean because the battery life of MTK based receivers was 3x that of SiRFstar III receivers. Sensitivities are informed to be: acquisition -148dBHz and navigation -165dBHz. The iBT747A+ GPS Data Logger has 66 channels (Anonymous).

3.4.2 Other hardware

Suunto t6c measures elevation based on the air pressure. Suunto t6c was used for acquiring elevation data when GPS acquisition in Ngangao was not achieved.

3.4.7 Panasonic Toughbook

A Toughbook Tablet PC for field working in both study areas. The touch screen Tablet PC with a Windows XP operating system may be carried in a purpose designed harness in order to perform ergonomically ideal field working. Three regular PC batteries were utilized in order to secure a power source during long field work days. The Toughbook is water-resistant and designed for field work and thus durable.

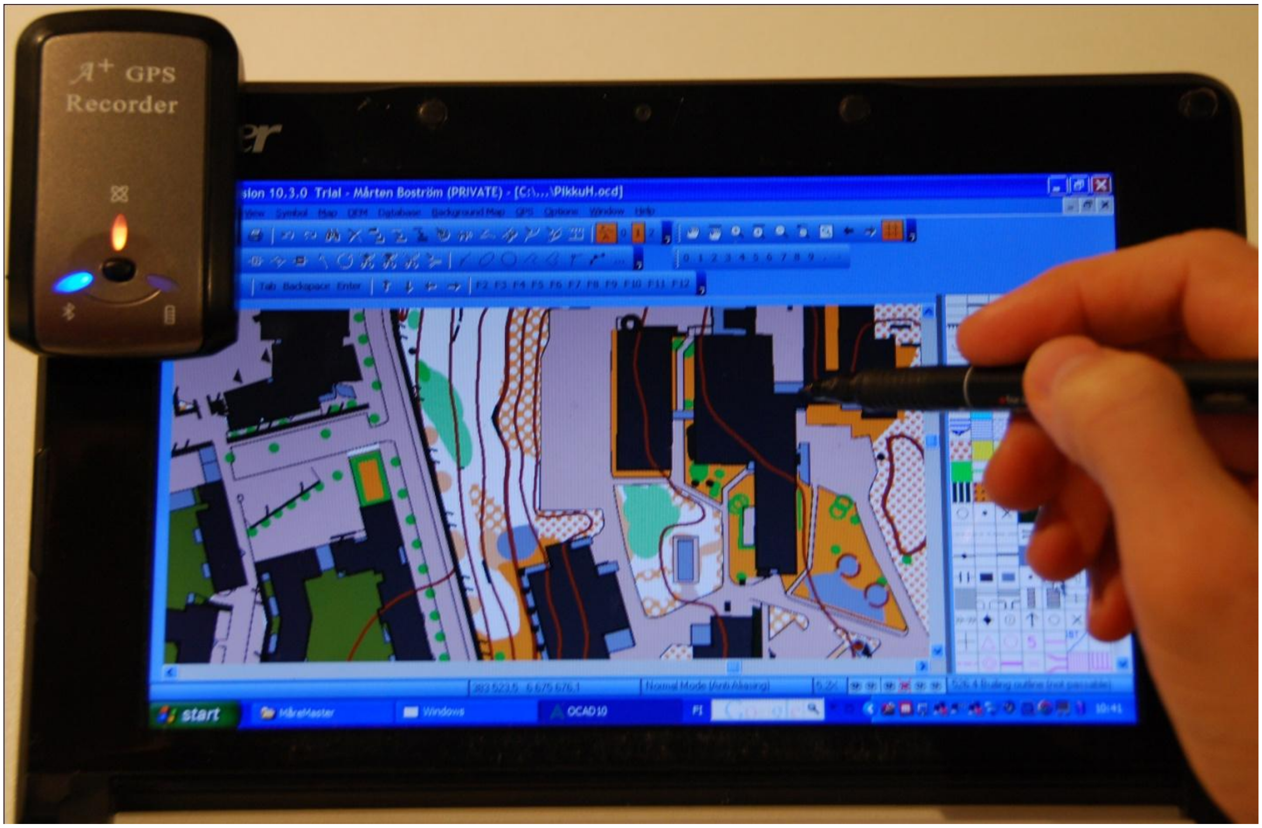


Figure 5. The iBT747A+ GPS Data Logger connected to a Tablet PC showing OCAD as used in field working.

3.4.8 Dell Inspiron E1405

Since the tablet PC (Panasonic Toughbook) does not provide an ergonomically ideal working form when working on a desk I used a Dell Inspiron E1405 in the initial data setup and to create the final layout of the produced maps. All the software used in the study, were also installed on this laptop.

4 Methods

The field work was carried out in OCAD using a 1:1,000 scale with the final orienteering maps being drawn in the scale 1:5,000 for Pikku-Huopalahti and 1:10,000 for Ngangao. The contour interval of the Pikku-Huopalahti map is 2.5m and 5m for the hillier Ngangao terrain.

4.1 GPS

The GPS position is shown on the screen in OCAD as a crosshair and when a symbol is selected the features in the terrain may be drawn automatically while traversing the terrain or draw the surroundings while the crosshair indicates the position of the GPS receiver.

4.1.1 GPS Timetable.

Especially when working in mountainous terrain one needs to plan ahead when the polar sky plot is feasible for GPS measurements and GPS signals are not blocked behind objects (Poutanen 1998). PDOP values gives the information needed for GPS accuracy.

4.1.2 Tablet PC connection

There are tablet PCs with built-in GPS-receivers, but when using one of these the user may not pick the ideal placement of the GPS receivers and may thus be blocking some signals. Since OCAD works only in Windows this study was restricted to a Windows Tablet PC, instead of a specifically designed portable GPS device with a built-in screen. The connection between the Tablet PC and the GPS is through Bluetooth or a USB cable so the used GPS receiver needs to have either of these capabilities.

4.1.3 Placement of GPS-receiver

The placement of the GPS receiver is critical as the human body blocks some signals. Keeping the GPS receiver on the belt will give an inferior result to keeping it one one’s head, where no signals will be blocked by the human body (Viitala 2009).

4.2 Preprocessing

Terrain mapping is always more convenient to perform during the dormant season, since the visibility is better, but certain features needs to represent the terrain in the season the map will be used on (Ake et al. 1989). Forests in which the runability changes between spring, summer and fall, needs to be mapped according to the circumstances when the event on the map will take place. Neither of these maps were produced for a certain event, so the field work on Pikku-Huopalahti was completed during the summer, which is the season during which the map will most probably be most used. The conditions in Ngangao do not significantly vary from one season to the other and mapping was thus done at most convenient time for researcher, in January.

4.2.1 Ngangao

ArcGIS was used for pre-processing of the orthorectified airborne digital camera image mosaic of Ngangao, the ArcGIS Land Cover Vector Model shapefiles of road, rock, field and pine forest. These layers of differing land cover were originally acquired from the Ngangao aerial image. The rock layer included all the bare rock features present in Ngangao forest. The imported road layer included all roads from footpaths to wide dirt roads as one feature type. The imported pine layer included pine forest, which are distinctive from indigenous and cypress forest stands and therefore this was converted to ISOM symbol *distinct vegetation boundary* (Persson 2000).

The first step for the road shapefile was performing Clip on the dataset in order to separate the data of study area. The road was selected by feature and the ArcMap Polygon Feature Class to CAD Lines was applied. This data was then exported to OCAD in .DXF -file format.

The corresponding operators were applied for the other shapefile features and exported in .DXF -file format to OCAD. The Metadata for the all exported feature layers are found in Appendices A and B.

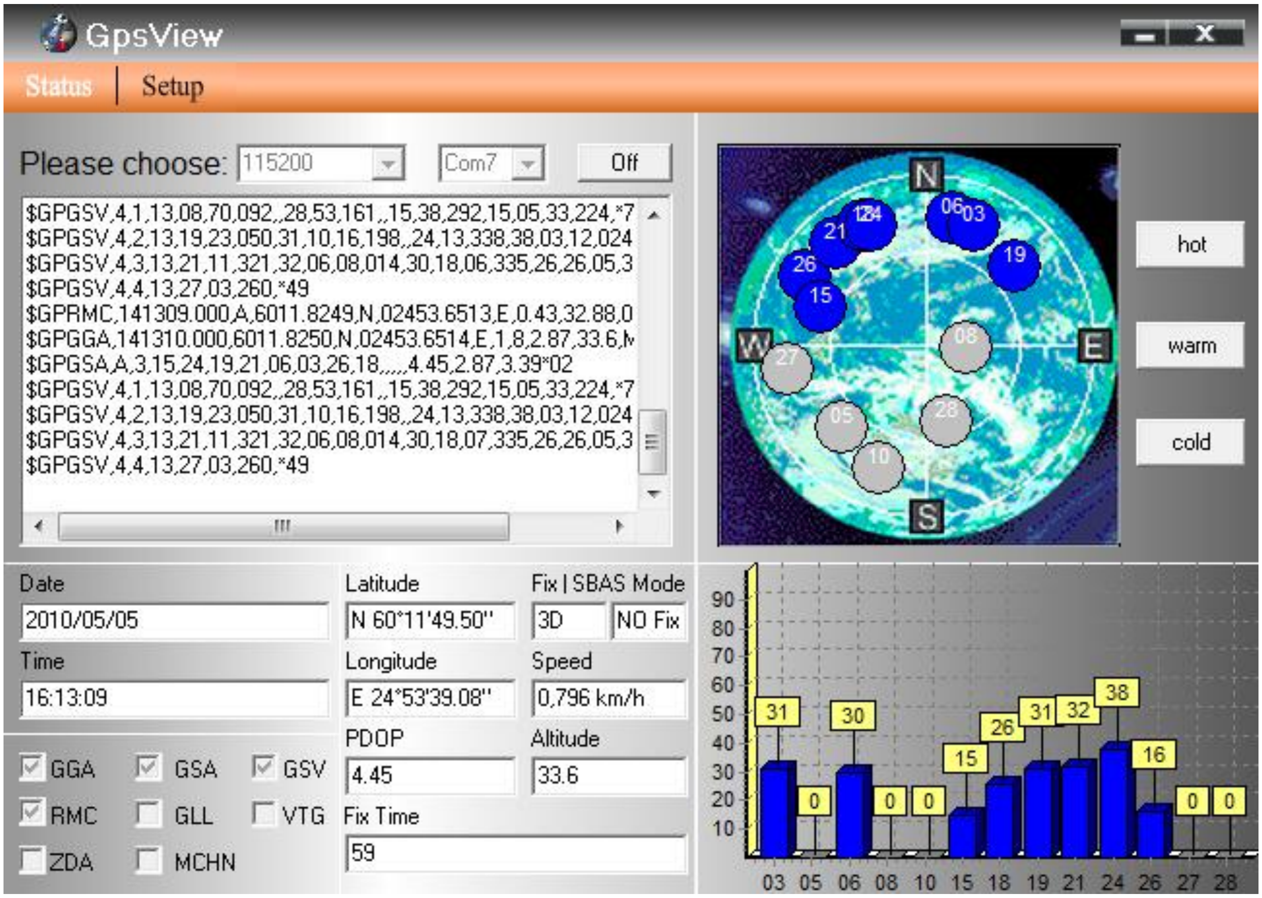
The Ngangao.tif aerial image was imported into OCAD as a background image and georeferenced based on the 11 ground control points using TerraSync, as shown in Appendix C. The points were acquired in the terrain using Trimble ProXT at such locations where the GPS signal was strong and the point easily found on the aerial image. The points are also scattered across the terrain in order to maximize the precision across the whole area.

Trimble TerraSync was used in Ngangao for planning fieldwork according to when the satellite conditions were most suitable and for monitoring the HDOP values and sky view while field working.

The DEM was derived from the Kenya Topographical Map of scale 1: 50,000. This dataset was imported into OCAD after which 5 meter contour lines with 25 meter index contour lines were calculated.

4.2.2 Pikku-Huopalahti

GpsView was used for setting up the connection between the iBT747A+ GPS Data Logger and OCAD and to check the current sky view showing the locations of satellites as shown in Figure 6. The window specifies the used connection on the top, followed by a list of details about the satellites, from which reception is available. The coordinates of the current location may also be seen as well as PDOP, Altitude and some other details concerning the connection. The top right half of the window displays the location of the tracked satellites in the sky graphically, while the bottom displays the signal strength from each of the corresponding satellites.



Please choose: 115200 Com7

```
$GPGSV,4,1,13,08,70,092,,28,53,161,,15,38,292,15,05,33,224,*7
$GPGSV,4,2,13,19,23,050,31,10,16,198,,24,13,338,38,03,12,024
$GPGSV,4,3,13,21,11,321,32,06,08,014,30,18,06,335,26,26,05,3
$GPGSV,4,4,13,27,03,260,*49
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$GPGGA,141310.000,6011.8250,N,02453.6514,E,1,8,2.87,33.6,M
$GPGSA,A,3,15,24,19,21,06,03,26,18,,,,,4.45,2.87,3.39*02
$GPGSV,4,1,13,08,70,092,,28,53,161,,15,38,292,15,05,33,224,*7
$GPGSV,4,2,13,19,23,050,31,10,16,198,,24,13,338,38,03,12,024
$GPGSV,4,3,13,21,11,321,32,06,08,014,30,18,07,335,26,26,05,3
$GPGSV,4,4,13,27,03,260,*49
```

Date: 2010/05/05

Time: 16:13:09

Latitude: N 60°11'49.50"

Longitude: E 24°53'39.08"

PDOP: 4.45

Fix Time: 59

Fix | SBAS Mode: 3D | NO Fix

Speed: 0,796 km/h

Altitude: 33.6

☑ GGA ☑ GSA ☑ GSV
☑ RMC ☐ GLL ☐ VTG
☐ ZDA ☐ MCHN

Figure 6. Skyview Status in GpsView software.

LiDAR scanned elevation data was used for contour lines on most of the Pikku-Huopalahti map. The work steps in ArcCatalog included creating a Geodatabase and Feature Dataset in it. The tools used were LAS to Multipoint (Avg point spacing: 1, Input Class: 2, Any Returns), where the laser signals, which were reflected from the ground were selected. The next step was creating a new terrain in the Feature Dataset (Approximate Point Spacing: 1, Default pyramid type, Calculate pyramid properties). The terrain was used to create a raster with the Terrain to Raster tool (Output Data Type: FLOAT, Method: LINEAR, Sampling Distance: OBSERVATIONS 250, Pyramid Level Resolution : 0). It was crucial to save this file in the Geodatabase. OCAD requires ASCII I used the Raster to ASCII conversion tool to get the data into the importable format.

The work in OCAD was initiated by DEM Import to convert the data to the ocdDEM –format. OCAD had to be closed and the ocdDEM reopened in order to be able to calculate contour lines from it. The contour lines were mostly good, except for a couple buildings, which had in LiDAR been classified as ground. Some small other errors, such as that in Figure 7, which were discovered during the fieldwork were also corrected. If the mappable area consists of several different DEMs they should be mosaicked together in ArcMap before importing to OCAD, since the boarders otherwise include gaps in the DEM.

The City of Helsinki Cadastral map was imported into OCAD as a .DXF file. Lines depicting different features were imported into separate layers, which made the conversion into ISSOM symbols simple. Some layers, such as water bodies could be converted directly, while the definition of other terrain features in the Cadastral map did not match those of ISSOM. For example fences had only one class in the Cadastral map while ISSOM separates between passable and impassable fences. Since orienteering maps aim to depict the terrain according to running possibilities and the Cadastral map is based on management and ownership the difference is understandable.

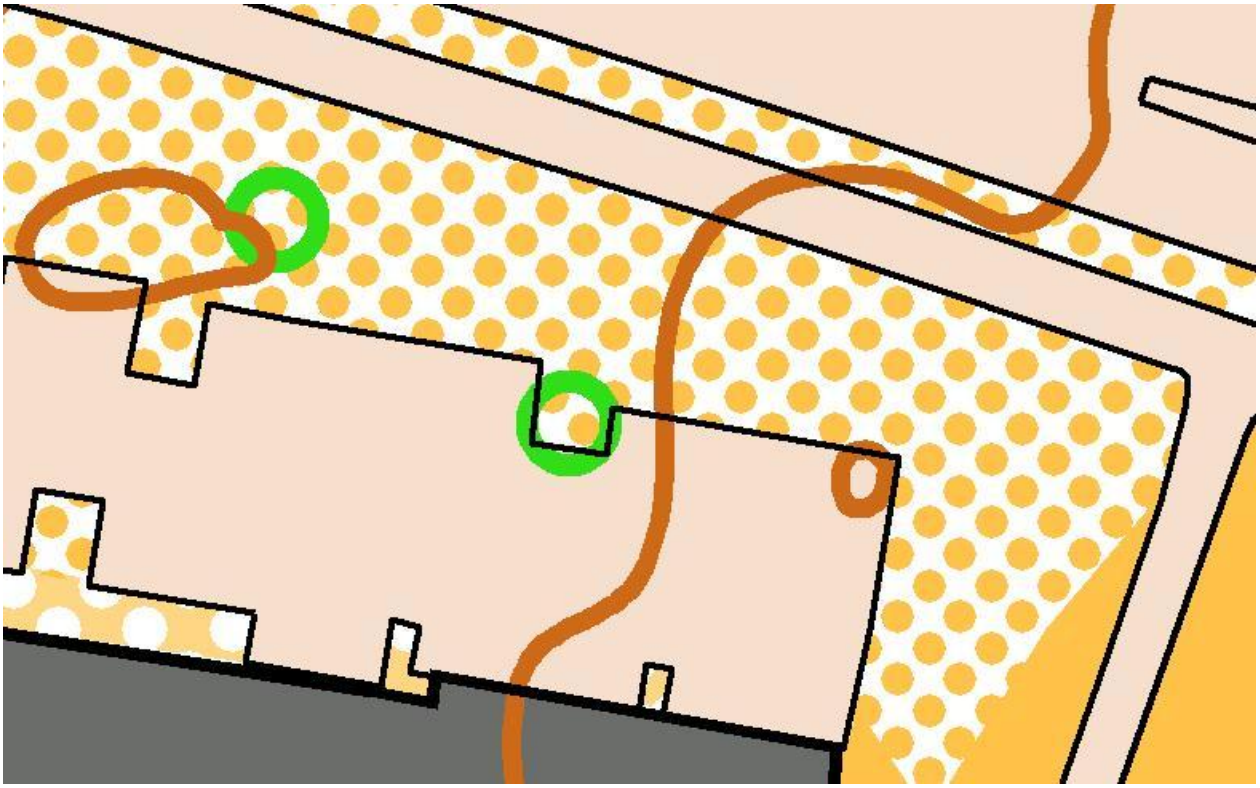


Figure 7. A LiDAR error in the northeast corner of the parking lot, where the LiDAR has recorded a car as a knoll.

4.3 Fieldwork

4.3.1 Ngangao

Garmin GPSMAP 60CSx was used for mapping trails in Ngangao by traversing the trails and recording the path. The Garmin GPSMAP 60CSx picked up satellite signals well, but the accuracy of the recorded path was subpar and not quite sufficient for the purpose of the study. The recorded paths were converted to OCAD format, but these trails had to be corrected during later field work sessions.

The contour lines acquired by digitizing from the 1:50,000 topographical map proved to be erroneous. The actual elevations in the DEM datasets were correct, but the geographical position of the elevations were incorrect. It eased the mapping process to have the correct contours on the map, but every single contour was dragged to the correct location according to observations in the field. A comparison between the finalized contours on the orienteering map and the elevation on the DEM is shown in Figure 8.

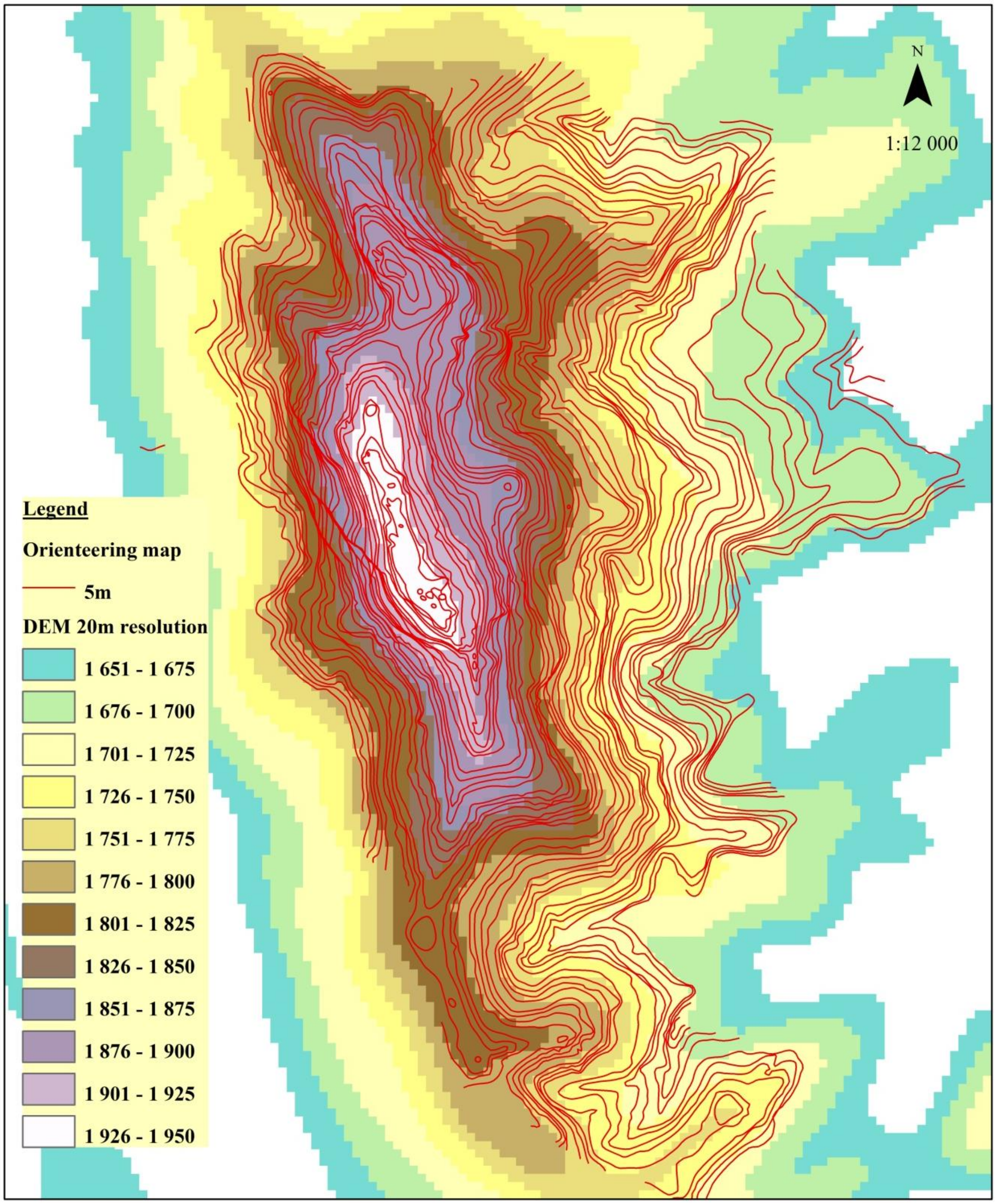


Figure 8. Comparison between orienteering map contours and DEM.

The ProXT GPS-receiver had problems picking up signals from satellites in the dense forest, of which a typical hemispheric view is shown in Figure 9, so I had to rely on signals from open areas from where I traversed with a compass bearing towards a predetermined direction. This way I was able to map areas where the canopy was too dense to acquire appropriate GPS-signals.

Acquisition of GPS signals was done by waiting in an open area, where good GPS reception was guaranteed, for a few minutes before to the start of each field working session. GPS receivers usually have lower acquisition sensitivity than the navigation sensitivity, meaning they require better GPS conditions for initial connection.

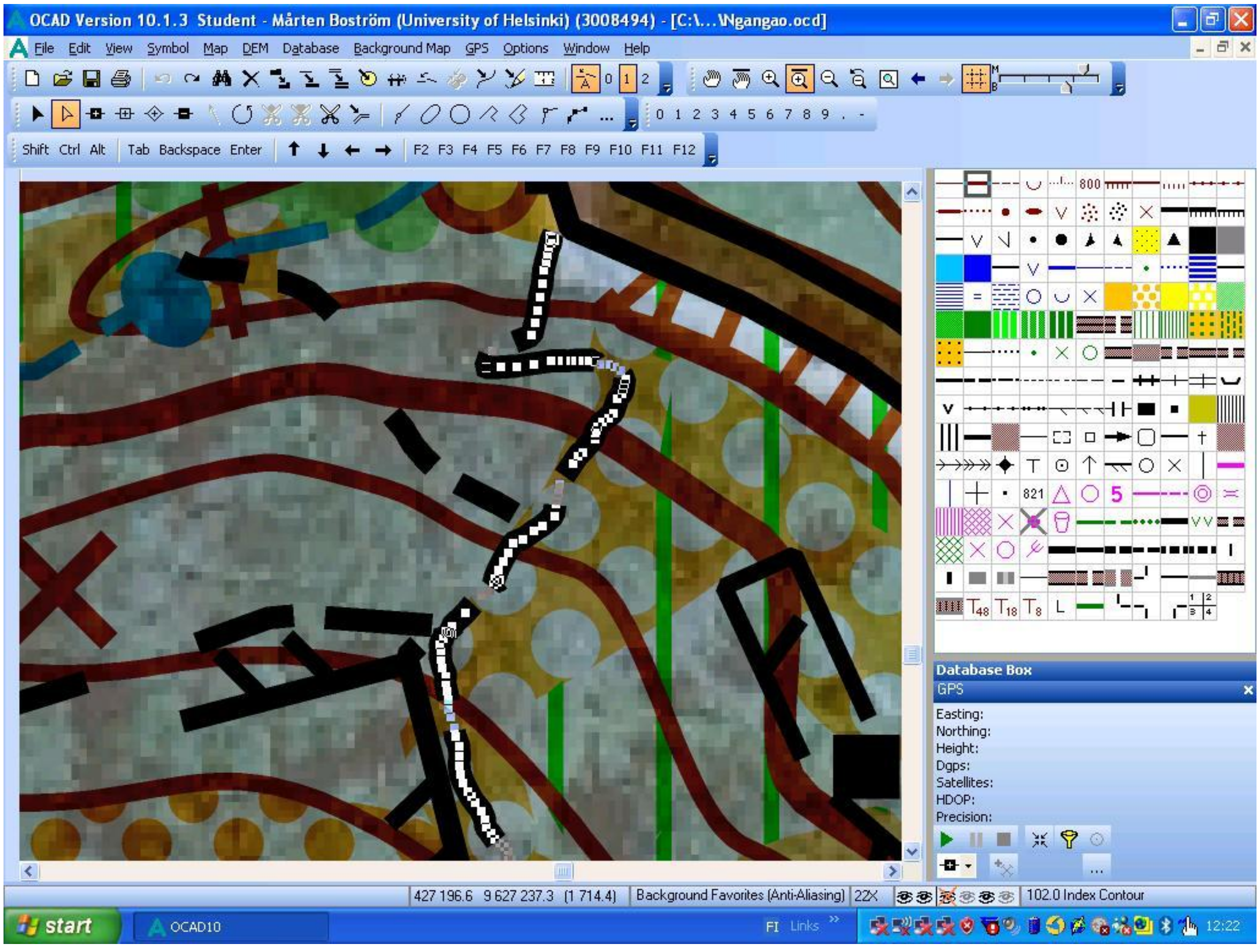
Figure 9. Hemispheric photograph showing typical view towards the sky in Ngangao (Gonsamo, Pellikka 2009)**.**

Since the GPS is not a very reliable method in measuring height, especially when the HDOP is low also a Suunto t6c, which uses air pressure for height measurements was used. In situations when a GPS fix was not acquired due to the conditions, contour lines were drawn based on the

Suunto t6c. Whenever a good GPS fix was acquired the GPS and the Suunto t6c altitude estimations were compared and the Suunto t6c was calibrated accordingly when needed.

The field work was started in the southern part of the area continuing northward according to the most feasible GPS conditions acquired from TerraSync. Since parts of Ngangao are compromised of a south-northerly ridge the slope on one side was mapped before moving to the other side. The GPS conditions are comparable for an extended time period in the same area.

The OCAD GPS window shows the geographical coordinates of the current position. Height, DGPS usage, the number of satellites, HDOP and precision are also shown. Point objects are drawn by picking the desired symbol from the right-hand side symbol window. Line objects may be drawn by recording waypoints while traversing, as shown in Figure 10. When using this method the number of vertices is usually too high as the GPS is constantly recording points of which some are erroneous. Therefore generalization during post-processing is needed in order to ensure the readability of the map.



427 196.6 9 627 237.3 (1 714.4) Background Favorites (Anti-Aliasing) 22X 102.0 Index Contour

Figure 10. Screen capture from OCAD workspace showing a section of a trail in Ngangao, which is recorded as waypoints.

Line objects may also be recorded manually, as illustrated in Figure 11, by recording a point at the start of the object and recording points at a sufficient interval to ensure the noteworthy features are included, while the readability is not jeopardized.

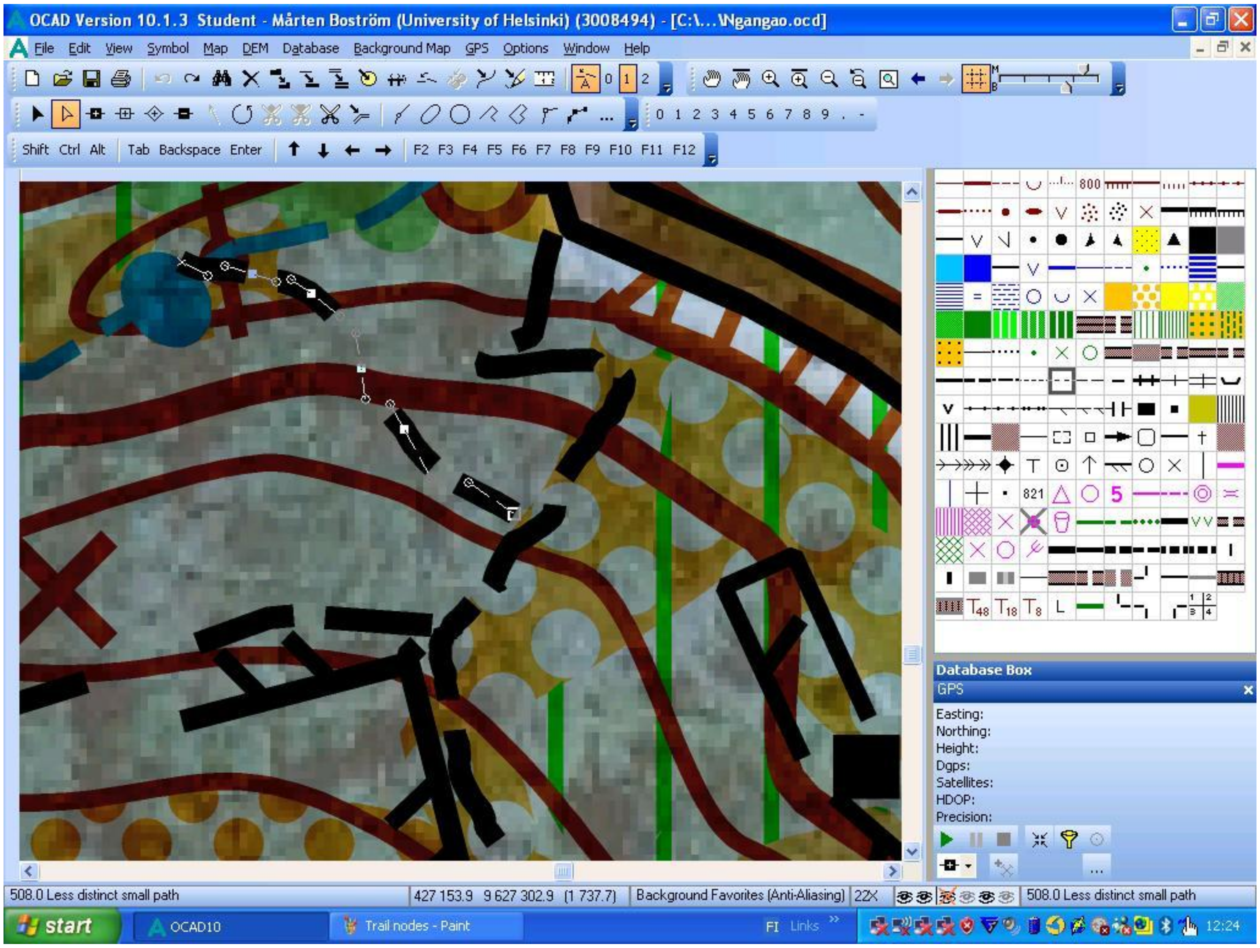


Figure 11. Screen capture from OCAD workspace showing a manually drawn section of a trail in Ngangao.

The “rock” layer acquired from the Land Cover Vector model (Pellikka et al. 2004) was compared to the “Bare Rock” features on the finalized orienteering map. Since the Land Cover Vector model is based primarily on aerial image interpretation while an orienteering map is drawn mainly based on field observations there is some deviation between these two layers. The large area in the north as seen in Figure 12 consists of shrub growing on a rocky surface. Since the vegetation in this area is very thick, prohibiting running, it is represented with ISSOM symbol “410 Vegetation, very difficult to run” (Tveite, Gloor & Zentai 2006) on the orienteering map, while in an aerial image interpretation the rock surface on the bottom is observed.

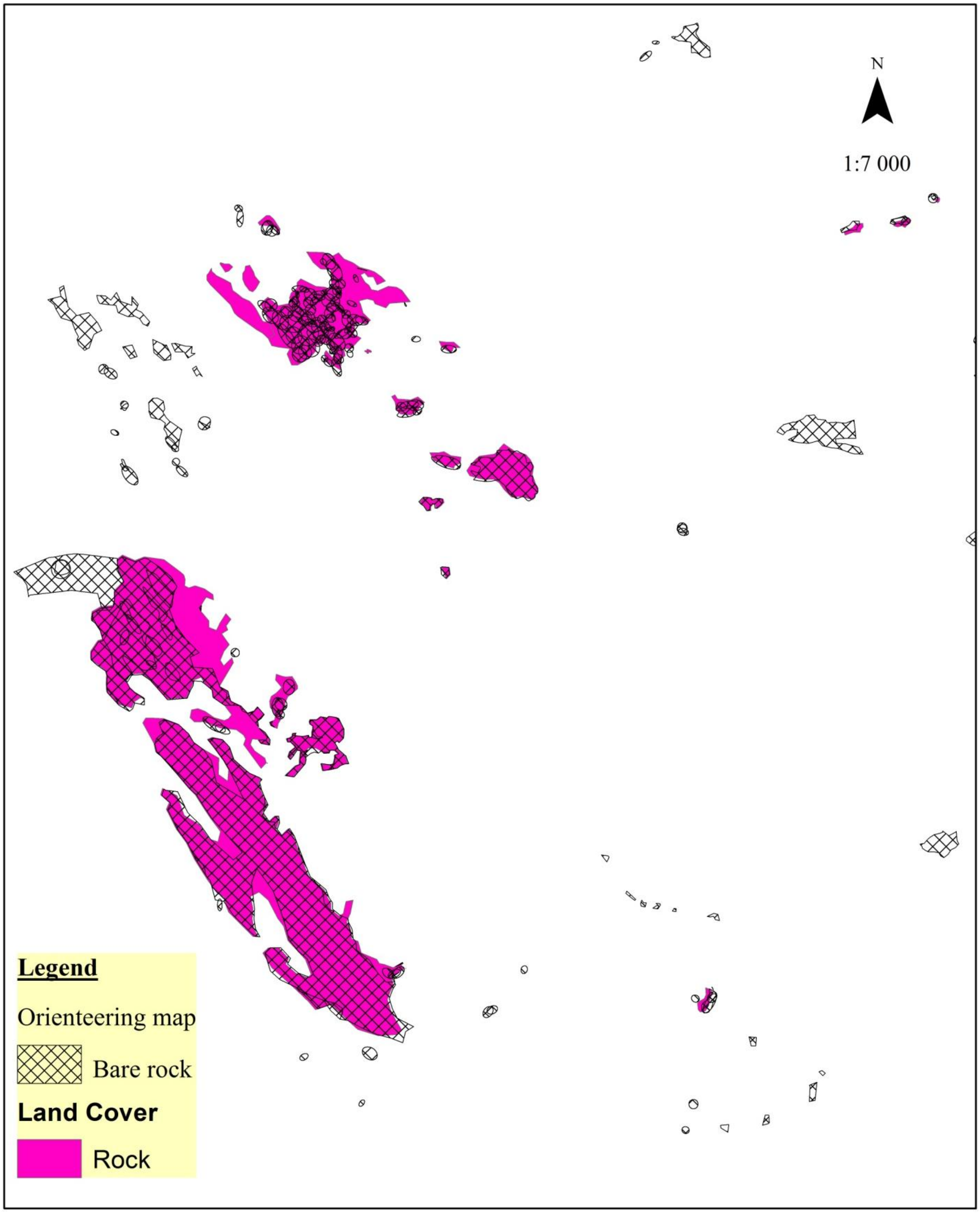


Figure 12. Feature comparison between land cover classification and orienteering map in the northern part of the Ngangao study area.

4.3.2 Pikku-Huopalahti

The field work in Pikku-Huopalahti was initiated in the southern part of the area, which was planned to be mapped. This area has the steepest profile and the tallest buildings in it so acquiring reliable GPS signals proved challenging nearby these features. Building outlines were simplest to map from a distance at a position where the GPS reception was good. Luckily the surroundings of the buildings in most of the map consist of open areas. It is effortless to zoom in while drawing in OCAD and therefore it is challenge to generalize enough in detailed sections such as inner yards. In order to make the map readable in running speed according to ISSOM one needs to simplify some features and concentrate on depicting the passages understandably. Inner yards that had signs declaring it to be private property were mapped as area with forbidden access.

OCAD enables the user to set the required HDOP target value so that the position is not shown when the HDOP is below this. By using this feature the mapmaker does not constantly need to monitor the HDOP value but may rely on the position displayed on the screen to be of good quality.

The whole eastern half of the map was drawn before work on the western part of the water body was started. The forest cover in Pikku-Huopalahti is not very dense and did therefore not disturb the acquired GPS signals considerably. Having good base material made drawing quicker in most of the mapped area. The eastern half of the map is more readable, which is partly because the terrain is simpler and partly due to better routine in urban mapping since this part was drawn last.

The contour intervals, which were derived from LiDAR data show absolute altitude. If a section of a parking lot is 20cm higher than the rest this is recorded in LiDAR. Objects like this were deleted and contour lines corrected accordingly to make the map more readable.

Two of the benchmarks of Uusimaa District Survey Office were visited during field work in order to check the accuracy of the GPS receiver in those locations. The two benchmarks (which both situated in the northeast section of the study area) were found in the field, but it was decided that recording of the GPS errors would not give more value to the study.

During field working several people were questioning the mapmaking and wondering about the equipment, which was carried while mapping. Urban areas like this the face constant changes, so the map should be checked in the field and updated accordingly before organizing events on it.

4.4 Post-processing

4.4.1 Ngangao

Since the time used for field work in Ngangao was limited the work on the map was concluded afterwards by cleaning up some features, which had been hastily drawn in the field. This work phase also included adding items such as a title, localizer map, legend, scale, village names and credentials as well as finalizing of the design.

4.4.2 Pikku-Huopalahti

The Pikku-Huopalahti map was finalized in the field, without any post-processing corrections needed. The map was delivered to the Rasti-Jyry orienteering club only in digital format as an OCAD -file since it exceeds the A4 paper size which is used in most orienteering events. The final layout of the map in each event is made based on the extent of the terrain area which is used.

4.5 GPS testing in Pikku-Huopalahti

An alternating route on which the variability of the GPS signal reliability varies in different terrain was planned. The route started on high open ground after which it traversed close to buildings, through tunnels in buildings, across streets of different width, through flat and gradually hilly forest, through forests with differing properties, across paths, underneath a major power line and nearby the ocean shore. I tested the iBT747A+ GPS Data Logger and Trimble ProXT by walking the exactly same path twice within an hour in order to have similar constellations of satellites and equally good DOP values. At both times I walked at a pace at which I would map line features, but which would be too fast for mapping the surrounding terrain within my field of vision.

It shows in Figure 13 that the iBT747A+ GPS Data Logger recorded a more truthful path, while the Trimble ProXT cut several corners along the path. While walking close to buildings the Trimble ProXT looses sufficient contact to satellites, which results in a straight line across buildings. Sharp corners proved to be challenging for both GPS receivers since the resulting line in these places is smoother than the traversed path, even more significantly smoother in the Trimble Pro XT recorded line. Both GPS receivers were most accurate in open terrain and in sparse forest regions. Also, when traversing in a straight line the resulting GPS line is accurate.

Figure 13. Path on which the GPS devices and GPS reception was tested on.

4.6 Comparing of mapping methods

Based on an aerial image of the Pikku-Huopalahti area (Figure 14) two approximately identical areas were chosen to perform a test between traditional mapping methods and the tablet-GPS system. Elevation data was not available for either of the areas. The areas are 3.4 hectares, the northern area has 7 and the southern area 8 buildings and both areas share the same terrain characteristics of mixed courtyard and urban forest. It was by chance picked between the two areas which would be mapped by which means. The result was that the northern test area was to be mapped with the Tablet-GPS and the southern area using traditional mapping methods.

4.6.1 Traditional mapping

Using traditional mapping methods it took 0.3 hours to prepare the material and equipment, that would be used in the field. It was calculated that scale 1:2,500 would be ample for the field work and color pencils were assembled atop a blank white paper on a specially designed map holder (also used in ski orienteering) attached to my chest. A compass and a ruler were used along with the altimeter found in the Suunto t6c during the field mapping process.

Field work was started by measuring the road at the southern edge and the road at the eastern edge to create a frame into which the remaining terrain features would be mapped into according to ISSOM (Tveite, Gloor & Zentai 2006). Features visible from the road on the eastern edge were mapped first in order to get some reference points for both positioning and elevation for the more challenging forest mapping. While traversing the road stride length was calculated to be used for later terrain measurements. The time spent completing the fieldwork totaled 3.5 hours. After this remained the scanning of the manually drawn map (Figure 15), importing of it into OCAD and digitizing of all the features on the map. The total time used for the mapping of the southern test site was 5.3 hours.

Figure 14. Aerial image of northwestern corner of the Pikku-Huopalahti study area from which the two areas for comparison of mapping methods were derived.

4.6.2 Tablet-GPS mapping

The test was begun by mapping the roads surrounding the mappable area and simultaneously recording the elevation. This way a frame to work within was established and the ends of most elevation curves in the area were mapped. Next all the roads and paths were traversed in the area as it would be easier to map the smaller areas in between. Following this step was proceeding north from the southeastern tip of the test area drawing all relevant features according to ISSOM (Tveite, Gloor & Zentai 2006). The total time it took for this way of mapping 3.4 hectares was 2.5 hours.

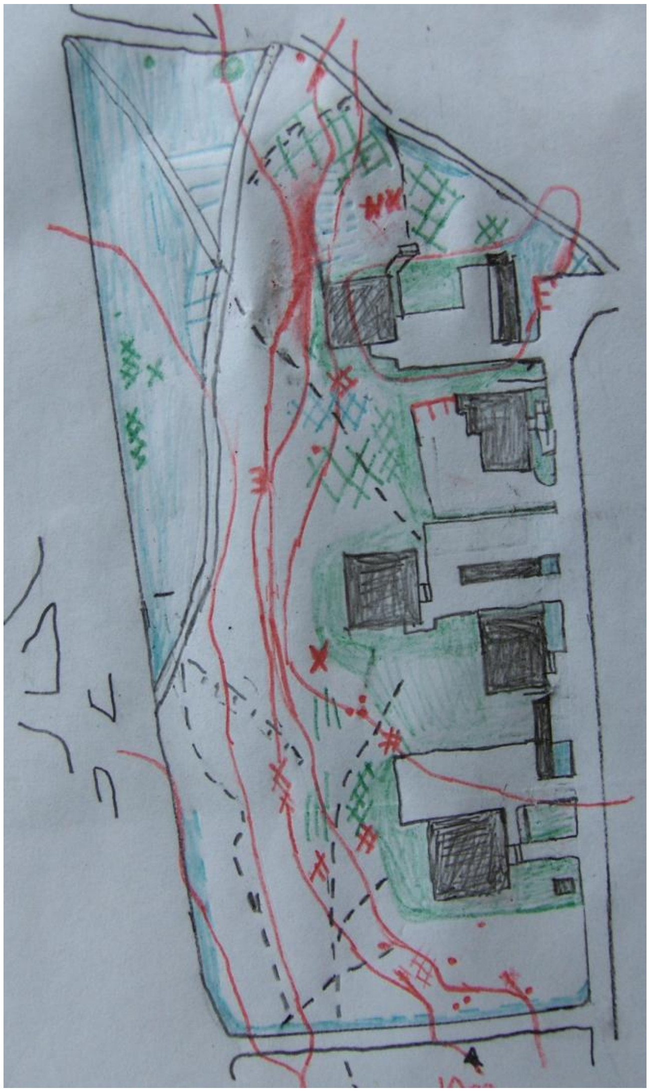


Figure 15. Field working concept of the southern test plot in scale 1:2,500.

4.7 Accuracy Assessment methods

Nine points were chosen on each of the GPS test sites on the Pikku-Huopalahti map which I was able to depict on both the map and the aerial image. The aerial image was rectified to fit into the OCAD map background using features surrounding the test sites.

5 Results

The requirements set forth by the ISSOM (Tveite, Gloor & Zentai 2006) and ISOM (Persson 2000) sets the standards for external quality. Fitness for use is the concept first introduced by Juran, Gryna & Bingham (1974), which implies that a product, in this case the orienteering map, bears the ability to satisfy the needs set by the standards. An orienteering map needs to be readable in running pace, which gives a challenge for generalization, but it also needs to have sufficient objects represented to ensure reasonable navigation in the most cumbersome areas.

5.1 Productivity

The total time it took to produce the Ngangao map covering 260 hectares utilizing tablet-GPS was 108 hours, which results in a total time of 41.5 hours per 100 hectares. This includes fieldwork and post-processing. According to Zentai (2008) it takes about 25 hours of fieldwork for each 100 hectares to make a map using the traditional mapping methods. In Finland mapmakers usually take 30-50 hours per 100 hectares of field working using stereographic base maps (Pikkarainen 2010). The time consumed varies however based on how good the available base map material is, how much detail the terrain has and on individual mapping styles.

The average cost of a stereographic base map is 380€ per 100 hectares (Pikkarainen 2010), so for a map the size of Ngangao the cost for this base material would have been 988€. The total cost for the maps produced using traditional mapping methods for the 2009 World Orienteering Championships in Hungary was on average 1550€ per 100 hectares (Zentai 2009). The cost of maps produced using traditional mapping methods varies from country to country since the availability and cost of orthographic photos differs. Considering the dense canopy cover in Ngangao the quality of a stereographic base map would probably not have been ideal for orienteering mapping.

Mapping of the Northern test site in Pikku-Huopalahti using Tablet-GPS mapping took 2.5 hours, while it took 5.3 hours to produce the map of the nearly identical Southern test site (Table 1).

These numbers suggest that the productivity of making orienteering maps utilizing a GPS - connected Tablet PC system is enhanced compared to using traditional mapping methods.

Table 1. Comparison of used time using different mapping methods.

	Traditional mapping	***Tablet-GPS mapping***
Area (ha)	3.4	3.4
Total time (h)	5.3	2.5
Time (h) /area (ha)	1.56	0.74

5.2 Accuracy assessment

Accuracy is the universal parameter used for navigation performance. It is the measure used to express the deviation or error of the estimated position to the unknown real-world true position. The term accuracy is used both for navigation tools and system errors. It is defined as a statistical quantity of the probabilistic distribution of position error (Petovello 2008).

Deficits in accuracy arise in Data Collection and Compilation, in Data Processing and in Data usage. The forms of error that occur include the Primary Errors; Positional and Attribute, as well as the Secondary Errors; Logical consistency and Completeness (Devillers, Jeansoulin 2006).

5.2.1 Root Mean Square Error

As discussed in section 2.3 the relative position is the critical accuracy demand on an orienteering map. Root-mean-square value is the positional accuracy requirement traditionally used for spatial data to compare the map representation to the corresponding position on earth’s surface (Devillers, Jeansoulin 2006). If the error is normally distributed, the statistical confidence level can be calculated from the root-mean-square error (RMSE) measurement as the standard derivation. The accuracy of an orienteering map can be grouped into vertical position accuracy and horizontal position accuracy. We require 95% of all points accurate to within half the contour to satisfy the vertical accuracy requirement. As the contour interval on my maps is 5 meter, the standard deviation of the elevation of the hill should be 2.5 / 1.96 = 1.28 meter. For one-dimensional errors, such as vertical errors, the 95% confidence interval region is 1.96 times the standard deviation or RMSE. Since there is a two-dimensional error distribution, the factor for 95% confidence is 2.447. With reference to our acceptable limit of 5 meter error, the RMSE should fall within 2 meter (5 / 2.447 = 2) (Wong, Lee 2005).

5.2.2 Attribute accuracy

Each object represented on the map must be appointed the correct attribute, as defined in the ISOM (Persson 2000) or ISSOM (Tveite, Gloor & Zentai 2006) specifications (Devillers, Jeansoulin 2006). For example green areas have to correspond to the actual runability of the represented forest and point objects on the map needs to represent the objects specified in the ISOM and ISSOM specifications.

5.2.3 Logical consistency

The topology of objects on the map needs to be complete (Devillers, Jeansoulin 2006). For example, roads should not have gaps, but the XY coordinates of the ending vertices of two separate segments needs to be identical. There must be no overshoots nor undershoots when two lines are connected in the terrain, but the lines in OCAD need to “snap” to produce a consistent topology. Buildings need to have identical starting and ending coordinates in order for the polygon not to ”leak” outside the border line of the feature.

5.2.4 Completeness

Completeness is an evaluation of the degree to which the map representation corresponds to the real world in accordance to the standards of ISOM (Persson 2000) and ISSOM (Tveite, Gloor & Zentai 2006). Non-conformance of the standards is measured by omission and commission. Omission is a situation that occurs where objects in the real world are not represented on the map. Commission occurs when an object is represented on a map but has disappeared in the terrain or is not to be represented on the map according to the specifications of the map (Devillers, Jeansoulin 2006).

5.2.5 Currency

Temporal validity is crucial in orienteering mapping, since progressing in the forest changes drastically from one season the next one. A map needs to be up-to-date in order to show the conditions in the race and guarantee fair play. Therefore the field work should ideally be done during the same season as the race for which the map is produced or updated according to the conditions of the race day.

5.2.6 Geometric Dilution of Precision

When visible GPS satellites are near each other in the sky (i.e., small angular separation), the DOP values are high; when separated by distance, the DOP values are low. Conceptually, satellites that are close together cannot present as much information as satellites that are far apart. Low DOP values stand for a better GPS positional accuracy due to the broader angular separation between the satellites used to compute GPS receiver position. HDOP, VDOP, PDOP and TDOP are respectively Horizontal, Vertical, Position and Time Dilution of Precision.

5.3 Ngangao

It is difficult to evaluate the quality of the Ngangao map (Figure 16) as objects on an orienteering map only need to be in the correct locations relative to other objects. There are not data of the same objects available as of today, but perhaps the quality of the Ngangao map could be evaluated in the future if LiDAR data is acquired.

Figure 16 (following page). Ngangao orienteering map, slightly scaled down to fit on page.

Mapped: 01/2010
Cartographer: Mårten Boström,
University of Helsinki, Finland
Ocad 10.1.13 Student: 3008494

Base material:
Orthorectified airborne digital
camera image mosaic 25.1.2004
Acquired by Petri Pellikka and
processed by Milla Lanne using
EnsoMOSAIC TAITA project,
www.helsinki.fi/science/taita

5.4 Pikku-Huopalahti

The results of the accuracy evaluation of the Pikku-Huopalahti map (Figure 17) from the chosen nine points are shown in Table 2. The table utilizes real world distances according to what the error on the ground, in the field, would be.

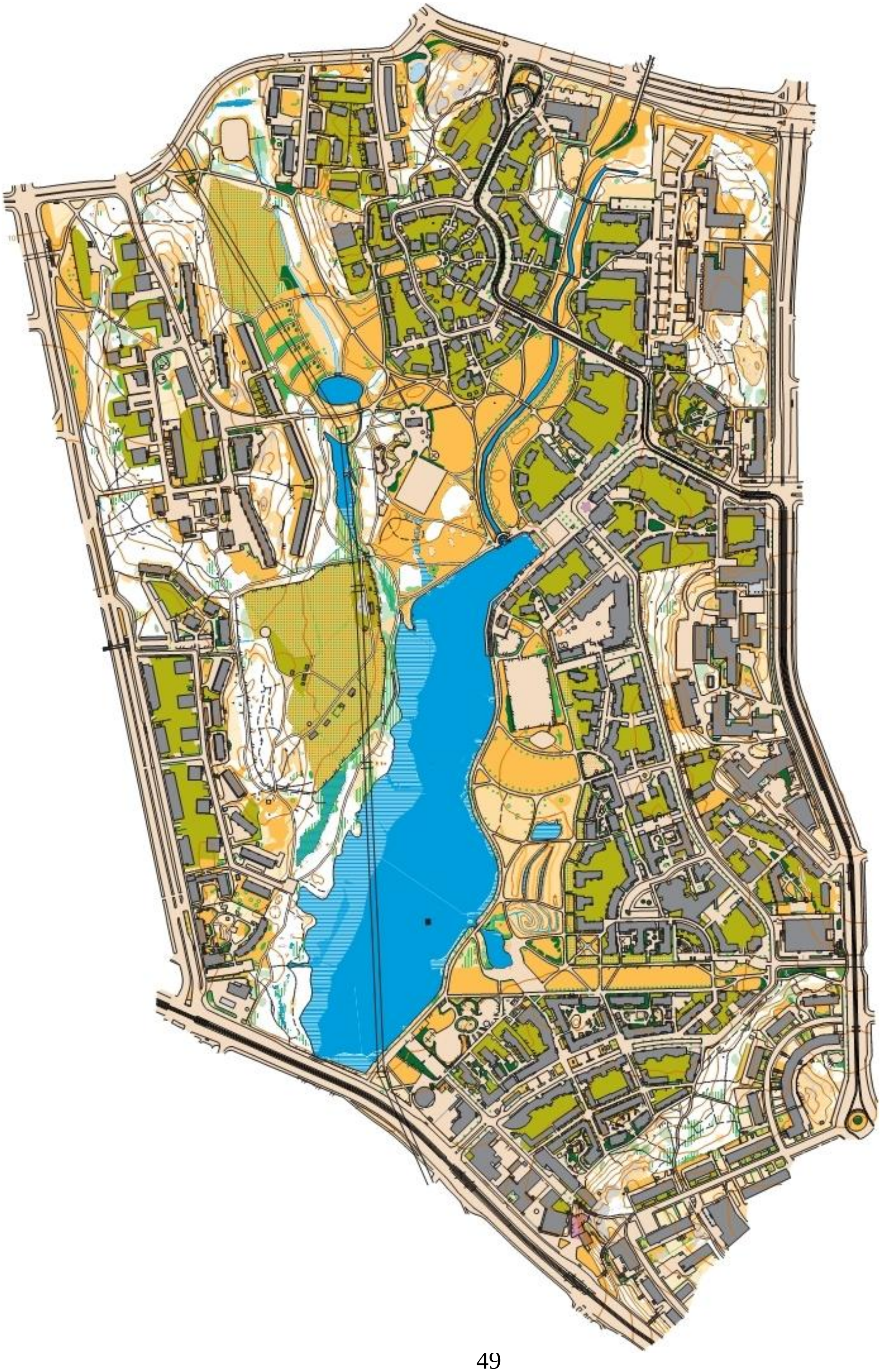
Table 2. Evaluation of final map product vs. Aerial image of Pikku-Huopalahti.

	GPS-Tablet mapping		***Traditional mapping***	
Point number	*Distance (m)*	*Azimuth (°)*	*Distance (m)*	*Azimuth (°)*
1	4,4	68	2,3	90
2	4,64	48	**12,49**	35
3	3,33	138	9,7	21
4	4,52	155	9,14	30
5	4,68	109	8,7	8
6	**1,23**	27	4,14	160
7	1,33	55	7,39	160
8	2,01	104	4,67	175
9	3,61	37	2,94	156
Average	**3,31**	82,33	6,83	92,78
Range	**3,45**	128	10,19	167
Max	**4,68**	155	12,49	175
Min	**1,23**	27	2,3	8
Standard Dev	**1,52**	**45,51**	3,38	70,63
Variance	**2,04**		12,12	

The positional errors vary from 1.33 meters to 4.68 meters on the Northern test site (GPS-Tablet mapping) and between 2.30 meters to 12.49 meters on the Southern site (Traditional mapping). On average the error is 3.31 meters on the Northern site while it more than doubles to 6.83 meters on the Southern site. The Standard Deviation is only 1.52 meters for the Northern site, but 3.38 meters on the Southern site. Further on the Variance is 2.04 meters on the Northern site but as large as 12.12 meters on the Southern site. All of these numbers prove that the Tablet-GPS mapping provided better accuracy than when using traditional mapping methods on these test sites.

The errors produced in GPS-Tablet mapping were randomly directed, while the errors produced in Traditional mapping shows some sign of clustering towards the same direction for Point numbers 6-9.

Figure 17 (following page). Pikku-Huopalahti orienteering map, scaled down from 1:5000 to 1:7500 in order to fit on page.



5.5 GPS reception

The reception of GPS signals are drastically limited by the tree canopy in equatorial indigenous forests, since the canopy may cover up to 100% of the view. With certain GPS devices one has to seek open areas where non-hindered sky visibility is available for accurate positioning.

The sensitivity of GPS receivers is a key factor in the GPS -connected Tablet PC mapping system. GPS receivers with a lower navigation sensitivity will not be able to pick up GPS signals in bad signal conditions, such as under thick canopy cover or close to steep hills or buildings. Based on the tested GPS receivers' navigation accuracy of >160 dBHz is preferred for accurate positioning. Dual-band GPS receivers with a lower navigation sensitivity are idealized for positional accuracy, not for sensitivity, and should therefore not be used in bad GPS acquisition conditions.

When mapping urban areas buildings will produce multipath situations. This condition is usually easily noticeable, since the suggested position is significantly shifted from the true position. Waiting for a different position is advised, but unless successful positions from nearby locations should be trusted.

5.6 Usability

The GPS -connected Tablet PC mapping system was tested in +30°C heat and in -20°C cold conditions as well as in rain, fog and snow. Being able to conduct fieldwork in various weather conditions is great advantage of the Tablet-GPS mapping method compared to traditional mapping methods. One needs to secure sufficient power sources for both the Tablet PC and the GPS receiver and make frequent back-ups in case of a system crash.

6 Discussion and future prospects of research

6.1 Productivity

The results of this thesis clearly demonstrate that utilizing a GPS -connected Tablet PC mapping system in orienteering mapping is beneficial compared to using traditional mapping techniques. The productivity numbers reported of time spent in the results do not give the whole truth of the effectivity of GPS assisted mapping, since it only compares the field work time of traditional mapping methods. The time spent for cleaning up and digitizing using traditional techniques is significant, while only minor corrections are needed when using a GPS -connected Tablet PC mapping system.

“Time is money” and “GPS is time” (McNeff 2002). The investment required assembling an operable GPS -connected Tablet PC mapping system will pay itself back not only economically, but through increased accuracy of orienteering maps. Mapmakers of the old generation will probably insist they work better using the methods they are accustomed to using and that the learning of a new technique would take too long to be beneficial. The author of this thesis would however argue that anyone investing the time to learn GPS mapping will see his or her productivity increasing within a short period of time. As soon as initial setup of the software and hardware is complete the continued productivity increase is withstanding.

6.2 Accuracy

Accuracy is according to the results of this thesis better when using GPS -connected Tablet PC mapping system compared to using traditional mapping methods. Since an orienteering map according to the ISOM specifications (Persson 2000) only requires objects to be in correct locations relative to other objects the significance of these numbers could be questioned. If the positional accuracy of the objects is exact, the objects are however arguably also in correct locations relatively to each other.

Accuracy could be further improved by using several GPS receivers and setting up one of the receivers as a base station to create network of observation. Also prolonging the time of observations should further decrease the position error (Næsset 1999).

6.3 Suggestions

When choosing the hardware to use in a GPS -connected Tablet PC mapping system one should make sure the GPS receiver has high navigation sensitivity to ensure mapping will be successful when the GPS reception is subpar. The tablet should be able to withstand rugged conditions and preferably have a harness to provide an ergonomical working form.

In the near future advances in Assisted Global Navigation Satellite System (AGNSS) should improve the positioning in urban environments (Syrjärinne, Wirola 2008). Within the next few years Galileo's Commercial Service and advancements in a network consisting of all global positioning system should bring down the constant positional accuracy to sub-meter level (Rainio 2010). With a greater number of satellites in the sky the acquisition of GNSS signals will improve.

As the Ngangao forest is located only 5 kilometers from the University of Helsinki Taita research station in Wundanyi, the map will be of use for researchers in the future for detailed navigation in the area. The data produced in Ngangao is also made available for researchers in ArcGIS format for use in future research. The map could be used for monitoring of the indigenous forest cover and the change in land use.

The Pikku-Huopalahti map will be used by the orienteering club Rasti-Jyry in their orienteering competitions and trainings. Since the mapped area is ideal for sprint orienteering and in close proximity to a great number of orienteers living in the metropolitan Helsinki area the map is expected to be extensively used for years to come. Two schools are located on the map, so the newly produced orienteering map provides a great opportunity for improved teaching in orienteering and an excellent source of motivation for increased exercise.

6.3 Future prospects of research

During this research two interesting questions which would require future research have arisen:

Does the quality of the GPS signal vary depending on the phenology of the forest?

Does the traversing pace affect the accuracy of the GPS logging?

In this study waiting for GPS signals in Ngangao was tested while using the Pro XT. No improvement in the reception was noticed. Other studies (Næsset 1999) however suggest differently. As productivity is one of the main reasons for discovering new orienteering mapping methods it does not make sense to have to wait for GPS reception, but instead do the field work while continuously traversing and still mapping all the adequate features.

Chopper images of the mappable areas could be used to prepare for the actual field work in order to cut down the time spent in the field. Coarse targets, such as open fields could be drawn using this method. The usage of chopper images ought to work well in open areas, as one may look at the same location from several directions.

The use of real-time Differential Global Navigation Satellite System (DGNSS) in orienteering mapping could be another possible research subject. The needed DGNSS-receiver is more expensive, but improved accuracy might level out the difference in cost over time.

Possibilities to future research on the subjects include incorporating raw LiDAR data with added potential for e.g. forest thickness analysis. The use of GNSS-receivers with adjustable sensitivity should also be studied. When the GNSS reception is inferior the sensitivity levels could be adjusted in order to receive less accurate GNSS signals, while during good GNSS reception conditions the accuracy would be maximized by adjusting the sensitivity level accordingly.

7 Conclusions

The tablet-GPS mapping system worked well in differing conditions - no matter if it rained or shone. Even humidity did not cause problems, contradictory to traditional mapping methods, drawing on paper with pencils. The time spent field working is considerable shorter when using a GPS -connected Tablet PC system compared to traditional mapping and thus also the total time and cost of mapping is reduced. The accuracy of the final map proved to be better using a GPS -connected Tablet PC mapping system, compared to the traditional mapping approach. Since traditional mapping methods includes several steps some error are always introduced when converting from one step to the next, especially in the process of digitizing.

“Time is money” and “GPS is time” (McNeff 2002). The investment required assembling an operable GPS -connected Tablet PC mapping system will pay itself back not only economically, but through increased accuracy of orienteering maps.

This study focused on the production of orienteering maps, but the results may be incorporated into any kind of terrain mapping, where the field work is a key factor for production. The demand for accurate maps, produced in a timely manner is beneficial for a great variety of fields in order to secure the safety of the environment we are living in. Utilizing GNSS in mapping procedure is in the current realm feasible, not only for producing maps faster, but also for improved accuracy.

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I am grateful for all the used datasets, which I was able to collect from a variety of sources and for the feedback and astonishing looks I received during fieldwork.

Thank you, Matleena, for giving an outsiders look from the inside into my research problems and for bearing with me when things did not go my way.

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APPENDICES

Appendix A

Ngangao DEM 20m Metadata

Horizontal coordinate system
Projected coordinate system name: Arc_1960_Transverse_Mercator
Geographic coordinate system name: GCS_Arc_1960

Map Projection Name: Transverse Mercator

Scale Factor at Central Meridian: 0.999600
Longitude of Central Meridian: 39.000000
Latitude of Projection Origin: 0.000000
False Easting: 500000.000000
False Northing: 10000000.000000

Planar Coordinate Information
Planar Distance Units: meters
Coordinate Encoding Method: row and column

Coordinate Representation
Abscissa Resolution: 20.000000
Ordinate Resolution: 20.000000

Geodetic Model
Horizontal Datum Name: D_Arc_1960
Ellipsoid Name: Clarke_1880_RGS
Semi-major Axis: 6378249.145000
Denominator of Flattening Ratio: 293.465000

Bounding coordinates
Horizontal
In decimal degrees
West: 38.313999
East: 38.364088
North: -3.323406
South: -3.385142

In projected or local coordinates
Left: 423794.406294
Right: 429354.406294
Top: 9632667.000025
Bottom: 9625847.000025

Appendix B

Ngangao Land Cover Vector model ArcGIS Metadata

Horizontal coordinate system
Projected coordinate system name: Transverse_Mercator
Geographic coordinate system name: Arc 1960

Map Projection Name: Transverse Mercator

Scale Factor at Central Meridian: 0.999600
Longitude of Central Meridian: 39.000000
Latitude of Projection Origin: 0.000000
False Easting: 500000.000000
False Northing: 10000000.000000

Planar Coordinate Information
Planar Distance Units: meters
Coordinate Encoding Method: row and column

Coordinate Representation
Abscissa Resolution: 0.500000
Ordinate Resolution: 0.500000

Geodetic Model
Horizontal Datum Name: D_Arc_1960
Ellipsoid Name: Clarke_1880_RGS
Semi-major Axis: 6378249.145000
Denominator of Flattening Ratio: 293.465000

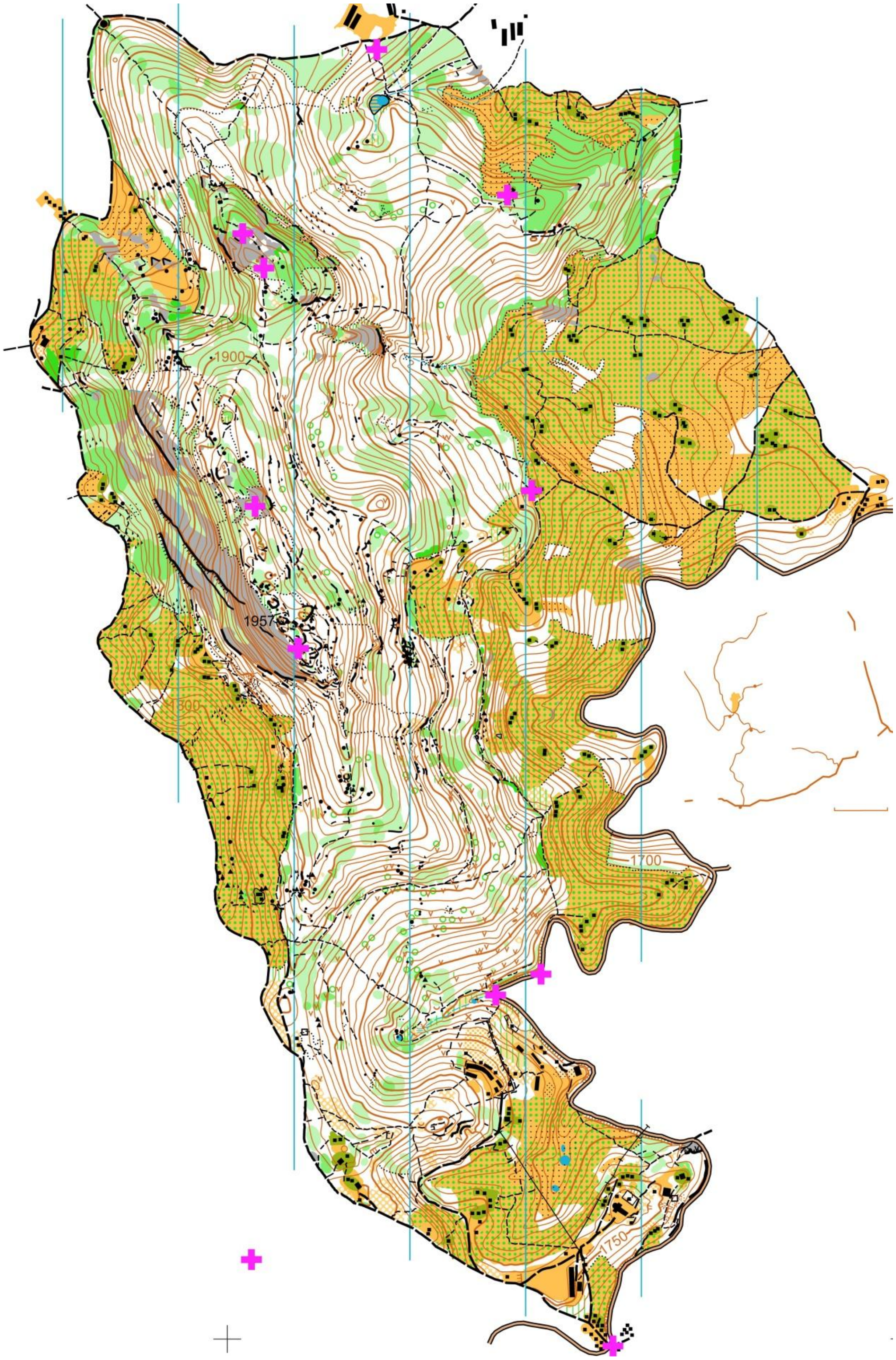
Bounding coordinates
Horizontal
In decimal degrees
West: 38.314110
East: 38.363996
North: -3.323537
South: -3.384979

In projected or local coordinates

Left: 423806.751474
Right: 429344.251474
Top: 9632652.560385
Bottom: 9625865.060385

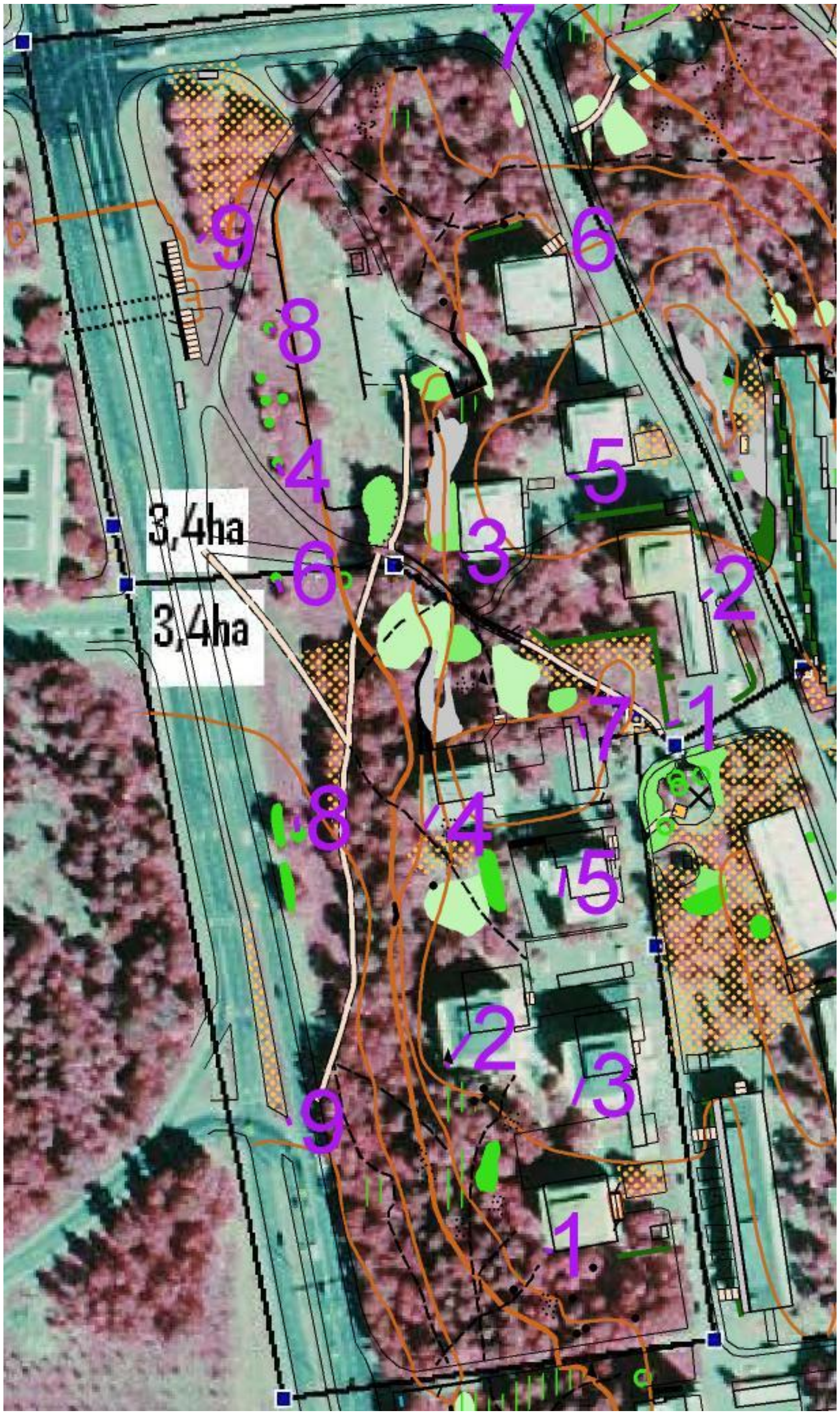
Appendix C

Aerial image rectification points in Ngangao, shown on the orienteering map



Appendix D

Rectification points for mapping method comparison in Pikku-Huopalahti

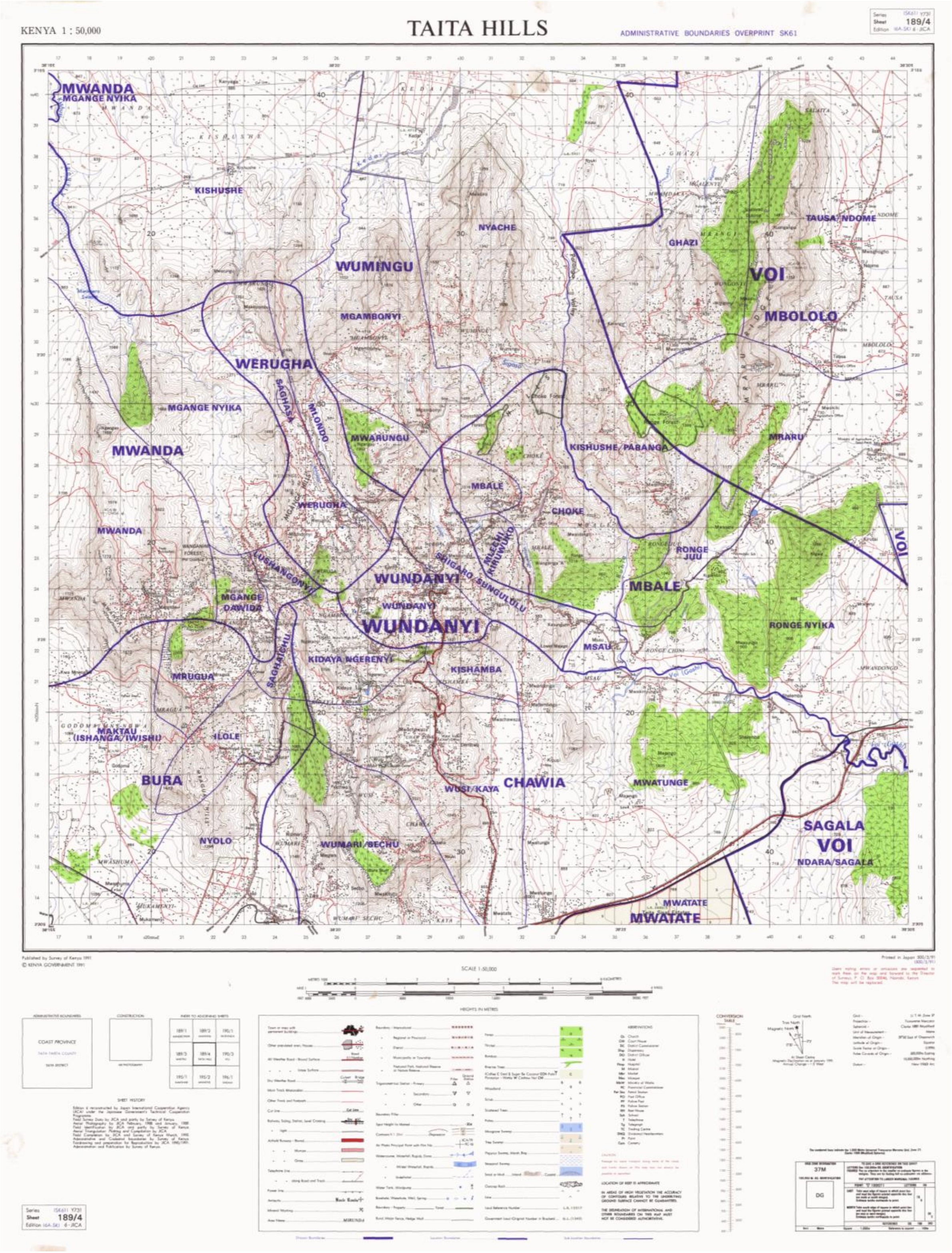


Appendix E

Orthorectified airborne digital camera image mosaic 25.1.2004 of Ngangao

Appendix F

Survey of Kenya map 189/4: Taita Hills, scaled to fit on page



Published by Survey of Kenya 1991