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"Where is the wisdom we have lost in knowledge -

Where is the knowledge we have lost in information"

(Eliot, T.S. The Rock)

ABSTRACT

The aim of this master's thesis ist to investigate the practicability and usability of mobile GIS applications in a selected real-world scenario in the field. Therefore the important questions are how to provide correct geospatial positioning values and how to support the gathering of useful data in extreme field situations by implementing a mobile GIS prototype. The whole project discussed in this thesis was initiated by the "Institute of Distributed and Multimedia Systems" (Faculty of Computer Sciences) through the "Austrian GRID" initiative in a close collaboration with the Umweltbundesamt, the "Federal Environment Agency of Austria". An environmental observation area in the national park "Northern Calcareous Alps" in Upper Austria, called „Zöbelboden“ was chosen to test the accuracy of GPS signals and according positioning data in forested or mountainous areas as well as to study the advantages and benefits of using mobile devices in outdoor situations and free nature. This area, a part of the UN ECE's Integrated Monitoring Programme, is used for long-term environmental data in selected observation areas. Exactly this project is a multi-disciplinary International Cooperative Programme (ICP) on Integrated Monitoring (IM) of Air Pollution Effects on Ecosystems, which covers regions of the United Nations Economic Commission for Europe (UN ECE).

In this master thesis a prototype will be introduced which allows capturing the desired ecological data digitally using a Personal Digital Assistant (PDA). An easy-to-use application based on ESRI's ArcPad Application Developer has been developed for use on Windows Mobile PocketPCs which integrates the Umweltbundesamt's own ESRI data layers. Thus, the mobile device is prepared for data integration into a data GRID infrastructure of the Umweltbundesamt. This new prototype is a GPS-assisted client, which enables location-awareness and further allows mobile users to augment the collected data with comments, digital photos, digital audio, or even small movies of artifacts, like trees and other plants. All digitally collected data by the mobile workers can be easily transferred to the Umweltbundesamt's currently used ecological information system MORIS (a relational database).

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1 INTRODUCTION

The motivation of this master's thesis is to investigate the usefulness of mobile computing for researchers in the field. Especially we focused on two main aspects, positioning accuracy and the overall usability in a field environment. The project was initiated as a part of the "Austrian GRID" (AGRID, www.austriangrid.at) initiative within a dedicated mobility work package (WP M-7b: Performance Engineering for Mobility in the GRID). The AGRID initiative is based on a national consortium in Austria to set up and to support grid computing in general and to provide coordination and collaboration between computer scientists for GRID technologies and developers of scientific computing applications. The aim of the consortium is to support and enhance advanced computing technologies in cooperation with well-recognized partners in grid-dependant application areas.

In the context of this AGRID project, this thesis is related to a close cooperation between the University of Vienna "Institute of Distributed and Multimedia Systems" and the "Federal Environment Agency of Austria" (Umweltbundesamt) with focus on a long term ecosystem monitoring program. The involved area of the monitoring activity shown in Figure 1 is called Zöbelboden, which is an environmental observation area in the national park "Northern Calcareous Alps" situated in Upper Austria. This area is part of the UN ECE's "Integrated Monitoring Program" and was set up to provide long-term data collection of pollution and ecological data.

The main objective of the joint AGRID subproject (from now on simply referred to as project) is to support and assist mobile workers in the case of collecting ecological data in extreme natural environments. Sarah Nusser [Nuss+03], [Nuss+04] conducts that especially mobile systems may be too complex and circumstantial during scientific field usage when researchers are interacting with objects or processing different tasks. In our current project we want to investigate if it is possible to provide a usable mobile client for this specific need, thereby deriving a scientific user's requirements, performing field tests, and investigating GPS accuracy in the field.

Currently, the collection of field data at the Umweltbundesamt is processed without support of mobile technology using paper filed protocols entered to the database afterwards, which results in a lot of paperwork and therefore costs a lot of time and resources. We expect that using a mobile device in the field provides high potential to save time and costs.

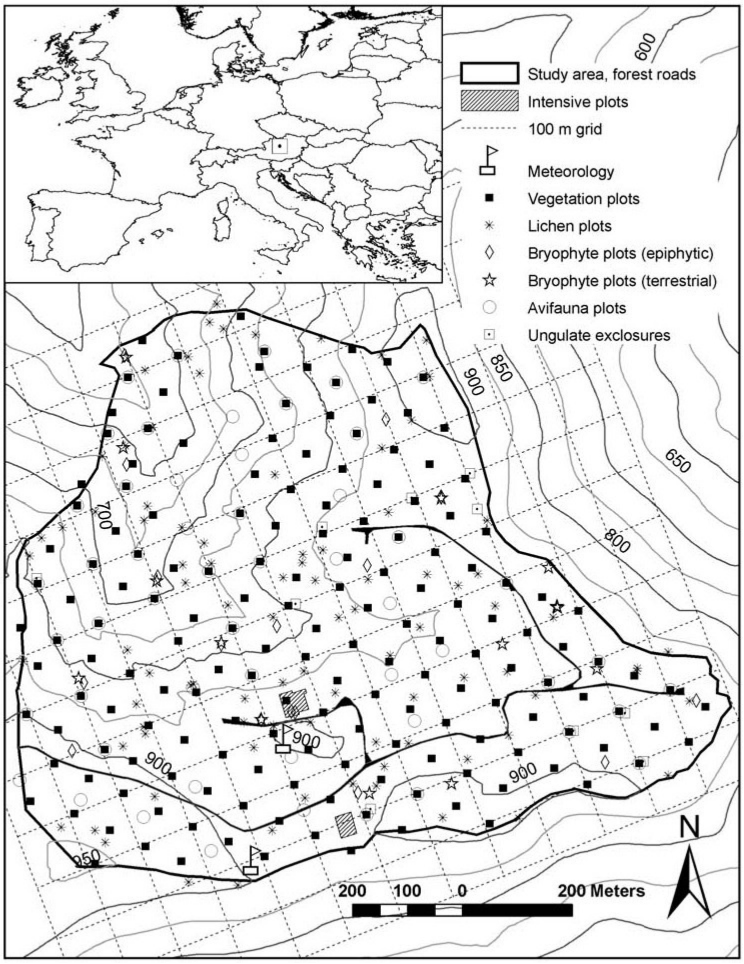

Figure 1: Zöbelboden Monitoring and Evaluation Area [Humm+06].

To exploit mobile technologies in a real world scientific application, we design and implement a useful und usable location-aware mobile client for immediate and user friendly data collection in field situations with provided opportunity of direct data integration into Umweltbundesamt's databases and therefore in a grid enabled and grid supported infrastructure.

The prototype is based on ESRI's Object Model provided by ArcPad Studio Application Builder [Arcb02] and ArcPad mobile GIS software [Arcp04] ensuring direct integration of Umweltbundesamt's own ESRI ArcGIS [Arcg06] data layers [ArSh98] of the monitoring area at the Zöbelboden plateau.

Location Aware Environmental Monitoring and GIS Application

The prototype should allow complete data capturing functionality using standard PocketPC or handheld devices with a continuous calculation of accurate positioning values, as already mentioned within Hasegawa's study on GPS accuracy in forest conditions [Hase+07]. With this we defined the following initial requirements: As already mentioned by Anand et al. [Anan+06], it should be possible to provide a usable mobile Geographic Information System (GIS) and data collection prototype solving positioning interferences and signal problems at extreme geographic locations. All digitally collected data should be easily transferred back to an ESRI database like ESRI ArcGIS or ArcGIS Server [Arcs07] and as a next step to the MORIS database referring to Schenz et al. [Schen+05] and Peterseil et al. [Pete+05], which represents a specific ontology based oracle database later discussed in this document.

In our case we generally focus as a first step on a single-user mobile environment development with a specific observation area's data set. In more detail we applied the configuration from a distributed system involving a separated data structure (MORIS database) and GIS server structure (ESRI ArcGIS Server). An interesting aspect of the prototype development is the data collection process of various parameters of defined permanent plots and trees situated at the monitoring site, allowing to capture additional data like pictures and other multimedia data and to link it with monitored objects and points of interest.

The usability of this prototype will be determined by interrogating the target users and the gained accuracy of GPS traces will be investigated by collecting geospatial data, in terms of changes of defined permanent observation areas (termed permanent plots) and monitored objects, like trees, at the monitoring site. These investigations represent a feasibility study to decide, if future development of mobile data collection clients is reasonable for this kind of observation work at extreme geographic locations. We summarize the various criteria for this study by the ease of use in free territory, the quality of captured environmental and scientific data and, of course, its achieved quality of positioning values in this kind of environment.

Aspects of "Mobile Human Computer Interaction"

It is intended to produce a mobile prototype which can be easily used in outdoor situations, especially with a strong focus on mountainous territory. Location-aware mobile clients can be single-user and multi-user systems as mentioned by Ashbrook et al. [Ashb+03] or as referenced by Pham and Wong [Pham+04] such systems can be designed within a multi component system with different structures depending on where data is stored, which server environment handles data transfer and how spatial data and gathered information is processed with a defined client structure. In this project we design a loose coupled single-user mobile client, offering manual data integration capabilities to UBA's existing data structure and GIS server infrastructure.

Focusing on usability aspects Jason Pascoe et al. [Pasc+00] defined Human Computer Interaction (HCI) in fieldwork environments by four characteristics:

- Dynamic user configuration
- Limited attention capacity
- High-speed interaction
- Context dependency

To consider these aspects within this work, we strongly concentrate on limited attention capacity, high speed interaction and context dependency, because these are the main aspects of an intuitive and convenient use in free field. It is important, that the usage of the prototype should not bother the mobile worker in extreme field situations.

Following initial challenges were defined for the proposed prototype:

- A clearly laid out, easy to use and functional arranged application structure
- A fully functional graphical user interface specially designed for Umweltbundesamt's needs
- A continuous display of geographical maps and important spatial objects
- The ability to include multimedia-based data (pictures, audio, videos, etc.)
- An interface for integration of collected scientific data into UBA's ESRI Database and integration into the MORIS database.

Implementation Supporting Mobile Work

In the following chapters of this document a prototype will be introduced which allows capturing the desired ecological data digitally using a PocketPC aka personal desktop assistant (PDA). An easy-to-use application based on ESRI's ArcPad Application Developer is been developed for use on GPS capable Pocket PCs with Windows Mobile OS which integrates the Umweltbundesamt's own ESRI data layers. Thus, the mobile device is prepared for data integration into a data GRID infrastructure with an UBA customized database interface for MORIS. This new prototype is a GPS-assisted client, which enables location-awareness and further allows mobile users to augment the collected data with comments, digital photos, digital audio or even small movies of artifacts, like trees and other plants.

A simple algorithm for determining nearest situated points of interest (POI's), in our case permanent plots, is implemented for use in our prototype depending on the current GPS data received. It calculates the distances of near situated spatial objects and shows it to the mobile user. This functionality is supposed to improve the usage of the mobile client and user's interaction in future by advancing the overall monitoring process. It is further expected that better positioning hardware and extensions like a compass device or a rangefinder component will also help to improve accurate detection and identification of scientific points of interest for our use case.

Structure of the Thesis

After a first introduction in chapter 1, we introduce fundamental positioning technologies and related applications in chapter 2 to give the background of knowledge needed for this thesis. As we used the stable and already widespread GPS positioning technique within our project, we are going to discuss the GPS technology in detail as well as basics of other positioning techniques in this area. Chapter 3 focuses on related work and already implemented GIS projects in order to show possibilities and approaches in this sector to provide an overview of different approaches in the same thematic area.

Chapter 4 concentrates on our project with the Umweltbundesamt and the involved information needed within ecological field studies. In the following chapter 5 we are going to introduce the prototype's concept and an overview of its desired functionality. Based on the requirements defined, chapter 6 informs about our concrete ArcPad prototyping work and software based background of the mobile prototype. It shows the techniques and methods used to implement and customize our prototype for Umweltbundesamt's needs.

Within chapter 7 we discuss the used technical equipment and mobile devices, the evaluation of the prototype within the field tests and gathered statistical information of the positioning quality. As outcome of this analysis we define metrics for positioning quality by analyzing positioning values gathered by different devices.

Finally, in chapter 8, we show our conclusions and possible outlooks for future work in the area of mobile positioning and location-aware applications.

2 POSITIONING TECHNOLOGIES AND APPLICATIONS

Accurate positioning is very important for the present work. Thus, here the fundamentals for positioning techniques are explained. As there are many different hardware based positioning techniques, systems and services available, we focus in the following part of this chapter on a short overview of fundamental positioning techniques and in the second part we concentrate on satellite based positioning techniques and specific enhancements relevant to our project.

Further there are many software based Geographic Information System (GIS) solutions and software packages available for server applications, desktop use, or mobile use especially for field worker. These systems basically enable analysis and handling of geospatial information. Hence we introduce in the third part of this chapter important GIS software packages. There is a wide range from commercial software packages to open source distributions, providing spatial and geographical services in conjunction with hardware based localization techniques.

Overview Positioning Techniques

Positioning techniques, systems and services provide geospatial information and therefore location-awareness to the end-user. Many applications can be enhanced by positioning systems offering various geospatial problem solving solutions either in personal, scientific, business or industrial use conditions. There are many different forms of location-based techniques available like cell based, infrared based, wireless LAN based or even satellite based localization systems. Each of these location-based services utilizes different base technologies (referring to Jürgen Roth [Roth05]). We want to describe three primary technologies for positioning which are Cell of Origin (COO), Time of Arrival (TOA) which also incorporates Time Difference of Arrival (TDOA), and as a last key technology Angle of Arrival (AOA).

Cell of Origin (COO)

This technique is usable within positioning systems based on a cell structure. Wireless transmission and telecommunication systems are often restricted to a limited range of coverage, which allows to assign a mobile terminal to a cell according to the area the user currently resides in. Therefore identification and measurement of position is derived from the cell information given by the system (as mostly used within GSM or UMTS networks).

This technique is often combined with the measurement of signal strength. Simply this method of calculating the position with signal strength needs sender devices due to known positions. As often used within wireless local area networks (WLAN), some access points exactly known are measuring the various signal strengths to a client and then approximating the position of the device.

Time of Arrival (TOA), Time Difference of Arrival (TDOA)

TOA and TDOA basically depend on the delay of electromagnetic waves and therefore on the speed of light which is about 300.000 km per second. Modern measurement devices enable to exactly quantify run-time periods of radiowaves and accordingly it is possible to compute nearly exact distances and the position of sender and receiver (as used within satellite based positioning techniques). When using this technology in connection with GSM or UMTS networks, it is also called Enhanced Observed Time Difference (EOTD).

Angle of Arrival (AOA)

When calculating positions by measuring angles we need a point-to-point or beam radio link system to determine the direction of the signal source. When receiving this targeted radio signal, it is possible to measure angles. This is done by measuring spatial reference objects, by combining measured angels it is possible to calculate the angular separation and therefore to estimate the position of the receiving device. For example antennas with direction characteristics allow measuring the direction of the received signal. This method is usually used by antenna arrays which can simultaneously measure different directions of a signal and, thus, estimate the position of a mobile device.

Satellite Based Positioning Techniques

In the next sections we focus on satellite based systems and services since they are used in the thesis project. For a better understanding we will now introduce the major technologies in this field, beginning with the wide spread NAVSTAR Global Positioning System (GPS) [Long+81]. Secondly we will pass on with its improved part Differential Global Positioning System (DGPS) corresponding to Beisner et al. [Beis+96] or as a counterpart Satellite Based Augmentation Services (SBAS), improving the overall positioning quality with additional correction signals. As a third important point we introduce the rarely used Russian positioning system Global Navigation Satellite System (GLONASS), which differs in some points to the GPS system. All mentioned satellite based positioning services grant real-time accuracy in free environments between 10 to 25 meters. With additional data required from separately geodynamic services (e.g., International GPS Service (IGS) for Geodynamics Centre) or additional satellite services (like SBAS) for GPS positioning systems, it is possible to grant real-time accuracy up to few meters and post-processing accuracy within some centimeters regarding to Zarraoa et al. [Zarr+98].

In order to provide correct positioning data within satellite navigation we are going to introduce coordinate systems to reference a geographic point on the earth's surface in a definite way. There are three main forms of referencing geospatial information displayed on Figure 2 [Roth05].

One of the most used method referencing this kind of information is a geodetic coordinate system using an ellipsoid for modeling the earth's surface, like the "World Geodetic System 1984" (WGS84) used for GPS positioning (refer to Figure 2 Part 1). Another but rather rarely used method (e.g., used for intermediate calculations) is a geocentric or cartesian coordinate system. This method specifies the position within three axes (refer to Figure 2 Part 2). The most accurate method is the transverse mercator projection. This projection divides earth's surface into different segments on a plain map projection which ensures very high accuracy of the projection (refer to Figure 2 Part 3, planar or transverse mercator projection). There are two important coordinate systems to mention within this projection method. On the one hand the Gauss-Krüger geographic coordinate system (GK) which is specifically subdivided and aligned to different geographic maps and on the other hand the Universal Transversal Mercator coordinate system (UTM) which defines a complete projection sight of the whole world.

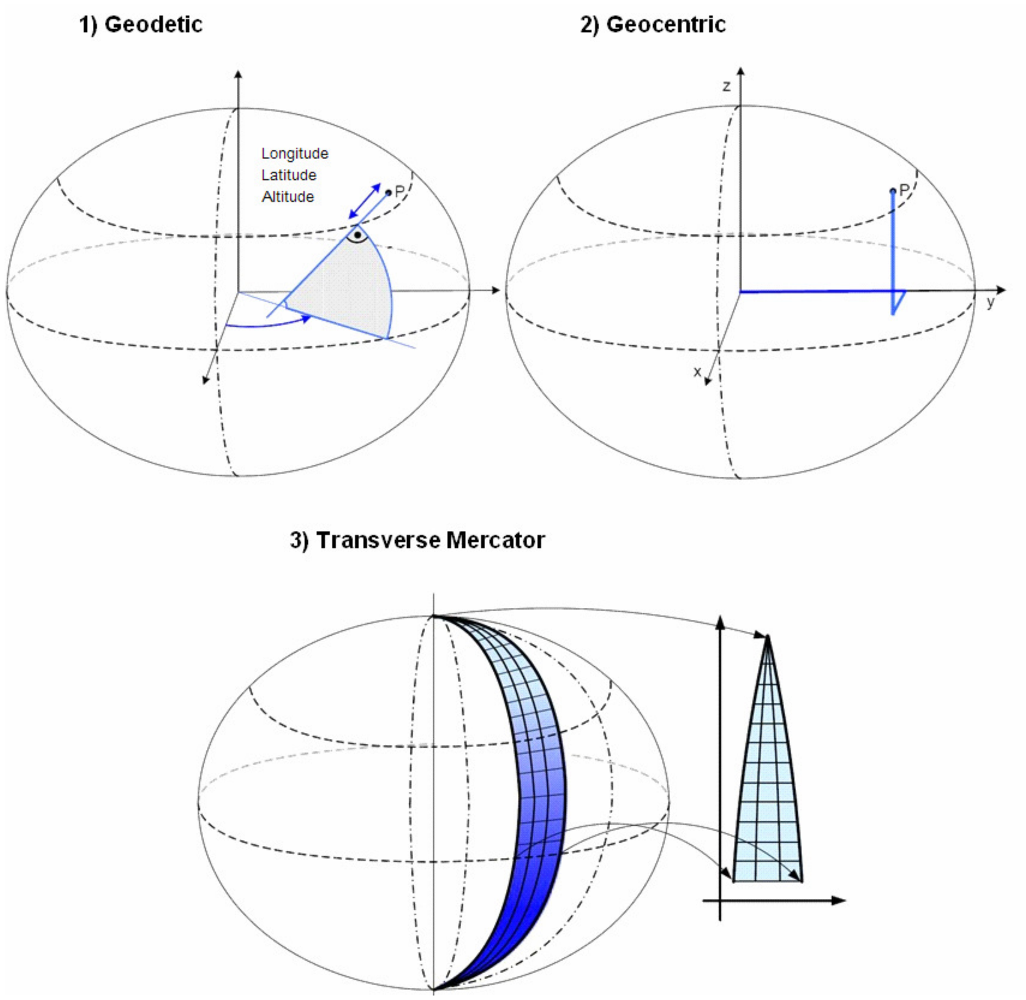

Figure 2: Coordinate Systems [Roth05].

If different coordinate systems are used for projection, we need to point out specific transformations to correctly align spatial objects on maps. The difference between various coordinate systems is commonly referred as a datum shift, which will be dealt with in context to our project in chapter 7.

Though satellite navigation provides the most accurate instant positioning method usable for every outdoor usage on earth locations, we should mention several error sources that influence satellite navigation. These errors are caused and affected by ionospheric propagation, receiver clock errors, multipath receiving problems, tropospheric propagation, ranging errors, multipath mitigation or onboard clock errors.

Global Positioning System

The Navstar Global Positioning System (GPS) development initially started in the late 1960's with its concept of creating a worldwide localization system [Pace95]. In the 1970's a Joint Program was initiated within the Department of Defense (DoD) and the Defense System Acquisition and Review Council (DSARC) [Long+81]. A schematic view of GPS satellite's constellation is shown in Figure 3.

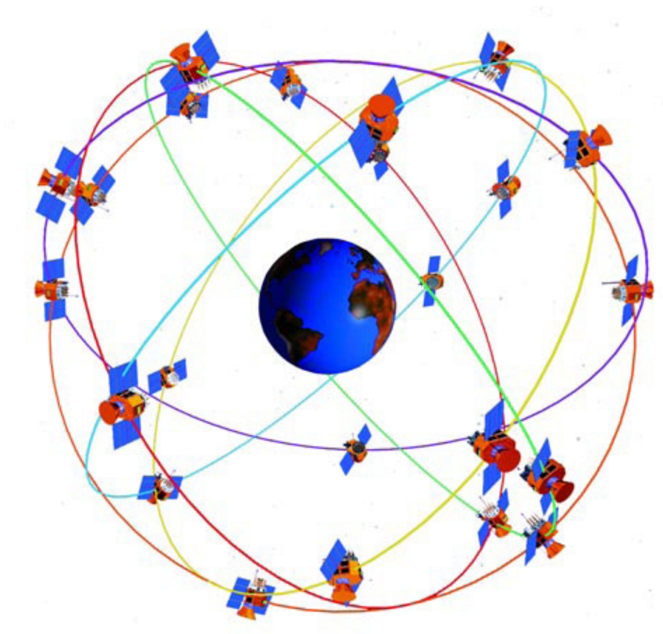

Figure 3: Schematic GPS Satellite Constellation [Aero03].

In February 1978 the first GPS satellite was launched followed by many more satellite launches [Pace95]. Generally the GPS service needs at least 24 satellites in orbit to support accurate positioning all over the world [Lang+06]. The satellites have to be replaced after a given time of usage in order to keep the system working and alive. It should be mentioned that before the year 2000 the GPS service was consciously downgraded for civil usage, so a horizontal accuracy was given from "no worse than" 100 meters. After this time, due to a presidential directive from the United States' president, the "Selective Availability" (SA) was turned off and now it is possible to achieve a standard horizontal accuracy of 10 to 25 meters without additional correction signals.

Described more exactly, GPS consists of three basic components. The first component defines a set of satellites, currently 32 operational satellites (as given by 15^{th} of March 2008) which are orbiting in about 20.200 kilometers above the earth's surface. These satellites are transmitting ranging signals (two different microwave frequencies in the radio spectrum) for defined parts of earth's surface. The second component are maintenance stations, a set of ground monitor stations and upload facilities in order to guarantee the permanent function of the GPS service. The third component is the GPS signal receiving unit, divided in civil and military use. Each satellite transmits a unique digital code which has to be exactly timed with an atomic clock [Lang+06] received by the GPS enabled device. This therefore called GPS receiver picks up the signal by an external or internal antenna. This signal then is computed with other code sequences inside the receiver's logical processing unit. These signal codes are lined up and matched and the receiver determines the travel time from a satellite to its position, this timing is taken for measurement and is converted into distances using the absolute speed of radio waves (which equals the speed of light 300.000 km / second) [Lang+06].

For measuring any location we theoretically need at least three satellite signals, but in real situations we require at least four or more signals for an exact measurement of location including altitude information which is called a three dimensional GPS fix (3D fix). To achieve a suitable positioning quality in forested and mountainous situations four and more satellite signals are needed for localization. The receiver determines its latitude, longitude, and altitude while synchronizing its clock with the GPS time standard [Ray+05]. This method of computing and determining a specific location with the measurement of distances (refer to pseudo ranges in section 2.3.2) with satellite signals is known as TDOA [Muel68]. We have to keep in mind that this is fundamentally different to AOA which involves the measurement of angles and is often mentioned within Location Based Services (LBS) or Mobile Location Services (MLS) on GSM networks, referring to Dao et al. [Dao+02], Zeimpekis et al. [Zeim+03] and Gabber & Wool [Gabb+98]. For example triangulation is also often used to localize mobile phones registered in different cells and giving cell specific information to the user (COO & AOA). Moreover this is additionally used within cheaper Assisted GPS (A-GPS) services provided by cellular networks which combine single channel receivers (they share one channel to receiver more different satellite signals) with cellular network's cell information in order to guarantee a minimum state of accuracy referring to Agarwal et al. [Agar+02].

GPS is a fundamentally passive receiver based service. GPS devices simply receive satellite signals and do not transmit or bounce signals to any other device or satellite, it is an absolutely anonymous und unlimited (anonymous and unlimited users) system which is also given with the later mentioned Russian GLONASS [GNSS02] service or the future European GALILEO [Boer00] positioning system. The Global Positioning System is a permanent and global positioning system and is used for civil and military purposes. It is controlled by an executive board of the U.S. government (joint civil and military) and is maintained by the U.S. Air Force on behalf of all users.

Technical Background

To mention technical properties for GPS receivers we start with Standard Positioning Service (SPS), in fact they access the civil C/A-code (Coarse/Acquisition Code) transmitted on the L1 frequency at 1575.42 MHz. Military receivers use the Precise Positioning Service (PPS), a separately and encrypted P(Y)-Code (Precise or Precision Code, Y stands for the encrypted P-Code) which is transmitted on both the L1 frequency with 1575,42 MHz and the additional L2 frequency at 1227.60 MHz. The additional L2 frequency channel allows receiving units correcting atmospheric and other propagation errors in real-time which offer more stable positioning. With this enhancement military GPS receivers work with more accurate measurements offering a higher reliability shown within the DoD defined accuracy of GPS as given in Table 1. P-Code receivers are designed to achieve localization accuracy with a maximum predictable error of 22 meters, while civilian C/A-Code receivers are designed for an accuracy with a maximum predictable error of 25 meters [Roth05]. Before the year 2000 there was an additional forced calculation error of C/A Code receivers added by the U.S. Government (Selective Availability "SA", already discussed in chapter 2.6) in order to decrease positioning quality as shown in Table 1.

GPS Service	Horizontal Accuracy	Vertical Accuracy
SPS with SA	≤ 100 meter	≤ 156 meter
SPS without SA	≤ 25 meter	≤ 43 meter
PPS	≤ 22 meter	≤ 27,7 meter

Table 1: Max. Predictable Positioning Errors (Probability 95%) [Roth05].

Measurement of Pseudo Ranges

Referring to Jürgen Roth [Roth05] the principle of calculating a user's position u on the earth's surface with the measurement of (at least) three, or for better probability four satellites s signal ranges r is defined by the speed of light c and transmission time t.

The range is therefore defined as:

$$r = c \cdot \Delta t$$

If involved clocks are set up to transmit the exact time we would get the requested range with the formula $r = c \cdot t = c \cdot (t_u - t_s)$, where t_u defines the time of the signal at position u (when receiving the signal) and t_s defines the time of sent satellite signal. However a received signal is mostly affected by errors within all clocks involved in the system and by transmission interferences (not included in the approximation), we have to approximate the ranges for an effective calculation, which is then called pseudo range p [Roth05].

The following variables are introduced for calculation of pseudo ranges: t_s time of sent satellite signal, t_u time of received signal from user, t'_s local estimated time of sent satellite signal, δt_s offset from satellite time to system time, t'_u local estimated time of received signal from user, δt_u offset from user time to system time, Δt exact runtime of signal range, $\Delta t'$ estimated runtime of signal range, c speed of light.

$$\begin{aligned} p &= c \cdot \Delta t' \\ &= c \cdot (t'_u - t'_s) \\ &= c \cdot ((t_u + \delta t_u) - (t_s + \delta t_s)) \\ &= c \cdot (t_u - t_s) + c \cdot (\delta t_u - \delta t_s) \\ &= r + c \cdot (\delta t_u - \delta t_s) \end{aligned}$$

Assuming satellite clocks are exactly timed to system time we set $\delta t_s = 0$ and range r is expressed as coordinates from satellite and user (assuming a cartesian coordinate system with a zero-point in earths barycenter) we get the following formula:

$$\begin{aligned} p &= r + c \cdot \delta t_u \\ &= \sqrt{(s_x - u_x)^2 + (s_y - u_y)^2 + (s_z - u_z)^2} + c \cdot \delta t_u \end{aligned}$$

With this formula representing a calculated pseudo range we are able to start a Taylor series approximation approach [Roth05], calculating a position with intersections of the circles that are defined by the approximated positions within overlapping pseudo ranges on earth's surface as shown in Figure 4.

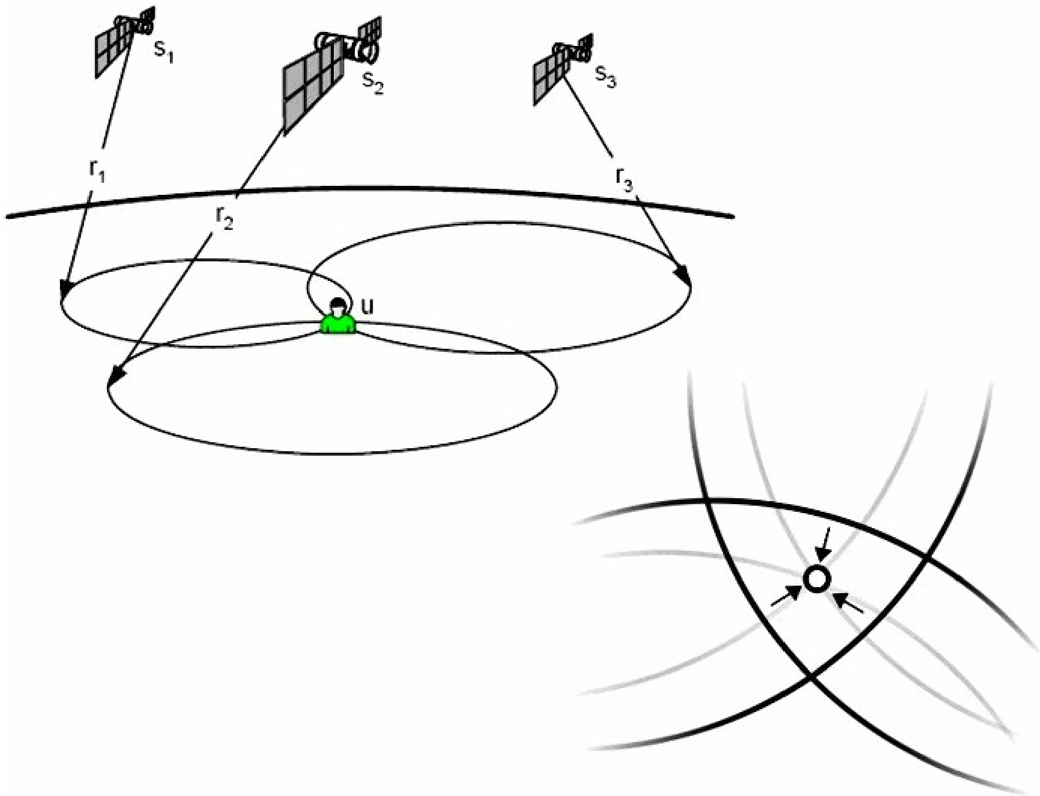

Figure 4: GPS – Determination of Position [Roth05].

The calculation of positions with GPS systems needs the exact position of satellites, the exact range from each satellite to receiver and exact adjusted clocks within all affected GPS parts. An error of only 1 μs within all involved clocks results in a computed positioning error of 300 meter [Roth05].

There are many sources of errors and so ranging errors are principally grouped into different classes. These errors are in detail, referring to Parkinson et al. [Park+96], ephermis errors (errors in transmitted location of satellites), satellite clock errors (errors of transmitted clocks), ionosphere errors (errors in correction of pseudo range - caused by ionospheric effects), troposphere errors (errors in correction of pseudo range - caused by tropospheric effects), multipath errors (errors caused by reflected signals at receiver's antenna) and of course receiver errors (errors in receiver's measurement of range - caused by thermal noise, software and channel-bias). Refer to Table 2 for a short overview of different sources of errors [Park+96].

Source	Error / Effect
Ephemeris errors	± 2.5 meter
Satellite clock errors	± 2 meter
Ionospheric effects	± 5 meter
Tropospheric effects	± 0.5 meter
Multipath distortion	± 1 meter
Numerical errors	± 1 meter

Table 2: GPS – Measurement Error Sources [Park+96].

There are important enhancements for GPS services with additional computed and transmitted correction signals which provide an improvement of accuracy and reliability for GPS. Either this signal is provided by ground stations whose service is generally called Differential GPS (DGPS) service or it is transmitted via additional satellites called Satellite Based Augmentation System (SBAS).

Differential GPS (DGPS)

A DGPS receiver system receives GPS correction data which was sent form a reference station on the earth's surface. Each DGPS reference station receives GPS positioning data, processes the gathered information and compares its own precisely known position with the position calculated from GPS satellites. In this way the reference station permanently calculates the differences between the true position known and the calculated GPS positioning data. With this information the DGPS reference station then retransmits the calculated difference via radio stations or a separated long wave band (283.5 - 325.0 KHz) back to a DGPS capable receiver in range of the DGPS transmitting station. This receiver is either an additional receiver or a second receiver integrated in a GPS receiver.

With this added differential GPS technology an average accuracy of three to five meters can be achieve in normal circumstances. But a great drawback to mention with DGPS services is the transmission distance. If the distance to the differential GPS receiving unit increases (e.g., signal must not exceed a transmission range more than 200 kilometers from source), the signals provided from the reference station get inaccurate. Another way of broadcasting corrections signals is over the Radio Data System (RDS).

Satellite Based Augmentation Systems (SBAS)

With Satellite Based Augmentation Systems (SBAS), we summarize different systems and services covering different areas and continents [Woes+07] like WAAS for USA, EGNOS for Europe and MSAS for the Asian region (Figure 5). We now focus on the Wide Area Augmentation System (WAAS) for the North American area and the European Geostationary Navigation Overlay Service (EGNOS). While WAAS is already fully operational since the year 2003, EGNOS is still under development and under testing. EGNOS transmits its signal in WAAS compatible data format over additional satellites (Figure 5) and can be already received with WAAS enabled receivers.

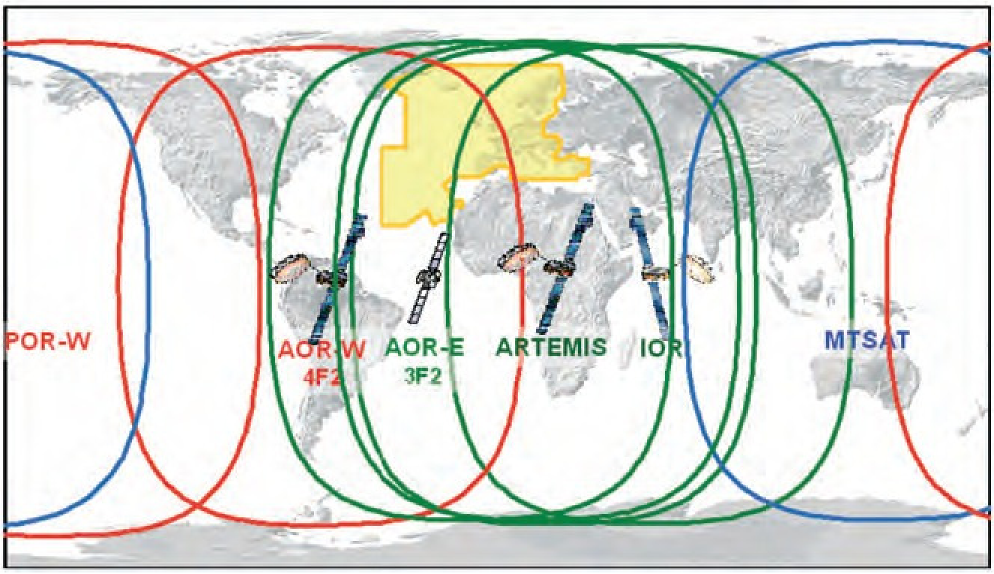

Figure 5: SBAS (Red-WAAS, Green-EGNOS, Blue-MSAS) [www.esa.int].

These SBAS signals sent by additional satellites are used to improve standard GPS receiver calculations for positioning with information about influences (due to ephemeris, ionospheric or tropospheric errors referenced in Table 2). The concrete difference between DGPS services and SBAS services is that the latter do not need any additional long wave receiver and of course no additional signals from ground stations are needed. Each SBAS service has to build up a number of Ranging and Integrity Monitor Stations (RIMS, now 25 stations in the U.S. and 10 stations in the EU) which receive GPS data, calculate differences and retransmits GPS correction data to additionally set up Geostationary Earth Orbit (GEO) satellites. These GEO satellites are orbiting in about 36000 meters above the earth's surface mostly used for telecommunication purposes [Gau+05].

GPS Mode	**Typical Accuracy**
GPS SPS (with activated Selective Availability)	± 100 Meter
GPS SPS (without Selective Availability)	± 15 Meter
GPS PPS (L1 C/A + L2 P(Y) Code)	± 10 Meter
Differential-GPS (DGPS, L1 C/A + external Code)	± 3 - 5 Meter
GPS with SBAS (WAAS/EGNOS)	± 1 - 3 Meter

Table 3: Combined Typical Positioning Accuracy [Woes+05] [Park+96].

The covered area by SBAS systems therefore depends on where RIMS stations are set up and if GEO satellites are received in the actual target area shown in Figure 5 [Gau+05]). WAAS and EGNOS are able to improve GPS measurement accuracy to a level of one to three meters according to Gauthier et al. [Gau+05], which is supposed to be very good. The European Space Agency (ESA) which is responsible for EGNOS claims to reach positioning accuracy less than two meters when using EGNOS augmenting. But we should take account of, if SBAS enhancements are used in forested or mountainous areas WAAS or EGNOS probably will not work as desired. Wößner and Köhne [Woes+07] say that this is caused due to the fact that there are now three SBAS satellites over Europe with angles between 15 and 40 degrees which are relatively low over the horizon and therefore easily covered by objects like trees, buildings and even mountains. Table 3 (in addition to the statistical probability of accuracy shown in Table 1) provides an overview of average positioning accuracy typical in real world use cases for GPS and assisted technology combinations [Woes+05], [Park+96], [Gau+05].

Global Navigation Satellite System

GLONASS, the Russian pendant to the Navstar GPS system, is similar to the GPS positioning technology and is also based on trilateration (TDOA). Referencing to Börjesson [Boer00] and GLONASS Center Papers [GNSS02], it also requires at least four satellites for a three dimensional (3D) position fix and a synchronized system time as well. It is also designed for a three component based passive receive only positioning system.

As already introduced with the previous mentioned GPS technology it is based on a ground based control segment, a space based orbiting segment and an user based receiving segment. These components operate together and provide accurate 3D positioning, timing, and velocity data. Actually there are 12 operational GLONASS satellites orbiting around the earth.

The Russian government [GNSS02] commits that there will be about 18 operational satellites by end of the year 2007 followed by promised 24 satellites by end of 2009. With this roadmap, GLONASS will be able to equally fit any need already provided by the GPS positioning system. GLONASS signals are transmitted in the two specific carrier frequencies L1 and L2 sub band. It is a multi component signal, L1 carrier signal is transmitted at 1602 MHz band and L2 carrier at 1246 MHz band. Both carrier signals are a combination of binary ranging codes, digital navigation data and auxiliary meander sequences. Each satellite has its own specific frequency on each L1 and L2 frequency band, which identifies them uniquely.

Combination of GPS and GLONASS

As, for example, described by Heinrichs et al. [Hein+02] it is already possible to combine GPS and GLONASS systems and there already exist a growing number of commercial combined receivers. So, if we look into the case to combine both GPS and GLONASS positioning systems already possible with a special combination of dual channel receivers together with additional augmenting services like WAAS, EGNOS or MSAS the accuracy of positioning will be increased even in strong forested or extreme hilly environments which now have accuracy problems like our field test area at Zöbelboden. The in some field tests achieved accuracy is under 50 cm (refer to FOGEPOS implementation at the end of this chapter), which defines a new high-performance position measurement. Nevertheless a simultaneous usage as mentioned by Carine Bruyninx [Bruy07] of GPS and GLONASS has to be tested individually in varying environments before reliable usage results in terms of accuracy and reliability can be stated. These dual receivers are significantly more expensive than low-cost receivers.

NMEA0183 Standard

NMEA0183 is an interface data format developed and specified by the National Marine Electronics Association (NMEA) which is intended to send positioning information in a WGS84 (World Geodetic System 1984) coordinate format (measured in longitude, latitude, and altitude) to computers and other equipment like marine devices. Therefore a GPS receiver's communication is defined within the NMEA standard referenced by Baddely [Badd07]. But there are various NMEA versions and other proprietary formats like Garmin [NMEA06] and Magellan. Ardalan et al. [Arda+00] describe in their work that NMEA specifications may seriously fluctuate within various manufacturers.

We focus on the specification version 2 of NMEA0183 standard; a full copy of NMEA0183 standard is available for purchase at NMEA's official web site (www.nmea.org). If we look into this specific NMEA0183 standard, the data received from a communications port of a GPS receiver includes complete position (including longitude, latitude and altitude in WGS84 projection format), velocity and time information computed by the GPS receiving device. Each defined sentence starts with a fixed initial character "$" followed by a two letter prefix "GP" for GPS devices. Then a three letter sequence follows defining the exact contents of the computed NMEA0183 sentence, in our case "GGA".

GGA generic data syntax:

$GPGGA,hhmmss.ss,ddmm.mmm,a,dddmm.mmm,b,q,xx,p.p,a.b,M,c.d,M,x.x,nnnn,*c

Example field test data:

$GPGGA,161858.590,4750.5404,N,01426.6038,E,1,06,1.9,875.7,M, , , ,0000*0C

Now we introduce this specific "GGA" NMEA sentence used in our project, a valid type of this sentence is shown in Table 4.

Definition	Generic data	Example data	Description of Ex. Data
Sentence Identifier	$GPGGA	$GPGGA	Global Positioning System Fix Data
Time	hhmmss.ss	170834	16:18:58 UTC
Latitude	ddmm.mmm, a	4124.8963, N	47d 50.5404' North
Longitude	ddmm.mmm, b	08151.6838, W	14d 26.6038' West
Fix Quality: - 0 = Invalid - 1 = GPS fix - 2 = DGPS fix	q	1	Data is from a GPS fix
Number of Satellites	xx	05	6 satellites are in view
Horizontal Dilution of Precision (HDOP)	p.p	1.9	Relative accuracy of horizontal position
Altitude	a.b, M	875.7, M	280.2 meters above mean sea level
Height of Geoid above WGS84 Ellipsoid	c.d, M	blank, blank	No height of Geoid
Time since last DGPS update	x.x	blank	No last update
DGPS reference station id	nnnn	blank	No station id
Checksum	*c	*75	Check for hardware transmission errors

Table 4: NMEA0183 Sentence: $GPGGA.

Geographic Information System Overview

Information software systems, including geographic and spatial data are called Geographical Information Systems (GIS). They are developed for any need of capturing, analyzing, managing and storing geographic data and according metadata, which are spatially connected and referenced on earth according to the definition given by Tor Bernhardsen [Bern+99].

GIS systems generally define a computer system involving hardware, software, data and applications which are capable of displaying, integrating, editing, analyzing, and storing geographical information. GIS systems even enable manual interactive and automated statistical queries in a specific geographic context as summarized by Henk Ottens [Otte99]. These geographic systems can be used for different purpose, for example in governmental resource and asset management, scientific investigation, environmental impact studies (in context to our project), urban or land planning purposes, cartographic, history, business needs, etc.

GIS systems can be classified in three main classes according to their functionality and complexity. A server GIS system provides various and extensive analysis and processing functionality for multiple users, desktop GIS software provides special and customizable analysis and statistical functionality for workstation users and mobile GIS software provides essential and basic functionality for everywhere instant usage with focus on mobile worker's use. The three types are visualized in Figure 6.

Another way of classifying a GIS system is to classify it based on license issues. GIS software can be distributed as open source software with open code sources under GPL license, as free software with restricted code sources and even as commercial proprietary software.

Focusing on two wide spread software environments in this sector, we refer to an open source software package "Geographic Resources Analysis Support System" (GRASS) under GPL license and to a proprietary system named ArcGIS from the "Environmental Systems Research Institute" (ESRI). Often discussed disadvantages of early open source GIS software packages, mentioned by Kim et al. [Kim+01], are problems with interoperability and much implementation work for specific needs.

These restrictions are neither in the open source nor in the proprietary software environments mentioned. Both support and built on a component basis with interface specifications to add and change a program's logic or an operation process which is defined via open standards referring to Henriksen et al. [Henr+94]. Spatial modeling is also basically defined within an open GIS system by Choi et al. [Choi+00] and supported by these packages.

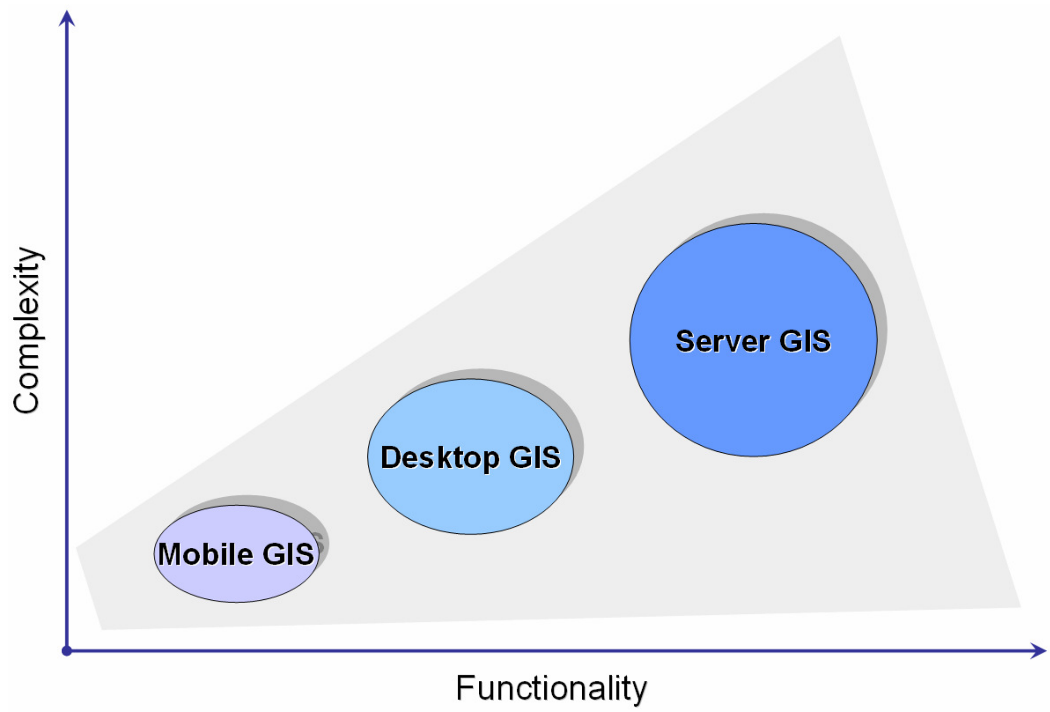

Figure 6: GIS - Basic Functionality Classification.

GRASS

The "Geographic Resources Analysis Support System" (GRASS) [GRAS07] is an Open Source software package. This GIS system originally was developed by the US Army Corps of Engineers (US Army Construction and Engineering Research Laboratories). The Open Source software package can be used for data management, image and object processing, graphics production. GRASS is also suitable for accessing and visualizing many types of different GIS and data formats provided by other software packages and platforms and therefore offers rich functionality for import and export of various data formats. It allows a wide range of applications in different parts of scientific research und is used in academic applications, scientific research, commercial projects, and by several governmental organizations.

GRASS fundamentally offers raster or vector GIS and image processing, but also offers functionality for graphics production. Summarized, this package offers near to 400 tools and programs to store spatial data, manage, create and manipulate it. Also rendering maps and images, manipulating vector and raster data and processing multi spectral images and data is supported with this software. It presents an intuitive program interface with a well designed window desktop, but also supports a wide range of functionality with command line syntax, eg., for periodic batch processing. As mentioned before, the GIS package offers a rich choice of import and export formats for 2D raster data, 3D raster data, and 2D / 3D topological vector data.

GRASS is generally released under GNU GPL. The GIS package provides an advanced GIS library (C and C++ API) an can be used for any kind of development on many platforms like x86, PPC, SGI MIPS and much more with GNU/Linux, Solaris, UNIX, handheld and native Windows operating systems.

ESRI GIS

ESRI provides several products for GIS and geoprocessing functionality which are covered under the commercial ArcGIS software licenses. There is also a free to use ESRI version of GIS software available named ArcExplorer providing basic GIS viewing and displaying functionality. ArcGIS products, especially the ESRI ArcDesktop software packages, define the industry standard in geospatial information processing and count near a million installations (e.g., governmental, scientific) worldwide.

These GIS products shown in Figure 7 can easily be integrated with one another. Hence, ESRI enable users to create, edit, import, map, query, analyze, and publish geographic information and spatial data. ESRI also provides interfaces and a comprehensive development environment (VB, VC++, .NET or Java based). With these facilities, users are able to easily share geospatial information with others and adopt functionality provided by the software. With various extensions, ESRI also allows to perform raster geoprocessing, three-dimensional visualization, and geostatistical analysis.

To enhance the functionality of mobile GIS interoperation ESRI developed a mobile GIS application with GPS positioning ability called ArcPad, which allows users to display maps and operate objects stored in shapefiles at real-time with lightweight handheld computers based on Microsoft Windows Mobile. After evaluation of different mobile GIS solutions we decided to develop a mobile GIS client based on this often used mobile GIS software package which can be customized for different needs. All spatial data and information is exported from a server system (ArcGIS) and fully stored on the device, if there is a demand in future it will be also possible to develop a dynamical Web based solution which was already defined by Li et al. [Li+06].

The previously mentioned GRASS is an Open Source pendant to the commercial ESRI software package and offers similar GIS functionality.

ESRI Software Packages

ESRI products (www.esri.com) represent an integrated collection of GIS software covering complete GIS solution with a very rich choice of functionality. ESRI ArcGIS Framework enables any kind of user or institutions to deploy own customized GIS functionality wherever it is needed. This means several usage conditions can be supported in desktop environments, server systems, to deploy custom applications and access GIS data directly, over the web or in the field. ArcGIS Framework can be fundamentally classified in Desktop GIS [Arcg06], Server GIS [Arcs07], Mobile GIS [Arcp04] and Web Hosted GIS [Arcs07].

Desktop, Web and Mobile GIS are specifically intended to serve end-user's needs in data preparation or analysis work and are able to interactively connect to Server GIS systems, which are designed to store, spread and offer services for various needs of different user groups. All system components are basically intended to fit specific needs with a different focus on functionality depending on each other component which you can see within a simplified component view of ESRI software in Figure 7.

Each part can be individually configured and accessed through different programming languages to customize functionality for individual user's needs. Specifically, we used ArcView, ArcPad and ArcPad Studio Application Developer in our project to realize specified mobile client functionality.

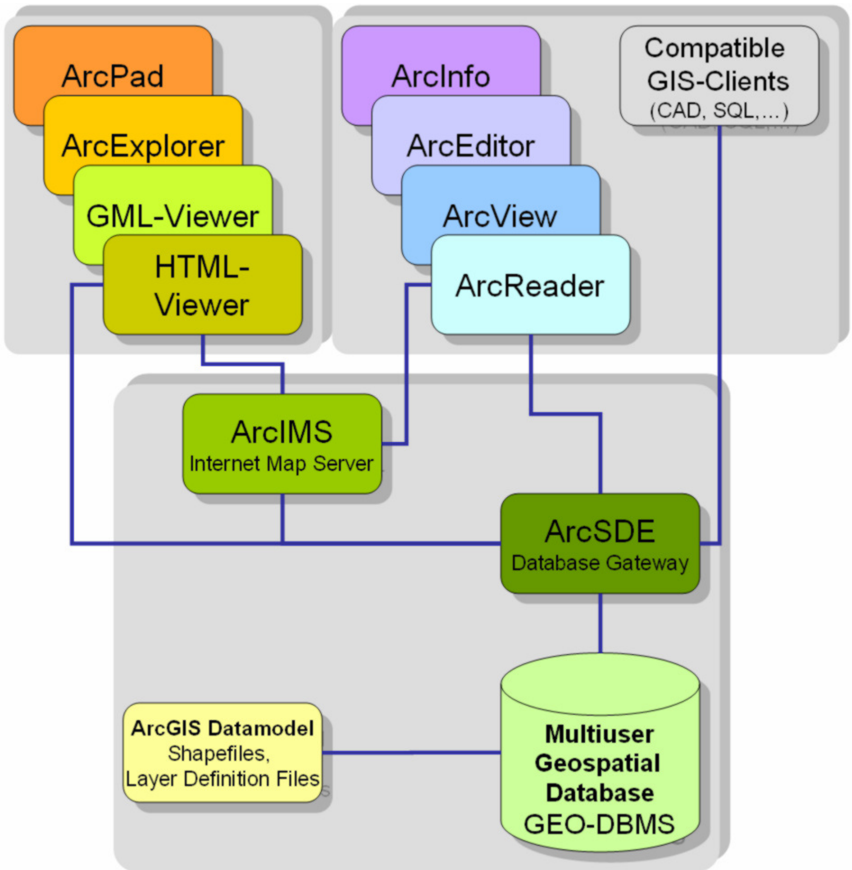

Figure 7: ESRI Component View [www.esri.com].

We used ESRI ArcPad for customization and together with the ArcPad Studio Application Developer software for implementation work. To be able to manipulate and prepare the provided Umweltbundesamt's maps for the mobile client we used ArcMap. The choice for this particular development environment was driven by already used predefined standards in this use case, but also by the fact that ESRI software is mainly used within all geospatial work at the Umweltbundesamt. The Umweltbundesamt stores all geospatial data mapped in an ERSI ArcGIS database

[Arcs07] and in a simultaneously used Oracle database (customized for Umweltbundesamt's needs) called MORIS to save all data of objects represented at specific layer definition files and shapefiles [ArSh98]. ESRI ArcMap was used to operate and extract all needed data stored in shapefiles for usage with the mobile prototype.

3 RELATED WORK: GIS PROJECTS AND LOCATION-AWARE IMPLEMENTATIONS

In this chapter we focus on mobile environmental monitoring work in the field and involved accuracy in real-world positioning. Further we discuss related GIS applications giving a short view of state-of-the-art implementations in the mobile GIS sector. Further on we discuss which hardware and software is specifically used for these geospatial applications to gather needed scientific and industrial data. We introduce already implemented location-aware prototypes in different areas within different applications. We will show the commonness of the approaches in comparison to our approach, as well as differences and additional functionality introduced by the other projects.

Accuracy in Real-World Positioning

Designing applications for real-world positioning in extreme geographic environments represents a challenge when supplying continuous and high accurate positioning data.

The usage of mobile devices at the Umweltbundesamt for Integrated Monitoring work in Austria, but also in Europe in general, combined with GPS assisted positioning was only a theoretical approach so far due to restricting geographic conditions, volatile weather conditions and complex data structures gathered at the monitoring sites. Within our project the usage of mobile devices by Umweltbundesamt's mobile workers defines an enhanced proceeding in the area of Integrated Monitoring work in Austria [Humm+07]. There are also some combined approaches, equally to this project, for spatially location-aware clients in order to capture data and information regarding to Hohl et al. [Hohl+99] or Hope et al. [Hope+00] involving different services and components which are adaptable for changing situations and needs. As a next possible scenario, mobile workers can be continuously guided through an area, referring to Brilingaite et al. [Bril+04], by previously defined ways and POI's to be investigated at the monitoring site to maximize the user's attention payload.

Various surveys based on GPS positioning technology mentioned problems that are affecting positioning accuracy up to the complete breakdown of GPS fixes caused by strong influences of the surrounding environment. Steven Taylor describes in his work the strong influences of densely wooded areas in context of the usage of GPS technology with forest machine systems [Tayl+01]. Based on the assumption of instantly needed high accurate position values it was our ambition within this project to define statistical basics for quality oriented GPS measurement. With the resulting metrics it will be possible to define precluding criterions of geographic positioning for future work in this field.

GISPAD Implementation Overview

The Ruhrgas GIS implementation GISPAD was developed by "con terra GmbH" (http://www.conterra.de/de/software/mobile-datenerfassung/gispad) and is based on GPS and differential GPS technology to provide highest accuracy when measuring points of interest (POI's).

This system offers interfaces for interoperation with customized ESRI GIS data and software, but GISPAD also provides interfaces to other actual geospatial information standards in order to support individual usage of various digital geospatial data and visualization of objects, an example usage at the organization "Wald und Holz Nordrhein-Westfalen" is shown in Figure 8. The figure shows a mobile worker using a mobile GIS device (embedded Tablet PC) demonstrating interaction with the device's GUI. The worker is manipulating surrounding spatial objects on the device's map and processing ad hoc reports for the actual POI, which is also shown the figure. The implementation based on GISPAD assures exact positioning values up to some centimeters by combining standard GPS values with a differential GPS correction signal (DGPS) provided for example by the radio data system (RDS) signal through Ultra High Frequency (UHF) senders or other organizations, like ascos (http://www.ascos.de, Ruhrgas / EON – German private energy company) and SAPOS (www.sapos.de, German governmental institution). The Ruhrgas GIS reference project of the GISPAD implementation is used to manage the gas distribution network of over 11.000 kilometers. The Ruhrgas AG uses the system for measurement of the operational system, but also to support audit and maintenance as well as repair procedures (Figure 9).

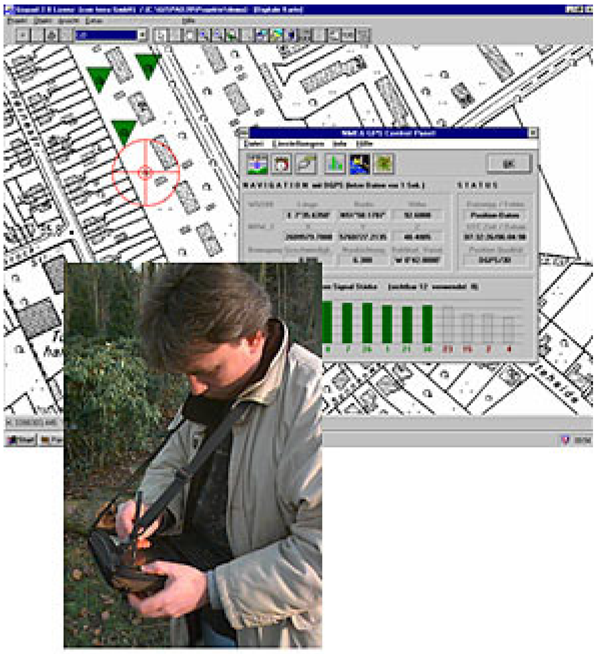

Figure 8: GISPAD Scenario and GUI (www.forstgis.eu).

With the gained accuracy and the powerful GISPAD application the field workers acquire much information, such as specific data about geospatial objects or distances between objects. As mentioned before a highly accurate real-time positioning is performed which optimizes the process of surveying and completion of complex geometric and object-centered data.

It enables a fully enabled quality management and control workflow. With these optimizations and the rich amount of provided functionality, this system offers a huge capability of saving expenditures of human labor, for example when measuring points of interest or various geospatial objects.

Figure 9: GISPAD Ruhrgas Scenario (www.ascos.de).

The technical environment mainly uses the GISPAD application for the end-user. All data is stored in a GIS database provided by GeoMedia, which supports all kind of geospatial data, the manipulation of survey data and problem or object orientated data. Actualization of datasets, database maintenance, and management is also provided with this database system. Program interfaces and application logic was implemented with the programming languages Delphi and C++ which ensure a powerful environment for geospatial and scientific applications.

FOGEPOS Implementation Overview

The FOGEPOS system implements standard GPS, GLONASS and DPGS technology in order to provide highest accuracy when measuring objects and areas in a highly forested area. The FOGEPOS implementations actually uses 24 successfully integrated systems in German forests to provide new methods for collecting, storing and processing various geospatial, ecological and land based data to enable a process based optimization of work in the forest and to minimize the enormous administration based spending by creating digital reports and processing directly digital saved data. Signal strength and signal quality of received satellite signals are the main limiting factors when measurement of positioning takes place in forests. With this fact FOGEPOS uses GPS and GLONASS signals to provide highly accurate positioning values better than 50 and up to two centimeters in extreme geographic situations like strong forested places (Figure 10). Ascos is one of few providers in Germany with GLONASS based correction through GSM signals. Usage of GLONASS as an additional service results in a better signal quality by improving the number of received satellites, in average 4 satellites more at one time. The initial hardware used with FOGEPOS was a PocketPC equipped with a GSM modem, a GPS receiver, a GNSS receiver and a reference signal antenna.

Figure 10: FOGEPOS Scenario (www.ascos.de).

As the German Landesforstpräsidium already uses ESRI ArcInfo and ESRI ArcView the actual implementation uses the ESRI ArcPad software for GIS functionality with specially adapted interfaces for individual usage in the field. A study to estimate the quality and the signal strength of positioning systems for use in forests of the "Fachhochschule für Forstwirtschaft" in Schwarzburg/Thürigen found out that in these situations a combination of GPS and GLONASS results to the best values for exact positioning values. The Landesforstpräsidium Sachsen uses a Fujitsu-Siemens PenPC with 10,4 inch TFT display and Windows 2000 in combination with an all in one receiver unit TOPCON Legacy-E (global.topcon.com), which calculates positioning values from the GPS and the GLONASS positioning system. This special receiver owns 40 independent channels for processing received signals and calculates satellite data up to 50 elevations.

Comparison and Relation to Our Approach

If we take a closer look on related work in context to our project, we consider two basic factors: on the one side functionality, and on the other side data quality (either measured ecological data or spatial information). When focusing on aspects for low attraction mobile applications, usability in fieldwork environments is mainly defined by mobile worker's limited attention capacity and the demand for a context dependent interaction. This means exactly, for each use case scenario within mobile work we have to set the focus on the needed information which is defined for this process.

We decided to provide a prototype with standard mobile hardware in conjunction with GPS positioning, because this is the most widespread technology in this area. We set a high priority on the mobile device's weight, usability, performance and extensibility for changing needs in free field in conjunction with the capability of rapidly deploying changing requirements of monitoring processes. The main use cases for the prototype usage are driven by monitoring work and data collection processes when collecting ecological field information during work. This work is mostly done in extreme field situations, which is for example given when monitoring tree disturbances in mountainous areas (e.g., steep slopes or rocks). Therefore we set up a specific customized prototype development based on the needs of a defined user group (ecological monitoring in conjunction with UBA's infrastructure). To ensure a simple and portable solution we agreed on a concept based on standard mobile devices and low cost GPS receivers and developed a Windows Mobile and ESRI ArcPad based mobile GIS solution.

To accomplish these aspects within this work, we strongly concentrate on limited attention capacity, high speed interaction and context dependency as previously mentioned within the first chapter. We analyzed the processes of mobile work done at Umweltbundesamt and identified the needed data structure for monitoring work, described in chapters four. After this work was done, we were able to design a prototype which integrates ecological, spatial, and geographic data focused on

Umweltbundesamt's needs which is described in chapter five. Within two field tests at the Zöbelboden monitoring area, as described in chapter six and chapter seven, we studied the quality of GPS satellites received and GPS accuracy achieved for data measurement work and the usability with focus on mobile worker's monitoring processes.

4 PROJECT BACKGROUND: ECOLOGICAL FIELD STUDIES

To understand the context of development and involved organizations we will now present with information in about the institutional background of the Umweltbundesamt (UBA), current environmental monitoring processes and the used Monitoring and Research Information System (MORIS).

Institutional Background

The designing und prototyping work done related to this thesis was done in close collaboration with Umweltbundesamt's "Ecosystem Monitoring" department also summarized within Karin Hummel's and Johannes Peterseil's work [Humm+06].

The Monitoring and Research Information System (MORIS) database referenced by Michael Mirtl [Mirt97] is used at the Umweltbundesamt. This database further supports interfaces to ESRI datalayers. To use UBA's existing maps and description formats including collected ecological data, we decided to use the ESRI ArcPad Studio Application Developer. With this approach we attempt to shorten the prototyping phase and maximize benefits of provided functionality.

Umweltbundesamt's Integrated Monitoring Observation Work

The Umweltbundesamt operates several meteorological and ecological instruments for measurement and analysis work located at Zöbelboden's plateau within the UN-ECE Integrated Monitoring Program [http://www.environment.fi].

Specifically, the UBA conducts remotely accessed containers at the plateau with a setting of high sensitive sensors, instruments and computer hardware to analyze environmental conditions such as temperature, air, rain, and fog (mesoclimatic analysis, shown in Figure 11). UBA also operates sensors reaching above the canopy in order to measure additional mesoclimatic conditions mentioned within Schenz et al. [Schen+05].

Figure 11: Zöbelboden Area (www.umweltbundesamt.at).

The predominating and main type of rock at Zöbelboden is the Norian Dolomite (German: “Hauptdolomit”) which is partly overlayed by a limestone (German: “Plattenkalk”). Important logging and recording areas are two dedicated intensive plots representing the slope and the plateau for measuring forest stand deposition, soil and water chemistry and more. There are further 64 main permanent plots in order to observe long-term trends all over the Zöbelboden area appointed by Schume et al. [Schu+98].

These permanent plots are spread in 100 meter grids (100m² squares distributed over the area) introduced for observing, e.g., forest stand, forest floor, soil, and more ecologic information. Another 10 fenced and control plots for large herbivore pressure ensure correct control values, in the center of each 100 meter cell there are additional forest floor vegetation plots. An example of a permanent plot is shown in

Figure 12. There are three categories of analyzed conditions: herbivore pressure, forest stand and forest floor vegetation.

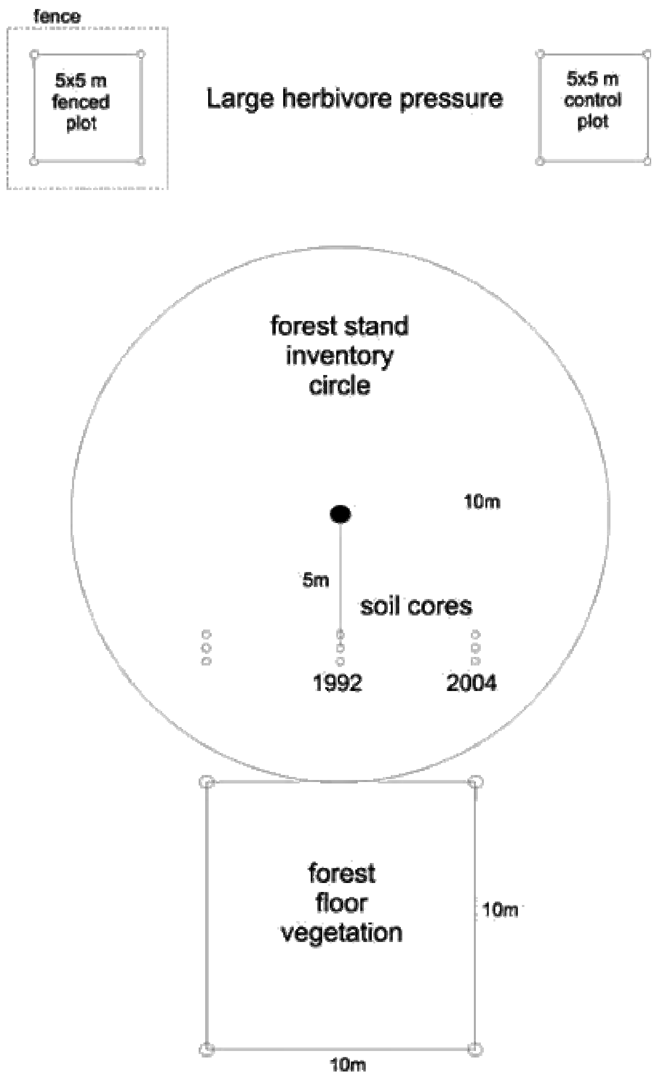

Figure 12: Design of a Permanent Plot.

Mapping of lichens and bryophyte or bird monitoring is done irregularly on different distributed plots according to the specific needs of the UBA, e.g., on some host trees for lichen monitoring. In the years 1992 and 1993 the first records of the permanent plots were generated. This procedure was repeated in the years 2004 and 2005. Bird population and herbivore impact started to be recorded in the years 1995 and 1997. The period for the different investigations ranges between 8 and up to 13 years, where herbivore, lichen and bryophyte were only recorded once in this duration. In addition to these fully monitoring activities at the Zöbelboden's plateau a yearly repeated additional rotating site monitoring (in order to check dynamic changes such as growth and diversity) is realized by the Umweltbundesamt's mobile workers. All plots are surveyed with standard methods defined by the UBA. Additionally the whole study area is surveyed and changes with impact on the monitored plots are recorded like dead trees or wind throw through bark-beetle [Schu+98], see Figure **13** showing permanent plots and an overview of the observation area.

Figure 13: Zöbelboden Observation Overview.

Interaction with the mobile client should improve the whole process of measuring objects, like entering ecological data and processing the gathered information of the observation area. Ecological data should be easily recorded and it was our approach to define a suitable tool according to Umweltbundesamt's needs for MORIS (see Schenz et al. [Schen+05]). Therefore we have to keep in mind that usage of our location-aware mobile client should improve and never negatively influence the observation work in any aspect. The intended benefits for UBA's observation work are summarized as follows:

Summary of intended benefits for observation work:

- Fast transfer and simple handling of collected geo-located ecological data
- No need of cumbersome re-entering gathered information
- Reliable transfer by automation which helps avoiding human errors
- Full support for observation work and information collection processes.

Monitored Processes and Recorded Parameters

The whole information collection process within the study area is defined by a specific monitoring process described in Schume et al. [Schu+98]. The data and information collection using the mobile device adress the following issues:

Remarks on Events

Information on various events in the study area, like climatic events (heavy rainfall, floods or other effects on plots), are tracked and any changes in the study area are recorded in a systematic way.

Photo Documentation

Changes at the study area, like erosion or wind throws, are documented, stored and named in a standardized way; position and direction while taking photos are recorded on the protocol sheets with a short description of the content. Later the images are managed itself in the digital image archive.

Plot Protocol Sheet

This plot protocol records disturbances at the plots in the whole monitoring area (main, additional, bryophyte plots, etc) by drawing an illustration of the situation, like fallen trees or erosion areas with date, type and the effects on the plots (e.g., change in the light regime, strong erosion with fallen trees, bark beetle calamity).

Tree Specific Disturbance Parameters

Changes in the structure of the tree layer, specific attributes and effects nearby the plot are recorded together with information about species, BHD (breast-height-diameter), sociological position, vitality, beetle infestations, wind influence, changes in light regime, date of disturbance, and accuracy.

Tree Recruitment

The recruitment of trees is estimated for each permanent plot. Each tree species is classified in terms of height (<20cm and ≥20cm) and in coarse abundance classes (0;1-10;>10) which defines the growth abilities of specific tree species.

Marker Structure

The markers placed in the study place (plots are marked with iron pipes and markers) are checked on a regular basis via rotating site monitoring.

Data Collection Process and Data Architecture

It is a complex process to store ecological data taken over years with steadily changing measurement methods or processing methods in one information system in order to fulfill a permanently and continuously research in this field.

In order to support changing processes and methods, the Umweltbundesamt specified and introduced an ontology based meta-data orientated architecture to fulfill future needs of changing methods and to process and compare information gathered over years with different processes and methods.

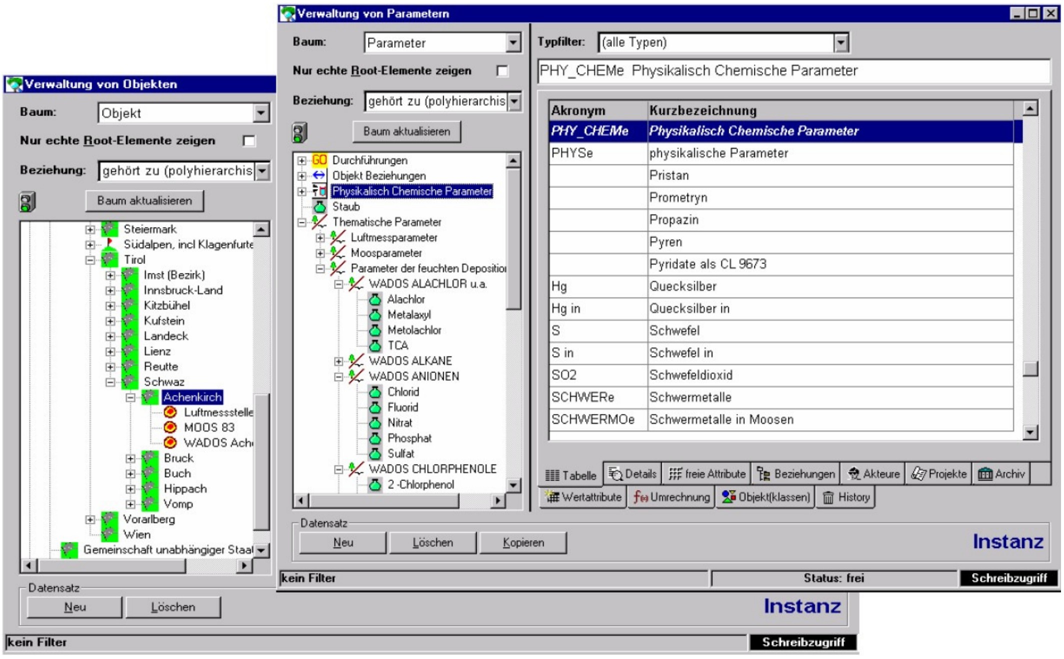

Figure 14: MORIS Database User Interface Example[Schen+05].

Figure 14 shows the user interface of the MORIS system with objects, parameters and values (e.g., physical and chemical data) gathered within Umweltbundesamt's monitoring work. All data is stored in the Integrated Monitoring database and can be displayed or processed. All spatial information and data of the Zöbelboden site is stored within ESRI shapefiles and processed by ArcGIS 9 as described in Section 5.5.

Protocol name	Description
aaFeldprotokoll_Liste	permanent plot information
aaFeldprotokoll_Verjüngung	data about young plants
aaFeldprotokoll_Hemifoto	data about relevant pictures
aaFeldprotokoll_Baumdaten	single tree specific data
aaFotos_Liste	list of all taken pictures

Table 5: List of Field Protocols used at Zöbelboden.

Currently, data collection is paper-based. All collected data is recorded on paper protocols in the field and at the end of the survey this information has to be entered manually and transferred with a specific transfer database application developed based on MS Access.

By exchanging paper-based data collection with a mobile GIS client based solution, it is possible to establish fully automated import functionality for data and values captured for Zöbelboden monitoring and minimizing human errors. Table 5 shows recorded parameters on protocol sheets used at the Umweltbundesamt for integrated monitoring work. The five protocols sheets which hold different ecological information for permanent plots, young plants, relevant information about pictures, tree data, and all taken photos. These field protocols are transferred to the MORIS database via transactions.

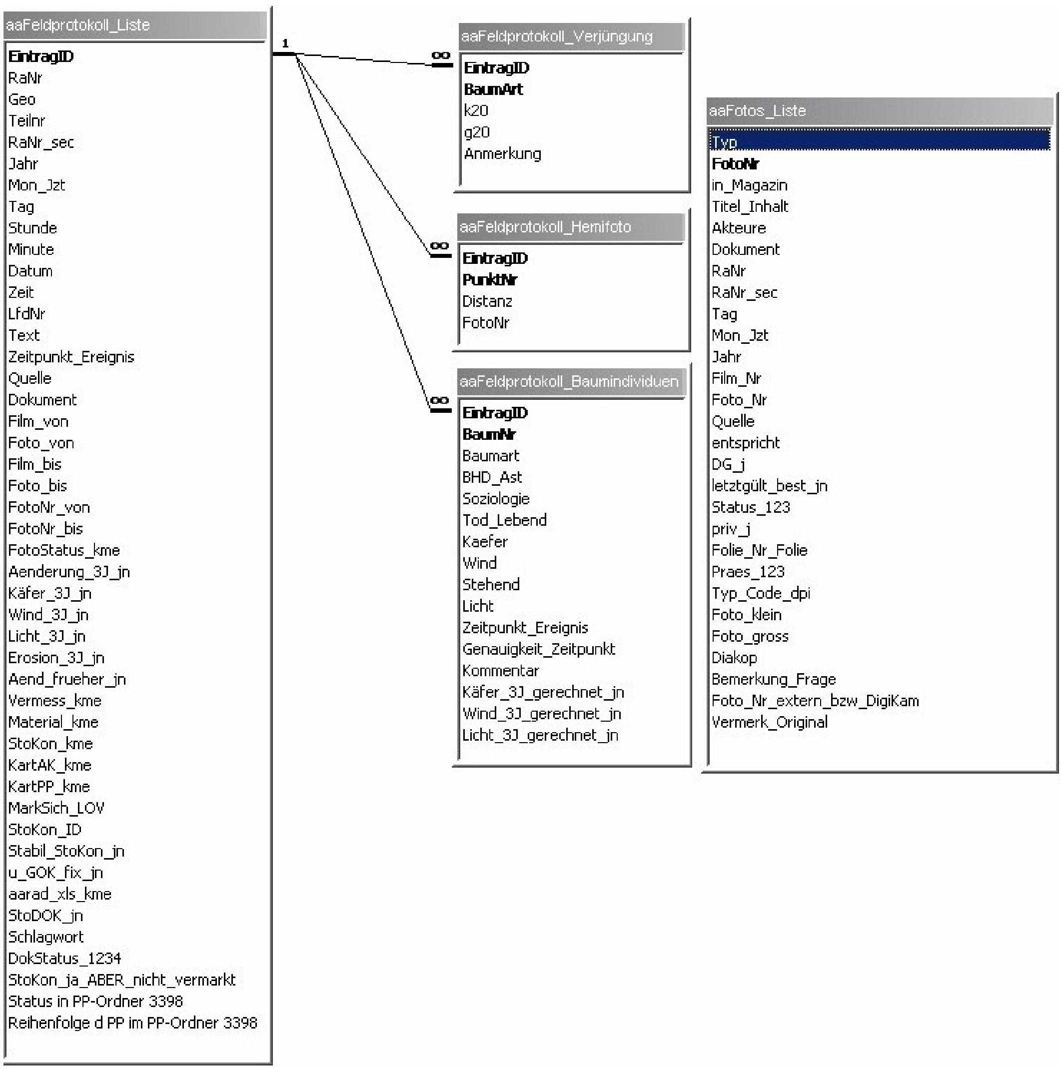

Figure 15: Data Structure of Collected IM Parameters.

Figure 15 shows the data structure (UML format) used with the database transaction application by mobile workers.

This data structure was integrated into our prototype's data structure in order to capture the identical data needed for the transaction application.

The transfer application produces the final import formats for the MORIS object orientated information system. Generally, all data in MORIS is stored in hierarchical thematic sections, discussed in the following Section 4.5.

MORIS Database

MORIS is an Oracle database based information system at Umweltbundesamt specially designed to be easily adopted for long-term research usage [Schen+05, Mirt97]. The information system is used mainly for monitoring and comprehensive ecosystem research program, mainly to store and manage all data derived from the UN-ECE "Integrated Monitoring Program" in Austria. This project also became of scientific interest for the University for Agricultural Sciences with their forest ecosystem research program. With these framework requirements, the Ministry of Science and Traffic decided to join the development of the MORIS implementation. With this new alliance, MORIS was further developed and adopted according to the various needs of the research program "Research Initiative against Forest Decline" and a special research program called "Restoration of Forest Ecosystems" mentioned by Johannes Peterseil [Pete+05].

One of the main concepts of this ecological information system is the strong focus on meta-information about methodological and spatial design while gathering the environment data and information (also called primary meta-information). Object oriented analysis and design methods have been applied additionally to ensure an easily adoption with new methods and analysis techniques.

MORIS stores the ecological and scientific data in a specific hierarchical order refered to as section (Herbert Schenz [Schen+05], Michael Mirtl [Mirt97]). These sections are:

Cluster Level Information

Cluster information consists of information assigned to the whole monitoring study area (e.g., ecological / environmental information, general remarks, etc).

Plot Information

Plot information consists of data belonging to permanent plots taken at the monitoring site (Especially types of disturbances in the last three years, recruitment, etc).

Tree Information

This information consists of specific tree information at the monitoring site (e.g., Species, height, BHD, disturbances, effects on light regime of plot, etc)

The Umweltbundesamt established a link ID (called MORIS ID) from spatial objects in the GIS database to the thematic information in the MORIS database. This was done by using a specific acronym and a special geographic identifier in order to synchronize data with a database transfer application for rotating site monitoring.

The main elements of the MORIS information system are [Mirt97]:

Objects

Objects (like permanent plots) are divided in spatial objects which are geodetically surveyed and marked points in the field, in investigated media objects like soil or springs, and in auxiliary objects such as measuring devices, and species.

Properties / Parameters

These properties represent monitored variables and define investigated values, such as chemical elements (like “NO_3”, “CO_2”, etc).

Methods

These methods represent sampling methods and analysis methods which are sequentially combined to methodological designs.

Objects, properties, and methods can be variously typified, hierarchically classified, and related to each other. With this flexible structure, any kind of relation between instances of these elements can be accurately defined. Predefined object-object combinations in association with parameters and methods form MORIS "datapoints". These points are finally associated with measured values and used measurement processes, as demonstrated in Figure 16.

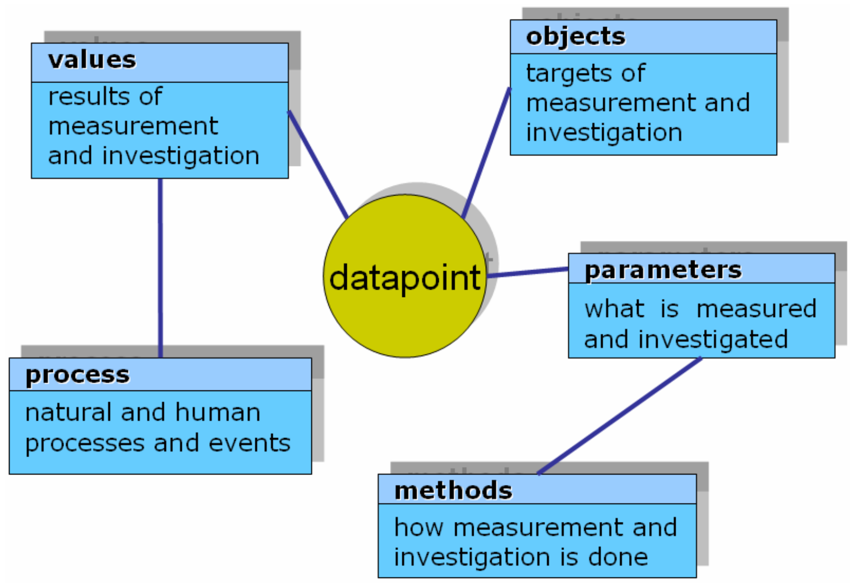

Figure 16: MORIS Data Model Overview.

This MORIS data structure includes administrative parts containing secondary meta-information as follows:

Actors

Actors are persons, teams, and institutions involved in any of the depicted ecological study processes.

Archive

This is any kind of linked information, either soft- or hardcopy of files, objects, or elements.

Projects

Projects define activities and their relations, like monitoring activities to be managed, scientific sub-programs, or measuring campaigns.

Standards and Thresholds

These elements describe activity-/value-/method-related thresholds, standards, laws, or legal obligations.

With this functionality and data structure the MORIS information system ensures a complex and dynamic data archive supporting a huge amount of long-term ecosystem data and their meta-data.

5 PROTOTYPE CONCEPT AND OVERVIEW

In this chapter we describe the location-aware prototype, the according development background and implemented functionality. First we summarize most important aspects of the desired prototype, as a second step we detail predefined requirements for mobile applications and how they have been addressed by our approach. We focus on implementation work and design decisions as a third step. In the last two parts of this chapter we focus on layers and map projection and the finally implemented functions for the intended field test.

View and Purpose of the Location-Aware Prototype

The project's implementation work follows a rapid prototyping software engineering process and is set up with the commercial ArcGIS software provided by ESRI. The software packages ESRI ArcPad and ArcMap enable us to involve already captured and defined GIS data from the Umweltbundesamt and to ensure a simple way of retransferring the collected data back to the database infrastructure of the Umweltbundesamt, which is generally based on ESRI products and a specific Oracle database development, the "Monitoring and Research Information System". We used rapid prototyping to quickly audit and assure the requirements given to us from Umweltbundesamt. We used ESRI ArcPad to fasten up prototyping work.

Predefined GIS data is used with the client application and a Visual Basic (VB) based application logic was added by using ESRI's Object Model for ArcPad customization [Arcb02]. Umweltbundesamt's GIS data used in this project is based on ESRI shapefile standard [ArSh98] which can be easily integrated for usage with the mobile client. After completion of the prototype, the application was tested and evaluated in cooperation with representatives of Umweltbundesamt within the target area Zöbelboden. The validation criteria in the scope of the field evaluation at the Zöbelboden area was defined as the accuracy of the collected positioning data, the ease of handling and collecting data with a mobile device, and the rating of the overall usability.

Challenges and Functions of the Location-Aware Prototype

The main goals of the mobile location-aware prototype application are to improve of the whole process of collecting ecological data in a field situation without increasing overall time consumption for using the mobile device, as also mentioned by Yeh et al. [Yeh+06], and to evaluate the GPS assisted prototype running on mobile devices in extreme geographic situations, where signal strength and quality are low due to nearly situated trees, mountains, or valleys nearby. With these results we are able to define techniques to improve received GPS positioning data, especially in future implementation work, to refine estimated actual points of interest (POIs). There is also the possibility to show automated additional data (like pictures of a previously investigated site or other multimedia based data in the actual context) by entering a previous defined distance to POI's mentioned within Burigat et al's work [Buri+05]. The data collection process should be optimized with reduced time consumption at time of collecting and transferring data. Therefore the whole time for working with ecological and scientific data can be reduced to a minimum state. In this way, mobile workers gain more free time for observing target objects or any scientific work. Our intended system should fully support the process of collecting ecological data and should provide a simple designed location-aware user interface. These intentions lead us to following elementary challenges:

- Mobile worker centered usability
- Simple user interface, focused on monitoring processes
- Stable accuracy of GPS positioning
- Automated transfer to UBA databases

The initial prototype requirements were defined in autumn 2005 after a first field test and inspection phase at the Zöbelboden plateau within a first Java (Mobile Edition) based prototype not concretely mentioned within this work. This early field test was used to gather information about the requirements for implementing a specific customized and usable designed prototype. The experiences in the first field test and the new ideas and wishes from the Umweltbundesamt's project members were used to implement and develop the final advanced and user friendly PocketPC based prototype for mobile and outdoor use in extreme geographic areas. To meet the requirements without wasting resources, time and money, we applied a rapid prototyping software development process.

The IM ecological data is currently collected on paper and has to be transferred with the Access based transaction utility into Umweltbundesamt's databases. To improve this process, a newly defined system was introduced. This system provides support for directly transferring collected monitoring data using the already existing Access based transaction utility. Figure 17 shows the system architecture.

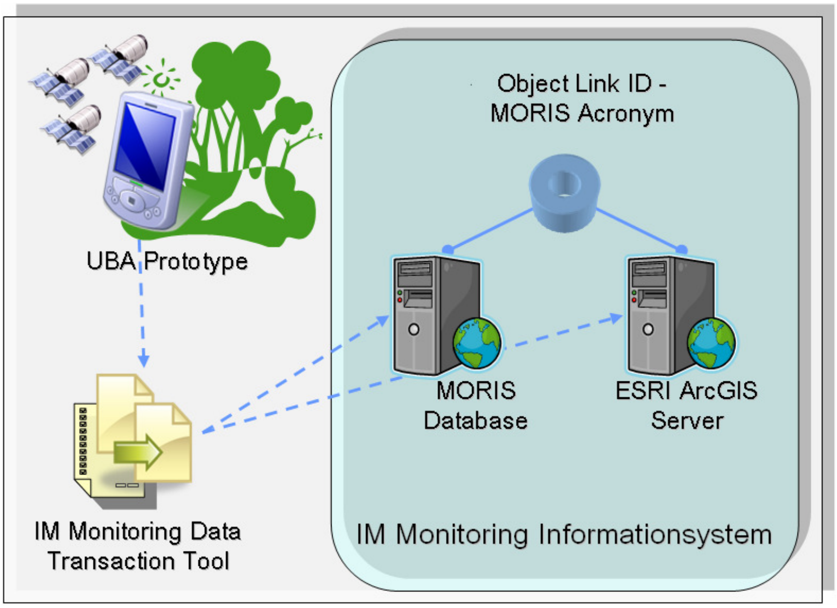

Figure 17: Integrated Monitoring – Prototype System Architecture.

Rapid prototyping helped us to provide a prototype easily adaptable to the changing requirements of the Umweltbundesamt. We were able to develop this advanced mobile GIS prototype until summer 2006 based on the ESRI ArcPad Studio

Application Developer [Arcb02]. This prototype confirmed our expectations when it was tested during a second field test conducted in autumn 2006 in cooperational work of UBA and the Distributed Systems Group. Our objective was to implement an application which supports the process of colleting environmental data, in this project especially for use in the "Integrated Monitoring Program" [Schu+98].

To accomplish the full functionality of providing geospatial map data of the monitoring area the actual ESRI map layers used at the Umweltbundesamt were imported into the prototype and an enhanced data structure was implemented into the provided layers in ESRI shapefile format [ArSh98]. The structure uses a Dbase file format version 4 which is defined by ESRI standards. Furthermore the application has to provide a permanent monitoring functionality in order to realize and capture site changes. In this context, the implemented mobile client enables fast user interaction for data collecting and a standardized method for documenting events, and creating waypoints to analyze the field work. For future development we also have to think about providing interoperability with other systems and services regarding to Tu et al. [Tu+02] or introducing an especially mobile field wrapper framework for mobile field data collection already mentioned by Zhao et al. [Zhao+02] in order to generate an interface framework for this kind of application.

In focus to successfully support the work of the Umweltbundesamt much data and knowledge of currently monitored properties was gained which aided the overall prototyping work. Another important aspect the prototype has to fulfill is an intuitive and easy to use user interface. Ease of use and therefore overall using of the software should not produce long training time and in this way the prototype achieves benefits in user acceptance by a clear structured layout and interactive functionality. The prototype uses ESRI shapefiles [ArSh98] for displaying GIS data provided by the Umweltbundesamt. Data interoperation is flexible and can easily be adapted to meet upcoming needs in context with future studies. Additionally the prototype has to prepare MORIS support, which is assured by transferring the achieved data with a unique MORIS ID acronym and with this the collected ecological data can be simply accessed and exported to update MORIS database with new ecological and environmental data. As maintainability represents an important long term aspect of using a software system, costs and efforts of computer scientists should be kept at a low level. With the choice of the ESRI framework and the already used ESRI standards at Umweltbundesamt, overall technical efforts and time consumption for this project was more than acceptable and confirmed our decisions for a specific customized prototype for UBA needs.

ESRI ArcPad Design Decisions

The prototype is a highly adaptable application. The possibilities of the ESRI framework assure low efforts in gaining needed functionality fast. Further important aspects are the usage of Umweltbundesamt's maps with the projection format Gauss-Krüger Meridian 31 (shortly called GK MGI 31) displaying GIS data from UBA layers on standard PDAs and a seamless integration of GPS data into the provided maps. These reasons conducted the usage of the ESRI product. Nevertheless, Umweltbundesamt already uses ESRI products in many areas (like ESRI ArcGIS 9 for spatial data), which was a major reason for choosing ESRI's mobile GIS ArcPad [Arcp04].

The application is fundamentally based on ESRI ArcPad and was concretely implemented using ArcPad Studio Application Developer and VBScript to implement additional and customized functionality. The prototype implementation work began after ESRI shapefiles of the Umweltbundesamt concerning the Integrated Monitoring area at Zöbelboden were imported to our ESRI development environment. The prototyping centers on navigating in the map using interactive dialog boxes for managing data input, from where VBScript-functions are called. Location-awareness is achieved by integrating actually received GPS data, which is supported by ArcPad through a standardized COM interface. This functionality allows mobile users to freely move the focus of the map to measured GPS positions and points of interest (POI) either manually or automatically. Automated focus can easily be implemented with focus on automation of surveys. As already figured out by Imielinski and Navas [Imie+99], there can be different ways to implement or define this functionality in a possible future work on this mobile client. For example, this can be either an automation of guiding through an augmented area, by automation of concrete data collection forms interacting with mobile workers within a defined distance to POI's or by a real-time analysis of covered distances discussed within Schindler [Schin04].

ESRI Map and Layer Definitions

As used in other GIS enabling products, ArdPad allows data and maps stored and defined in shapefile layer files [ArSh98]. The prototype uses layers for displaying internal data like the area boundaries, paths, and objects. Most important for the concrete Integrated Monitoring usage at UBA are tree and permanent plot layers. In these layers tree data and ecological information from permanent plots are stored as so called features, which define data rows with data entries and contain all the information needed to place objects. This information further contains the objects shape, like point or polygon, and may contain additional data, like the number of trees in a permanent plot or other additional ecological data. In future work it would be possible to resolve this spatial information also through a network connection resulting in a mobile dynamical location-aware geographic information client, see for example Tummala and Jones [Tumm+05].

As referenced in ESRI's documentation [ArSh98], a shapefile stores non topological geometry and attribute information for the spatial features in a data set. The geometry for a specific feature is stored as a set of vector coordinates. Because shapefiles do not require processing overhead of topological data structure, they have advantages over other data sources such as faster drawing speed and faster editing. Shapefiles handle single features that overlap or are noncontiguous. As shown in Figure 18 shapefiles only include the top three layers (points, polygons and objects) of a standard GIS layer definition which also include spatial and area information represented as the last two layers. Shapefiles typically require less disk space and are easier to read and write, which is essential for mobile devices. Shapefiles can support point, line, and area features. Area features are represented as closed loop, double-digitized polygons. Attributes are held in a dBASE format file. Each attribute record has a 1:1 relationship with the associated shape record.

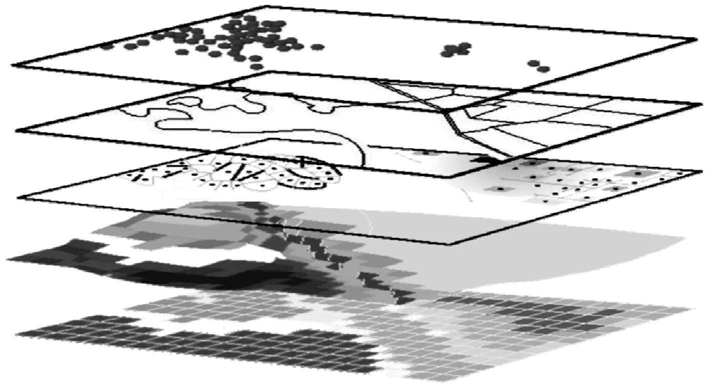

Figure 18: GIS Layer Definition [www.esri.com].

An ESRI shapefile consists of a main file, an index file, and a dBASE table, according to ESRI's technical reference [ArSh98]. The mainfile is a direct access, variable-record-length file in which each record describes a shape with a list of its vertices. In the index file, each record contains the offset of the corresponding main file record from the beginning of the main file. The dBASE table contains feature attributes with one record per feature.

The relationship between geometry and attributes (1:1 relationship) is based on record numbers, which define the reference from one attribute to a specific geometry object. Attribute records in the dBASE file must be in the same order as records in the main file. All files have to follow a certain naming convention 8.3. ESRI defines the suffix for the main file as .shp, the suffix for the index file is .shx, the suffix for the dBASE table is .dbf.

Analysis of Requirements for Implementation

For the improved location-aware data collection process there are some main aspects that should be considered, especially usability and Human Computer Interaction (HCI) issues in fieldwork environments. We define the following characteristics which are addressed in the prototypical implementation, they are:

Clearly laid out and arranged application structure

The prototype has to be usable. The system's interface should support an intuitive use of the application. The user should be prevented of program failures and the application should be aware of recovering itself from possible errors.

Fully functional and reasonable graphical user interface

The use of the location-aware application on a mobile device has to be supported in a highly reasonable way. Interaction and activities within the monitoring process should be supported by the application in order to conveniently use the device in an outdoor environment. Main functions should be reachable in few interaction steps considering the small display of mobile devices (no multiple windows, small icons, generally not to loose the mental picture of the applications logic, etc).

Continuous and exact display of geographical map data

This functionality is needed to help mobile workers to orientate and to help guiding them through a specific area, Points Of Interest (POIs) should be displayed in order to achieve better navigation from one point to another.

Ability to insert multimedia data and additional information

The prototype should be able to import multimedia files (like pictures, audio, video and even texts) and to link them to GIS data. Environmental phenomena can thus be tracked in more detail (e.g., including photos).

Interface for integration of collected ecological data into Umweltbundesamt's databases

The prototype has to provide a suitable format of the collected data to ensure a transfer to the ESRI ArcGIS database and as a next step to be transferred into the MORIS database.

Final Prototype GIS Functionalities

As a result of the introduced requirements and the permanent review process in coordination with Umweltbundesamt, the prototype now provides four important GPS supported GIS functionalities:

1. A virtual map view of the Integrated Monitoring area including several object layers with several landscapes and specific points of interest (POIs)
2. GPS-assisted, location-aware capturing/editing of ecological tree and permanent plot data and functionality for estimating near situated POIs
3. Adding and linking pictures or other multimedia based data to recently captured data, existing data, or in context to other POIs
4. Continuous GPS tracklogs, providing waypoints for extended track analysis and graphical visualization of the gained tracking points.

In order to enable a functional, reasonable, and usable user interface without wasting place on the PDA's display for better map display we defined a simple and straight toolbar with multidimensional function buttons. As presented in Figure 19 of the prototype, various functions are categorized and can be chosen from context menus.

The main window gives a geographic map of the field test area at Zöbelboden with trees situated on permanent plots. The specific main data collection related functions can be selected by pressing the toolbar visualized by the logo of the Umweltbundesamt.

In order to summarize and give an overview of these various functions and modes , we introduce a general overview of provided functionality. The following list of functions (referenced in order to the single toolbar) consists of several ESRI Object Framework customized functionality (described in more detail in the following chapter of this document).

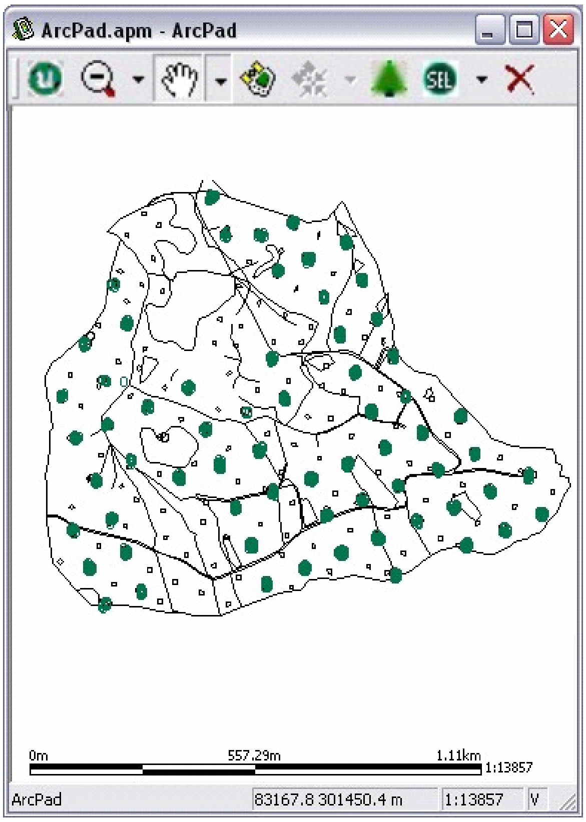

Figure 19: Prototype Interface and Single Toolbar.

Zoom in / zoom out

This function zooms in and out the focus of the shown map, each zoom step equals one scale step, which varies on the provided map. The actual scale of map display is shown in the bottom of the map.

Zoom to full extent of map

When using this function the prototype focuses automatically on the boarders of the provided map. The whole map is displayed at once and a good overview of the actual position in the area is given. This functionality can be simply used to re-center the map's focus if actual position's focus is lost. You can see the zooming functionality in Figure 20, this function provides a natural feeling for the user's position on the map and is very intuitive to use.

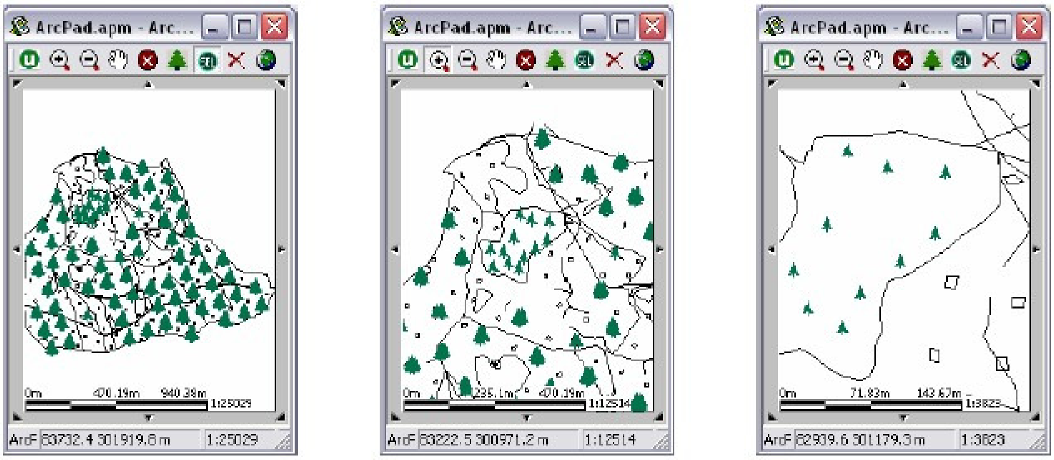

Figure 20: Zooming In and Out.

Move map focus

If this function button is activated, the map can be fixed at a specific geographical point and the whole map can be moved on the display. This helps navigating through a given waypoint or to a specific point on the map.

Exit the prototype

The exit button immediately closes the whole application, but it is guaranteed that no data can be lost.

Activate / deactivate GPS receiver

This function sets the GPS receiver on or off. Switching off is useful in buildings where no GPS fix can be found.

GPS satellite position window

This useful feature of the ESRI framework shows satellites and their status or if there are interferences. It helps to classify the actual quality of the GPS signal quality and to estimate the number of received satellite signals, more satellites implicate better signal quality and positioning data received with the device.

Enable / disable GPS tracklog visualization

Using this function sets the logging shapefile to a visible state, therefore the track (positions visited before) is visible and can be processed for an additional analysis.

Show nearest plot ID

This function is an improvement to estimate a set of near situated permanent plots. The return value defines the IDs of the permanent plots located next to either the manually pointed section of the map or a location-aware estimation from the actual GPS position. The user can decide to use this function to find permanent plots nearby. This function can easily be enhanced in future to provide automatically more accurate prediction of POI's for the user.

Create tree objects

With this function a new tree object is added to the tree's shapefile and a form is called to enter several tree specific information and data for long-term observation. Also multimedia files can be linked, such as additional pictures, sounds or movies (Figure 21).

Figure 21: Create Tree Objects.

Selection of objects

By choosing the "SEL" button, the prototype is able to manipulate tree and permanent plot data by directly altering objects and automatically opening individually defined data forms through different object's shape definition. These forms provide an input and control functionality for ecological and scientific data; additionally, multimedia files can be linked to the shapefile's feature records through these forms (Figure 22).

Figure 22: Selection of Objects.

Remove objects

Here, it is possible to remove certain objects on editable shapefile files, which means that tree and permanent plot objects can be deleted permanently from the layer's features (Figure 23).

Figure 23: Removing Objects.

Capturing Tree Monitoring Data

In order to capture new tree data and create a new tree object (covers basic tree data and specific disturbance parameters) the mode for "Create tree objects" has to be selected (Figure 24). When creating the tree object on the selected area in the map, a specific adapted form is opened for further interaction. The form consists of different bars representing ecological data to be measured and collected. As shown in the figure, the record of the dataset is capable of linking multimedia data like pictures, audio, and video.

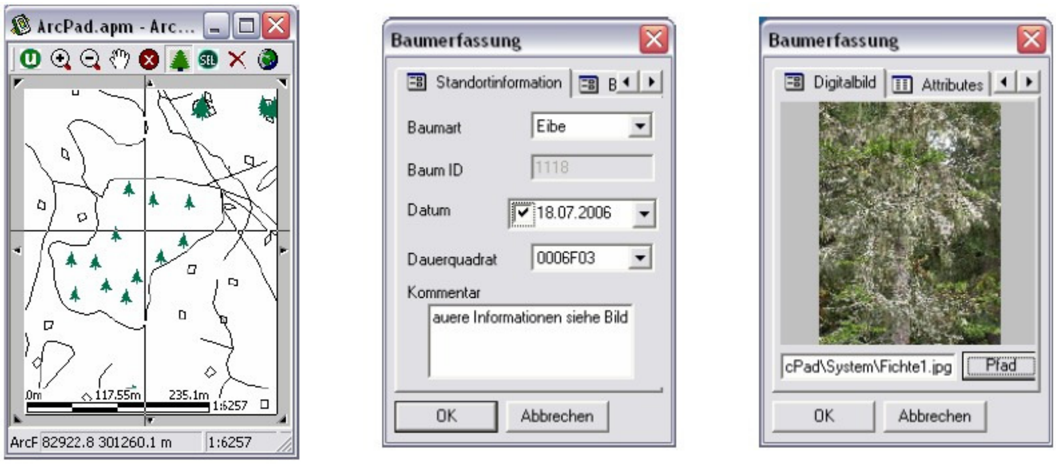

Figure 24: ArcPad - Entering / Altering Tree Data.

After confirming entered data the new tree object is placed on the map and a tree symbol appears. If the newly created object represented as tree symbol is reselected afterwards, the specific saved tree form appears to manipulate data and link additional multimedia data like pictures or audio files. This form is automatically initiated by our software through events on the map. The form extension of the trees layer owns the same namespace of the affected shapefile layer.

Capturing Permanent Plot Data

All permanent plots are defined for long-term monitoring and placed on the permanent plot layer. Permanent plot objects are different to tree objects (referencing points on the map), they are polygons which are referenced through several spatial points and they cannot be created. To manipulate und enter data, the user must switch to “Selection of Objects” by clicking the green “SEL” button situated on the UBA customized toolbar (Figure 25).

When the button is selected and a permanent plot is marked at the monitoring site, a dialog box appears for entering plot specific ecological data, which is stored automatically to the data structure of the features element in the shapefile’s dBase file. The form is divided into different tabs, providing the user boxes and selections for measured information and linking pictures to the site’s features.

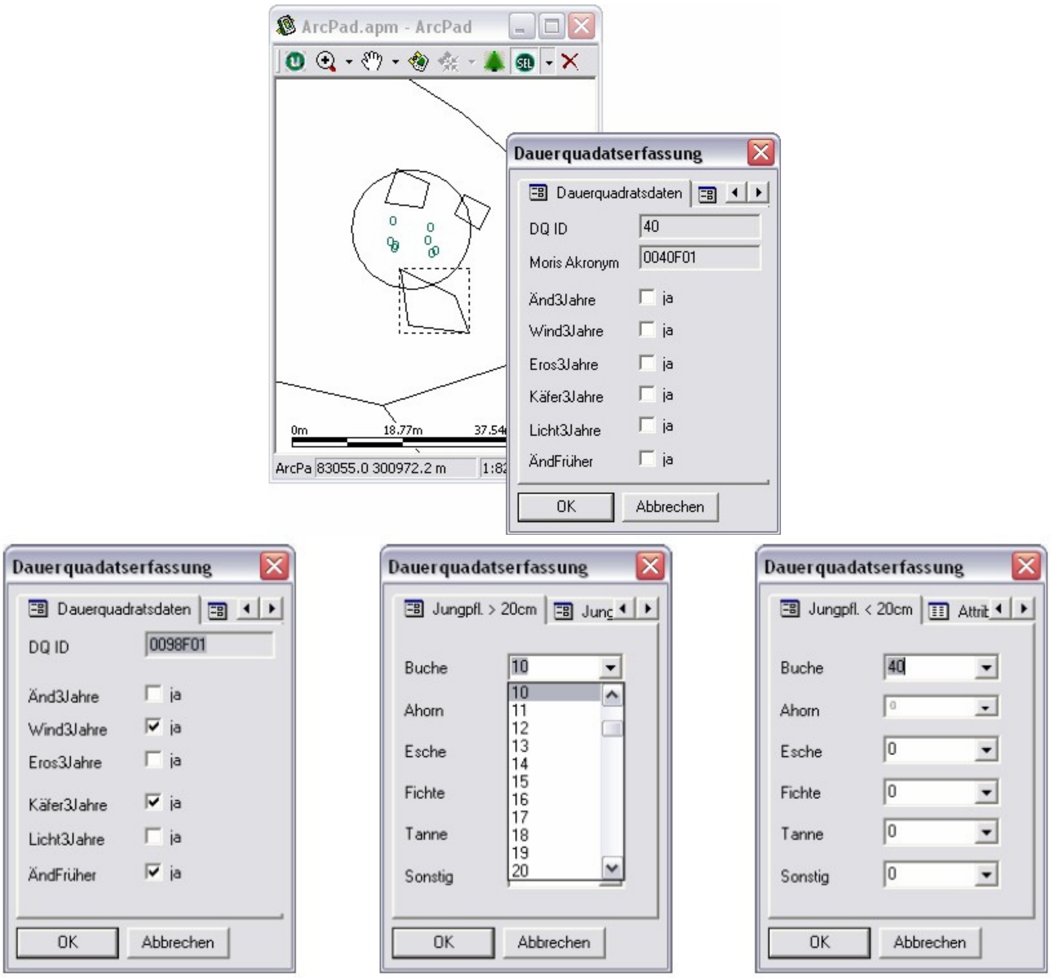

Figure 25: ArcPad - Entering / Altering Permanent Plot Data.

GIS Logging Functionality

The Prototype is able to track one GPS position with a configurable frequency, currently every second, and stores the movement history in a separately provided shapefile named "TrackLog.shp". This feature is provided by the ESRI Framework [Arcp04] and was extended with an additional defined application log file containing user interaction data at a given position. This feature was introduced to recover from system failures and to be able to analyze user's interactions at some track area. Hand in hand with the track's shapefile, the application log textfile provides information which can be used to evaluate the quality of GPS logs and helps optimizing the user interface with further analysis of the monitoring processes.

6 ESRI ARCPAD OBJECT MODEL PROTOTYPING

To provide a fully functional and usable prototype for outdoor environments, we define a clear customizing process. This process declares a main factor for useing ESRI based technology for our implementation. We will show the range of customization, describe affected files for customizing work, and provide a short insight into Visual Basic programming related to this work. Concretely, we will describe the ArcPad Object Model. An introduction of the implementation relevant aspects of this framework will be given and some customized and coded files involved in our project will be presented. All following information about the ArcPad Object Model is summarized and referenced from ESRI's ArcPad Guide [Arcp04] and ESRI's Application Builder Documentation [Arcb02].

Customization and prototyping work was done using Application Builder Version 6.0.1 and later on the development was deployed on ArcPad Version 6.0.3. The Object Model Version 6.0.1 utilized in this project is meant to use within all versions of the ArcPad 6 software and was not changed for later subversions. The objects are defined in overall 38 classes assigned to 12 class categories, which provide all necessary functionality for mobile GIS use. In this way ArcPad exposes its extensive object model that can be accessed through our own scripts whenever ArcPad is running.

Introduction of ESRI ArcPad Prototyping

ESRI introduces a range of customization options based on ArcPad's Object Model, which were unavailable in previous ArcPad versions. With this Object Model we are able to easily create custom toolbars, data entry forms and specific configuration files. It is further possible to create new tools, applets and extensions to support new data formats. As mobile workers are often in need of functionality for application specific tasks, it is necessary to create a custom GIS solution for mobile duties. With ArcPad Application Builder it is generally possible to implement an application which supports intuitive data collection. It is further possibe to write custom scripts interacting with ArcPad's internal objects and to develop extensions for new GPS receivers or other hardware like rangefinders, cameras, projections, and datum transformations.

In the Umweltbundesamt's use case, we used ArcPad's facilities to support previously paper-based field data forms for collecting environmental data by a mobile GIS application. The prototype therefore increases the efficiency and effectiveness of Umweltbundesamt's field-workers, reduces ArcPad's mobile GIS function set to the skill levels required for mobile workers, and automates tasks with extended GIS capabilities.

ArcPad Customization Overview

ArcPad Studio Developer provides several tools to customize ArcPad's features. With ArcPad Object Model [Arcb02] we can build and define new customization files from scratch or modify existing files to suit specific needs. It is possible to access ArcPad XML elements, attributes, and values directly from the main window's tree view and edit them directly. It is also possible to use one the various programming editors to speed up ArcPad development like Microsoft Visual Studio.

Interoperation with ArcPad system objects, which define ArcPad's internal object structure realized with Visual Basic Script, is fairly straight to understand and easy to adopt for developers. Visual Basic Script (VBS) defines a smaller version of Visual Basic with focus on simple and fast script development. In contrast to full Visual Basic it offers restricted error handling, no classification of some data types and it has smaller functionality focused on fast scripting work. Visual Basic Script files are started and interpreted beginning from the first line and do not own an explicit starting method. Each file defines a separate module and can be seen as a class which exists when the scripting host is initiated, in our case when ArcPad 6 is started. Then, all scripts are initiated which were previously referenced in the customized ArcPad XML definition files. Details of different configuration focuses are shown next section in **Fehler! Verweisquelle konnte nicht gefunden werden.**. A next aspect to be mentioned is the calling of parameters in sub routines. Call-By-Value parameters have to be explicitly declared by using the key word "ByVal" because in

Visual Basic Script parameters are handled as being of Call-By-Reference type. Although Visual Basic Script is in some cases a drawback when compared to other programming languages, ArcPad's customization framework [Arcb02] enable objects interaction of all later mentioned objects and allows scripts to be associated (in XML files) with object events that occur in the background while ArcPad is executed.

Development Environment for ArcPad

Most of ArcPad's customization for our prototype was performed in ArcPad Studio Developer [Arcb02]. With this developer it is possible to build and develop applets, customize toolbars and forms, create default configuration files and define different layers interaction as shown in Figure 26. Although customization can be realized without writing many lines of code, this fundamental feature of ArcPad's customization environment provides the ability to use Visual Basic code in to enhance the functionality for various needs.

To show a simple example of an ESRI ArcPad customization process we introduce the most important steps and configuration files used. First a shapefile layer has to be prepared with ESRI ArcGIS Software (e.g., ArcEditor, ArcView) and afterwards the map has to be ported with spatial objects to ArcPad Application Developer. When setting up the customization, we have to create initial configuration files. The Application Extension File (*.apx) defines the main configuration file for customization. It references additional code files, applets (*.apa) with packaged functionality, extensions for customized functionality, needed projection information and toolbars. In the Map File (*.apm) maps and spatial objects can be predefined and loaded automatically on startup. To manipulate shapefile layers and projected objects a Form File (*.apl) can be added providing functionality for creating or linking new record sets or manipulate existing information.

To provide additional functionality a Visual Basic Code File (*.vbs) can be attached, which interacts with the Application Framework and specified extension files. The extensions can be involved to provide an interface for external functions. If the form is called to create an object, a new record in the Index File (*.shx) and the Database File (*.dbf) is created and referenced in the shapefile.

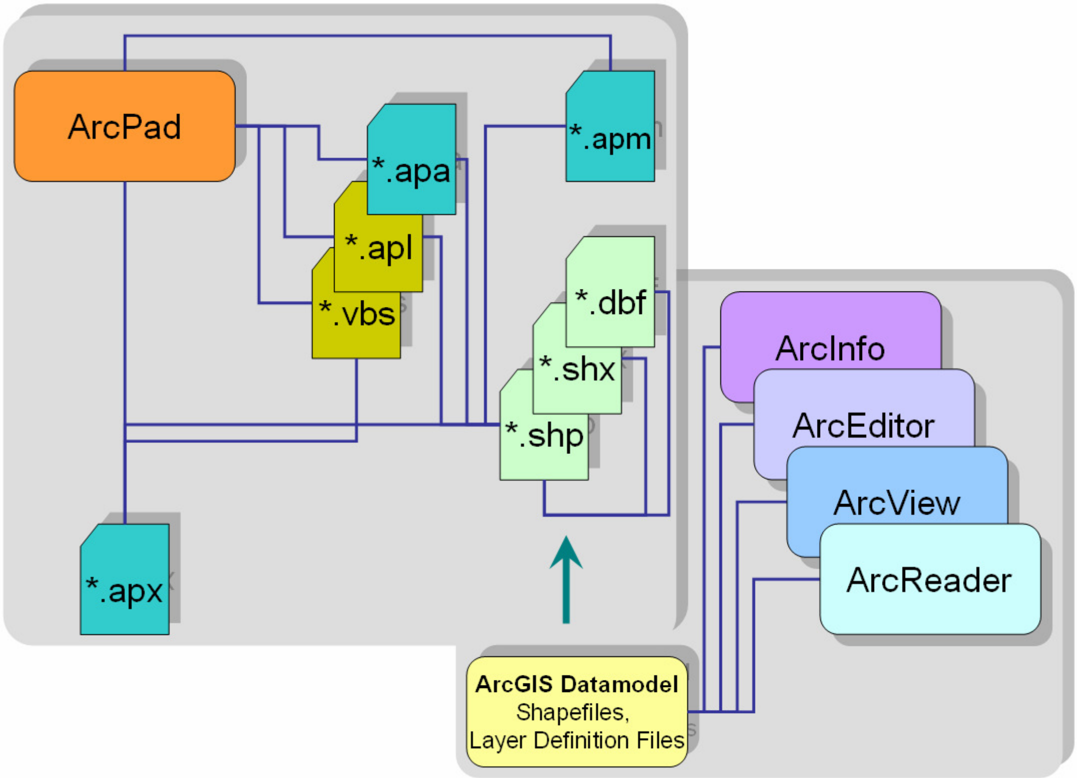

Figure 26: ArcPad Customization - Involved Files and Tools.

As mentioned in the ArcPad Studio Developer's description [Arcb02], the scripting support is delivered by ArcPad itself operating as a scripting host environment for Microsoft's VBScript language. VBScript is widely known and relatively easy to learn. The VBScript run-time library (vbscript.dll) is installed in ROM on most CE devices and is installed as part of Microsoft Internet Explorer version 4 or later on desktop Windows PCs.

Whether scripts are used or standard configurations are modified, every single customization file is stored in ArcPad's XML format, so familiarization with this format will allow working with any of ArcPad's customization files in any text or XML editor changing various functionalities. Data preparation for ArcPad, such as exporting a layer's specific symbology or an own provided symbology, is done in ArcGIS using the ArcPad Tools, for example ArcInfo, ArcEditor, or ArcView.

Customization Focus	Programming, Required Technology	Development Environment
Hide toolbars	XML configuration	ArcPad Studio/Development Tool
Create new toolbars	XML configuration	ArcPad Studio/Development Tool
Build new tools	Visual Basic	ArcPad Studio/Development Tool
Design custom forms	XML configuration	ArcPad Studio/Development Tool
Validate data in form controls	Visual Basic	ArcPad Studio/Development Tool
Access object properties and methods	Visual Basic	ArcPad Studio/Development Tool
Configure the status bar	XML configuration	ArcPad Studio/Development Tool
Develop applets	Visual Basic	ArcPad Studio/Development Tool
Prepare symbology	XML configuration	ArcPad Tools for ArcGIS/ArcView
Extentions and dataformats	C and C++	ArcPad Studio/Development Tool

Table 6: ArcPad Customization Overview.

ESRI accentuates [Arcb02] that programmers who want to provide support for new data formats or positioning protocols in ArcPad can do so by simply developing and deploying own extensions within various development tools and environments, for example Visual Studio. Extensions must be created as DLLs, and therefore will most likely be written in C or C++ (see also Table 6). Most ArcPad applications will be deployed for mobile Windows CE devices, so it is very important to make sure that any functionality provided in extensions is supported by these devices and must be tested before use.

We do not have to spend such effort, since we don't use self developed extensions for new data formats, but use standard shapefiles provided by the Umweltbundesamt. The customization development is done on a standard Windows desktop environment. This speeds up development, because we have no need to check every step of development on a mobile device. All different customizations, in the form of applets, default configurations, or other specific customizations are deployed on a mobile device via a copying ArcPad's system folder or only the involved customized files to the mobile client.

Customizing ArcPad - ESRI XML Files (ArcXML)

ArcPad XML format is designed for automation and customization of ArcPad and is based on the XML 1.0 specification. It adopts many of symbols (ESRI symbology elements) and attributes from ArcXML (AXL) standard. All customization files are stored as XML text files and the .ap* extension is used for following files (referenced from ESRI Documentation [Arcb02]):

ArcPad Configuration File (ArcPad.apx)

It is loaded by default each time ArcPad starts. The file contains custom toolbars, forms, and system object event handlers and other parameters that override ArcPad's default options (e.g., toolbars initially visible). Next file to mention is the Global Bookmark File (ArcPadBookMarks.apx) which contains spatial bookmarks.

ArcPad Preferences File (ArcPadPrefs.apx)

It contains ArcPad's default option parameters which are set in ArcPad's options dialog box, like GPS settings, default symbology, and default file paths.

ArcPad Applet Files (*.apa)

An applet delivers a small application in one single file with no need to check ArcPad's configuration. It may contain toolbars, forms, and system object event handlers. Applets load automatically after the default configuration has been loaded.

ArcPad Layer Definition Files (*.apl)

These layer definition files are associated with specific shapefiles holding the identical filename as the shapefile and the ending extension .apl. Layer definitions provide customizations that are delivered and loaded together with data. In our project customizations deliver data entry forms for adding tree objects. An associated script handles concrete data entry validation and other features offered on the forms, like inserting multimedia based data. These files may also contain custom symbology (i.e., own defined symbols for trees, instances, POIs, etc) exported by ArcView or other ArcGIS desktop environments.

ArcPad Map Files (*.apm)

This map files store different map layers of an ArcPad session. A map file lists all feature layers together with their display settings including the extent of maps, colors, and projection environments.

VBScript Files (*.vbs)

Most of sophisticated customization in ArcPad is, as in our project, accomplished by writing specific script files to add custom functionality. Our version of ArcPad supports Microsoft's Visual Basic Script language. Scripts may be embedded within ArcPad customization files directly within script sections. To support reuse and the adoption of scripts, it is more efficient to place related scripts in a separate .vbs file.

In our prototype, all code needed for additional functionality was written in Visual Basic Script. ESRI's own framework extends Visual Basic Script's basic functionality with ArcPad specific functions that are hierarchically and functionally separated in different object types, e.g., application objects, form objects, or event objects which are interacting with each other (Figure 27).

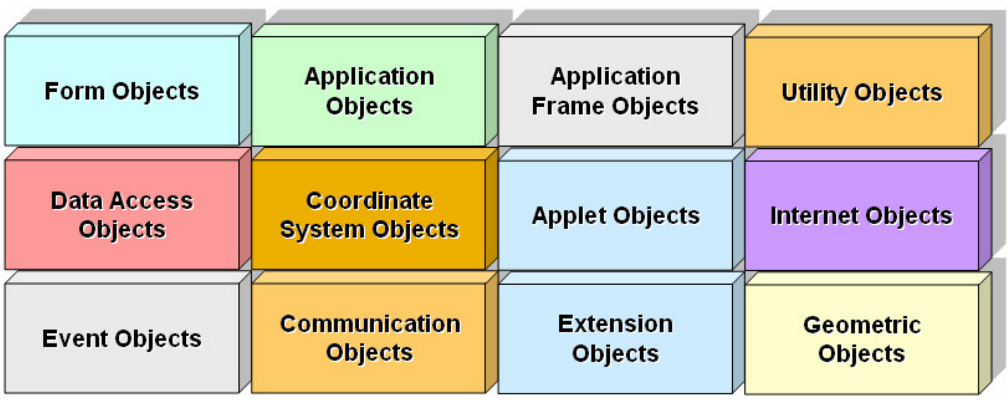

Figure 27: ESRI Object Model Overview [Arcb02].

As we used specific parts of possible customization provided by ESRI (main functionality was inherited within the Application, Form, Communication, and Event objects), we shall now give a short overview of the ESRI ArcPad Object Model. It consists of 12 placed over objects with an overall of 38 objects (Object Model 6.0.1 [Arcb02]) that are permanently supported while ArcPad is running on a mobile device. As long as ArcPad is running, it is possible to access and manipulate all these objects via Visual Basic Script code.

As shown in Table 7, the Application object consists of the Application, Map, Layers, Layer, Navigation, Symbol, TextSymbol, and Font objects. The application object represents the initial root object for any running application on ArcPad. Any other object related to the current map, display environment, or application command functions, is initialized in the application object.

OBJECT Classes	Scope of Subclasses
Application	Consists of Application, Map, Layers, Layer, Navigation, Symbol, TextSymbol, and Font objects
Application Frame	Consists of ToolBars, ToolBar, ToolItem, and StatusBar objects.
Form	Consist of Forms, Form, Pages, Page, Controls, and Control objects.
Applet	Consist of Applets and Applet objects.
Extension	Consist of Extensions and Extension objects.
Data Access	Consist of RecordSet, Fields, and Field objects
Coordinate System	Consist of only the CoordSys object.
Communication	Consist of AUX and GPS objects.
Geometric	Consists of Ellipse, Points, Line, Polygon, Parts, and Rectangle objects
Event	Consist of ThisEvent object.
Internet	Consist of ArcIMS and INET objects.
Utility	Consist of CommonDialog, File, Timer, and System objects

Table 7: ESRI Framework Object Overview.

Own Prototyping Work and Prototype's Customization

Now we are going to present an extract of our prototype's specific configuration files, their formal layout and some code parts which form a main part of our customized UBA location-aware prototype.

In order to provide all needed map layers at initial start of our prototype we defined an ArcPad.apm file within the AXL standard and inserted all needed layer information and defined coordinate transformations (datum shifts) for the previous mentioned GK M31 map projection.

Configuration Files and Involved Code

Next step was to define an ArcPad.apx file within the AXL standard, which defines the default configuration of ArcPad with Toolbars and inherited functionality from Visual Basic files, which are referenced within the various Layer files through customized forms for data manipulation. These Forms, which are referenced and called from layer files (shapefiles), are graphically customized with ESRI Application Builder and functionally extended with specifically coded Visual Basic Script files.

```xml
<?xml version="1.0" encoding="UTF-8" ?>
<ArcPad>
  <MAP name="ArcPad.apm">
    <PROPERTIES>
      <ENVELOPE minx="82395.9013002667" miny="300452.018521799" maxx="84010.9020837349" maxy="301579.690247199'
      <COORDSYS string="PROJCS[&quot;GK31_AUT&quot;,GEOGCS[&quot;GCS_MGI&quot;,DATUM[&quot;WGS84&quot;,SPHEROIL
    </PROPERTIES>
    <BOOKMARKS>
    </BOOKMARKS>
    <LAYER name="IM_BaumPkt_Raster_EOA1993" identify="true" edit="true">
      <DATASET name="IM_BaumPkt_Raster_EOA1993.shp"/>
      <METADATA>
      </METADATA>
      <SYMBOLOGY>
        <SIMPLERENDERER>
          <SIMPLEMARKERSYMBOL color="192,192,192" width="3" type="circle" outline="0,0,0" outlinetype="solid"/>
        </SIMPLERENDERER>
        <SIMPLELABELRENDERER field="MORIS_AKRO">
          <TEXTSYMBOL fontcolor="0,0,0" font="Arial" fontstyle="regular" fontsize="8"/>
        </SIMPLELABELRENDERER>
      </SYMBOLOGY>
    </LAYER>
```

Figure 28: Snippet - Customized ArcPad.apm.

As the “ENVELOPE” attribute as shown in Figure 28 defines the exact map extent, the “COORDSYS” attribute defines the correct transformation for WGS84 to GK M31 projection information. This means exactly that all information about positioning is transformed from GPS values, which use WGS84 projection format, to Umweltbundesamt’s provided maps which use the specific Gauss Krüger Meridian 31 projection format. In Figure 30 each involved layer within the “LAYER” elements is shown.

The corresponding Arcpad.apx file contains the specification of the prototype's toolbars, forms, and system object events introduced for mobile worker's observation work (see Figure 29).

```
<TOOLBARS>
  <TOOLBAR name="tlbZöbelEditor" caption="" visible="true" image="mini U 16 strong.bmp">
    <TOOLBUTTON command="modezoomin">
      <MENUITEM command="modezoomout">
      </MENUITEM>
      <MENUITEM command="zoomfullextent">
      </MENUITEM>
    </TOOLBUTTON>
    <TOOLBUTTON command="modepan">
      <MENUITEM command="exit">
      </MENUITEM>
    </TOOLBUTTON>
    <TOOLBUTTON command="gpsenable">
    </TOOLBUTTON>
    <TOOLBUTTON command="centerongps">
      <MENUITEM command="gpspositionwindow">
      </MENUITEM>
      <MENUITEM command="gpstracklog">
      </MENUITEM>
    </TOOLBUTTON>
    <TOOLBUTTON name="tlZoeblBaum" shortcut="" image="tree1.bmp" onpointerup="Call AddBaumPkt" oncl
    </TOOLBUTTON>
    <TOOLBUTTON name="tlZoeblDQ" shortcut="" image="mini SEL 16.bmp" onpointerup="Call SelectItem"
      <MENUITEM onpointerup="Call GetClosestDQUser" name="NearestUserDQ" shortcut="" image="@addim
      </MENUITEM>
      <MENUITEM onclick="Call Application.ExecuteCommand (&quot;centerongps&quot;) Call GetClosest
      </MENUITEM>
    </TOOLBUTTON>
    <TOOLBUTTON onpointerup="Call DeleteSelectedTree Call WriteLogLine(&quot;Objekt wurde gelöscht
    </TOOLBUTTON>
  </TOOLBAR>
  <TOOLBAR name="main" visible="true" create="true" caption="" image="">
  </TOOLBAR>
  <TOOLBAR name="browse" visible="false" create="false" caption="" image="">
  </TOOLBAR>
  <TOOLBAR name="draw" visible="false" create="false" caption="" image="">
  </TOOLBAR>
</TOOLBARS>
```

Figure 29: Snippet - Customized ArcPad.apx.

In Figure 29 the newly customized single toolbar introduced for Umweltbundesamt, called "tlbZöbelEditor" is presented with added functions like "Call AddBaumPkt" for adding tree objects and related data, "Call SelectedItem" to select an existing object, "Call GetClosestDQUser" for selecting a nearby permanent plot where the map was touched, "Call GetClosestGpsDQ" for selecting the nearest situated permanent plot (from the actual GPS position), "Call DeleteSelectedTree" to delete a tree object on the Layer or "Call writeLogLine" for writing to the Log file. We will now introduce some of the added functionality in the coded *.vbs files attached to different configuration files.

Selected Prototype's Functions and Code Fragments

To accomplish the implementation of the functional requirements, various files were customized for UBA needs. We introduce three main Visual Basic Script files of our mobile GIS prototype.

The first script file to introduce provides basic functionality for the application (configurations concerning the tracking of GPS data, start of the programs fundamental behaviour which layers are called with specific parameters, etc) is the ArcPad.vbs which is initiated and called when ArcPad is started. It is referenced through <SCRIPT src="ArcPad.vbs"></SCRIPT> in the ArcPad.apx file which represents the main configuration file for ArcPad customization. The functionality coded in this file is accessible from all imitated objects.

The second script file to mention is the IM_BaumPkt_Raster_EOA1993.vbs which adds specific functionality for interaction with tree objects on the shapefile. It owns the identical naming from the IM_BaumPkt_Raster_EOA1993.shp layer which holds all tree objects on the map. If a tree object on the map is selected or newly added, a specific form is referenced from the application object which is also named identically with the extension *.apl. With this additional Application Layer file (called IM_BaumPkt_Raster_EOA1993.apl) a custom form object is called, providing manipulation of an objects data with functionality of the inherited Visual Basic Script file and saving the object's information (feature's information) to a dBASE database file (*.dbf).

The third important script file providing main implementation's functionality is the IM_Dauerquadrate_Raster_20051205.vbs. It is related to a specific shapefile (*.shp) and an referenced Application Layer (*.apl) file holding a form which inherits the Visual Basic Script file with coded functionality. These files offer functionality for manipulating und interacting with permanent plot data and save monitored information into the *.dbf (dBASE) database file.

To give a minimum understanding how Visual Basic Script coding was done within this project and how the Object Model was used and referenced within the application, we demonstrate a few lines of code from different parts of the ArcPad prototype, showing important algorithms for customized functionality.

```
Sub SelectItem
   …
 'Get coordinates where user touches screen
  x = Map.PointerX
  y = Map.PointerY
    myRS = Map.SelectXY(x,y)
   'Get the layer of the selected feature
  Set objSelectedLayer = Map.SelectionLayer
  'If no feature has been selected, exit the subroutine
  If objSelectedLayer Is Nothing Then
    Exit Sub
  End If
   'Get the edit form for the layer
    If objSelectedLayer.CanEdit Then
        objSelectedLayer.Editable = True
        'Map.Refresh
        objSelectedLayer.Edit(Map.SelectionBookmark)
    End If
    objToolButton.Click
   …
End Sub
```

Figure 30: Algorithm – Selecting Trees and POIs.

In Figure 30 we see a function providing functionality to select tree and permanent plot data on a visible map layer and calls the feature's attributes (in our case, e.g., a tree object) saved in the referenced *.dbf database file. Within the previous customized form provided with the referenced *.apl file it enables changing or adding object information by selecting the layer, getting a reference to the selected feature and opening the form for this layer's feature.

```
Sub AddBaumPkt
    …
 'If the defined layer does exist: Get the coordinates of the map where the user clicked
 dblX = Map.PointerX;  dblY = Map.PointerY;
 Dim objLayer  'Get a reference to the Layer object
 Set objLayer = Map.Layers("IM_BaumPkt_Raster_EOA1993")
 'If the layer can be made editable, make it editable
 If objLayer.CanEdit Then
   objLayer.Editable = True
   Call Map.AddFeatureXY(dblX,dblY)    'Add a new element (point feature) at the clicked location
    objToolButton.Click    'Return the tool button to its original state
        Set objLayer = Nothing
 End If
    …
End Sub
```

Figure 31: Algorithm – Adding Tree Objects.

In Figure 31 we see the function which is called when a tree object should be added. It assigns a tree object to the IM_BaumPkt_Raster_EOA1993.shp layer features, referenced in its according *.dbf Database file which can be recalled and edited again by selecting the object.

When the object is added, the referenced *.apl file is called and a customized input form is shown to enter monitoring data and additional information to the object.

As shown in Figure 32, this code is intended to select, verify and add a storage path for an additionally added picture (or multimedia file) already taken with either the mobile device or stored on a previously inserted storage media like CompactFlash or SecureDisk (SD) cards. The algorithm opens a dialog box, giving the ability to select a multimedia file to be associated with the actual processed feature.

Prototype Installation Details

As mentioned before the prototype installation consists of copying the main application files and shapefile definitions into ArcPad's "system" folder. To configure a GPS receiver, the device's settings can be found in ArcPad's Options dialog. Required technical data for the GPS device, like COM port, baud rate and parity configuration are defined by the GPS receiver's manufacturer.

```
Sub SelectPhotoFile
 'Prompt the user to select a digital picture taken with a camera
 'The image name is placed in the shapefile
   …
   'Allow the user to select a .jpg, .bmp or other multimedia file
   Dim strFilter, strTitle, lngFlags, strResult
   'Set the arguments of the Open dialog box
   strFilter = "JPG Files|*.jpg|BMP Files|*.bmp|MP4 Files|*.mp4"
   strTitle = "Auswahl der Multimediadatei"
   lngFlags = &H1000   'only allow existing files to be specified
   'Show the Open dialog box and get the result
   strResult = CommonDialog.ShowOpen(,strFilter,strTitle,lngFlags)
   If Not IsEmpty(strResult) Then
       theTxtPictureImageControl.Value = strResult
       theImgPictureImageControl.Value = strResult
   End If
   …
End Sub
```

Figure 32: Algorithm - Adding Multimedia Files.

GPS device configuration takes place before all according application, configuration, script und layer files are copied to the mobile device for convenient use. This is an important fact, because all unneeded options and menus (like com port settings and other advanced settings) will be deactivated within our own customized prototype. This is exactly done by setting the standard graphical user interface to our own interface with our specifically designed toolbar.

After copying all system files to the previously properly configured PocketPC, the customized application starts automatically the next time. When ArcPad is launched it now offers our customized functionality with all including features.

7 EVALUATION AND FIELD TEST

To evaluate the mobile GIS prototype two field tests were conducted at Zöbelboden in cooperation with the Umweltbundesamt in summer of 2005 and in autumn of 2006. While the first test was primarily focused on investigating basic GPS accuracy and first feasibility insights, the second test was intended to investigate GPS accuracy in detail and to evaluate the final prototype in terms of robustness and usability. To provide a better understanding of this test and the involved issues, we state now a short overview of the field test area. We present the equipment used, then we describe the field test. Finally, we discuss the gathered values and quality of data received as results of the field test.

Field Test's Area Overview

This ecosystem monitoring site has a size of more than 90 hectares and is situated in upper Austria's northern part of the national park "Northern Calcereous Alps" (N 47°50'30", E 14°26'30") and defines the most recent area of 6 ICP sites (International Cooperative Programme) within the working group on effects of the UN-ECE "Convention on Long-Range Transboundary Air Pollution".

The area of Zöbelbonden's catchment is divided into two different parts with multiple permanent plots for measuring forest stand deposition, soil and water chemistry, and more. One part represents a steep slope from 550 meters to 850 meters above sea level with an incline of 30 to 70 degrees. The other part is a flat plateau ranging from 850 meters to 956 meters above sea level and represents the top of the mountain with an incline of up to 10 degrees. With this background information and the fact of a strong forested surface with weak and distorted GPS signals and much interferences due to the mountainous area we were looking forward to the results and the achieved signal quality of the GPS positioning values of Umweltbundesamt's monitoring site.

Equipment Used for the Field Test

We used three similar PocketPC mobile devices (Pocket LOOX 720, Windows Mobile SE 4.21, Intel PXA 272 processor at 520MHz) to guarantee reliable and comparable data capturing. This mobile device assures needed CPU power for simultaneous GPS positioning and processing geospatial objects and multimedia data.

We also used two additional GPS devices, one Garmin and a second Suunto personal GPS watch for plausibility checks. So we defined three reference mobile devices: martin, karin and gerda, each named, for simplicity reasons, according to the actual user in this field test.

Handheld's Specification:

Dimensions (WxDxH):	7.2 cm x 1.5 cm x 12.2 cm
Processor:	Intel XScale PXA272 520 MHz
ROM:	64 MB
RAM:	128 MB
Display:	3.6" TFT active matrix, transflective, 16-bit (64k colours)
Audio Output:	Speaker(s)
Input:	Microphone, Camera, Stylus
Wireless Connectivity:	IrDA, Bluetooth, IEEE 802.11b
Input Device:	Touch-screen, 5-way navigation button, stylus
Run Time (Up To):	12 hours
Operating System:	Microsoft Windows Mobile (Pocket PC 2003 SE)

Table 8: Handheld Specification.

This device was an ideal item for this test due to its powerful technical footprint shown Table 8. We wanted to ensure a long lasting usage of our prototype with the ability to insert multimedia based data and enabling a suitable map display with an extensive map display even on a mobile device.

The used mobile device Pocket LOOX 720 is shown in Figure 33

Figure 33: Mobile Device Used for Field Test.

Each mobile device was equipped with high speed compact flash GPS receivers (SysOn GPS CF plus II). The SysOn GPS receivers implement a highly sensitive 12 channel GPS receiver (up to 12 simultaneously satellites can be received at usage time) with a SiRF XTrac II LP chipset with a very low power profile.

As mentioned within Vancorenland et al’s work [Vanc+02] there is even much potential to decrease power consumption with future GPS receiver implementations. Refer to Table 9 for technical details of the GPS receiver.

GPS Receiver's Specification (Referenced from Manufacturer):

Chipset	SiRF Star IIe/LP
Channel	12 Channel parallel satellite tracking
Physical Dimension	100x47x16mm (LxWxD)
Hot Time To First Fix (TTFF)	< 8 seconds
Warm Time To First Fix (TTFF)	< 38 seconds
Cold Time To First Fix (TTFF)	< 45 seconds
Antenna	One built-in basic antenna / optional external antenna
Output Message	NMEA 0183 (GGA, GSA, GSV, RMC, VTG), SirF
H/W Interface	Compact Flash (CF) Type I (compatible CF Type II Slots)
Power Voltage	3.3v DC, Low Power SiRF Star IIe / LP chipset
Datum	WGS-84
Update Rate	every 1 second
Re-acquisition Time	0.1 second
Environmental Conditions	Operating Temperature -10C to 50C
	Humidity 95% non-condensing
	Maximum altitude 18,300 m
	Maximum speed 1,852 km/h

Table 9: GPS Receiver's Specification (SysOnChip Inc).

We used this low cost receiver because it provided sufficient capabilities and because of its small dimensions and low weight (see Figure 34). Mobile workers should not be forced to use and carry unnecessary equipment and weight in a field situation.

Figure 34: GPS Receiver SiRF II+ Used for Field Test.

The positioning data of nine selected permanent plots were captured and at the same time we generated a continuous GPS track log with the customized ArcPad prototype on the three PDAs.

Qualitative GPS Results

We collected geospatial positioning GPS data with two different methods during the integrated monitoring field test phase. The first method was the recording of a tracklog to gather information for further statistical analysis and investigation. The second method was the measurement of user selected individual points, which was used to test an automated selection of POIs.

Figure 35 shows the track log generated by one device (martin) at the UN-ECE ICP Integrated Monitoring area. The path is visualized as red markers on the map.

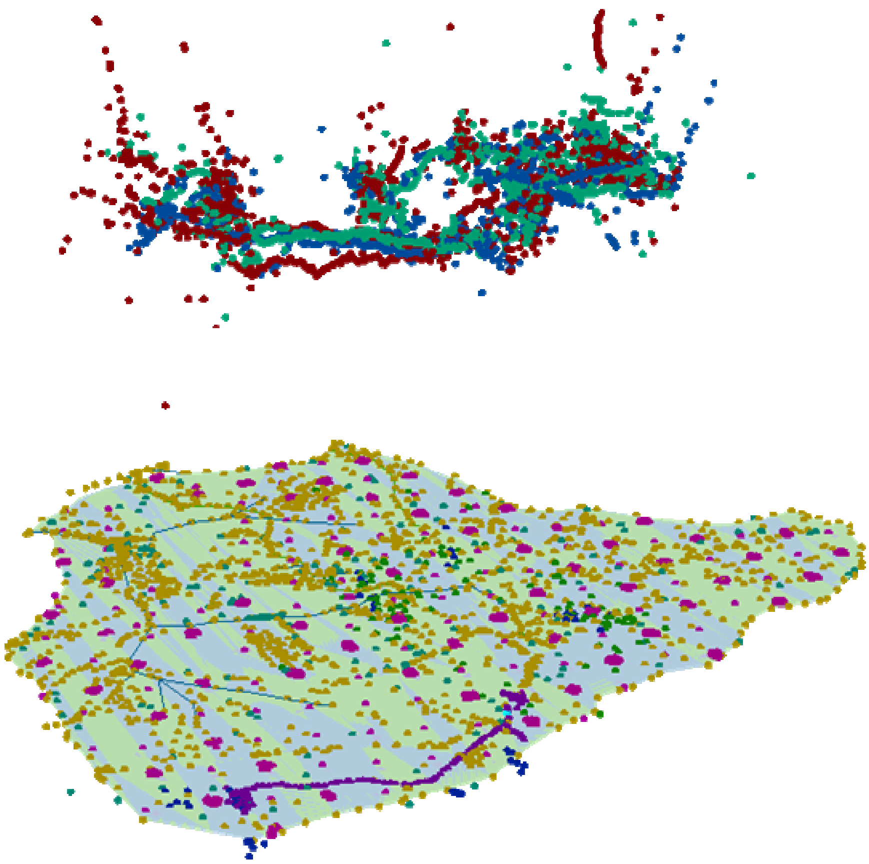

Figure 35: 3D View of Test Area with Spatial Marked Waypoints.

If we take a closer look to this track log, we are able to classify areas with a significant higher possibility of getting GPS. These areas are strongly covered with trees and with various valleys. When walking through the Zöbelboden area we basically noticed that GPS signal become significantly unreliable when action takes place in a deep valley or in a densely wooded area, as depicted in Figure 36. We expected an overall decreased GPS accuracy in conjunction with a higher number of outliers in these areas. The areas with higher occurrence of outliers (indicated with shattered red waypoints) are marked with blue shaded circles, we concretely defined four places with high impact on accuracy.

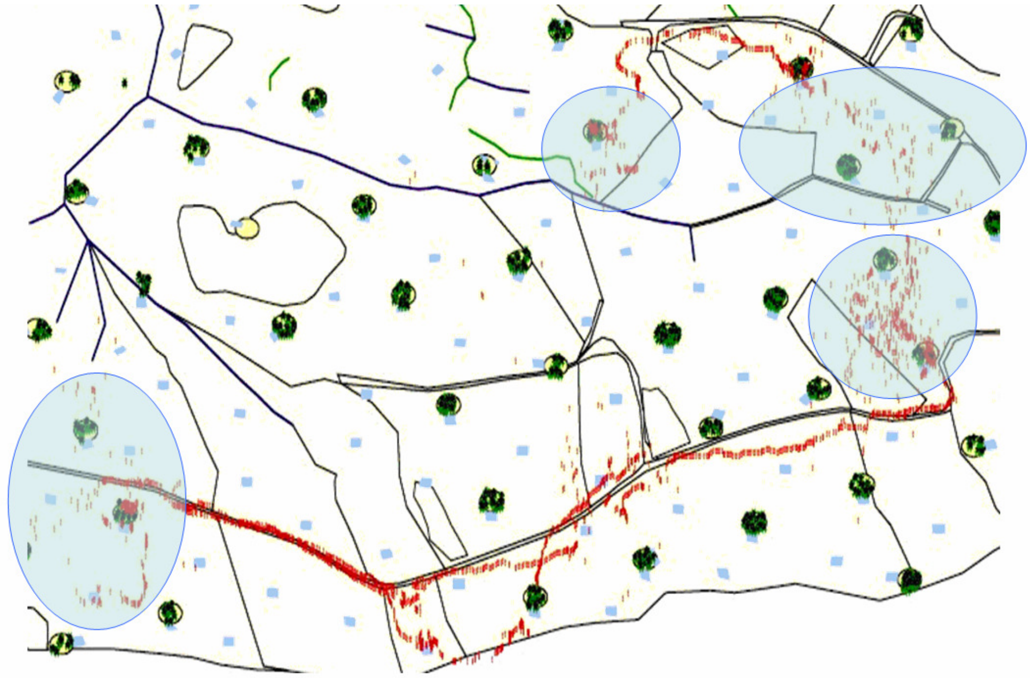

Figure 36: Closer Look of Field Test's Main Outlier Sections.

Furthermore attention has to be paid to the fact that the number of outliers is on the average increased if the users move often (and move faster) in the forested area. Summarized we can say due to deep valleys and forested areas we have seen that standing basically improves received values and moving generally worsens GPS accuracy. If we define a standing position in these specific areas (normally some investigation of the area has to take place), much more accurate positioning values are possible and can be achieved then without strictly changing the course of action in the field.

The next thing we found out with our previously presented equipment was that we were able to use the handheld devices with enabled GPS receiver about four to five hours, which also states that it is truly possible to use it over a defined period of time for field situations.

GPS Track Log Data and Projection Transformation

To measure the accuracy of GPS positioning, projection and transformation of received values was an important aspect. More exactly GPS is working with the WGS_1984 ellipsoid (World Geodetic System 1984) and Umweltbundesamt uses maps with the Gauss-Krüger projection, especially M31 for use in Austria. Refer to

Figure **37** for graphical projection details. To be able to compare both coordinate systems, a transformation of one system into the other was required.

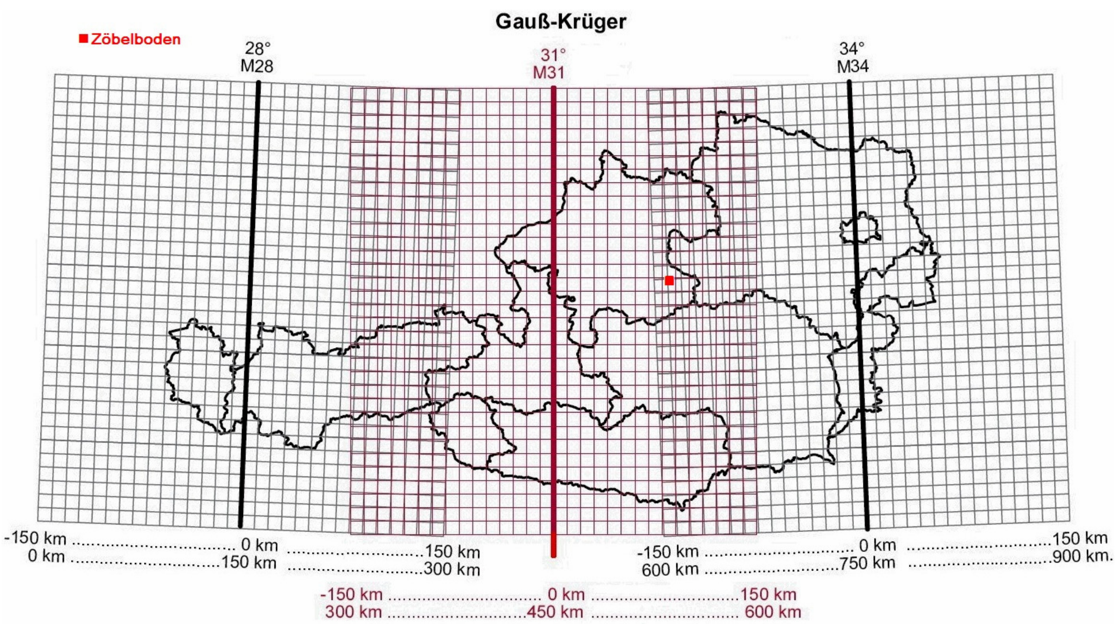

Figure 37: Gauss-Krüger Projection [www.statistik.at].

The maps of Zöbelboden originating from Umweltbundesamt are referenced with an Austrian specific map projection called "Gauss-Krüger 31" named GK_M31 which is exactly aligned with meridian 31. For Austria there are two more Gauss-Krüger projections available named GK_M28 and GK_M34, they are not relevant for the test case area.

This transformation from WGS84 to GK_M31 work was done using a standard ESRI ArcGIS function.

Statistical Analysis of Gathered Positioning Values

The purpose of the statistical analysis work was to discuss the received GPS quality in more detail. We wanted to derive estimates for good GPS accuracy and techniques to enhance GPS accuracy. We followed three strategies for investigation:

- counting the # of satellites as an indication of good GPS accuracy
- filtering of extreme positions (GPS positioning outliers)
- using averaging methods (for averaging GPS positioning values).

After integrating and combining all received GPS logs (see Figure 38 for aggregated view) as a first graphical analysis we afterwards combined the positioning values of the three PocketPC devices. We associated values from two reference devices separately (gerda and karin) to one reference device (martin) in order to gather statistical knowledge about these values and to analyze them.

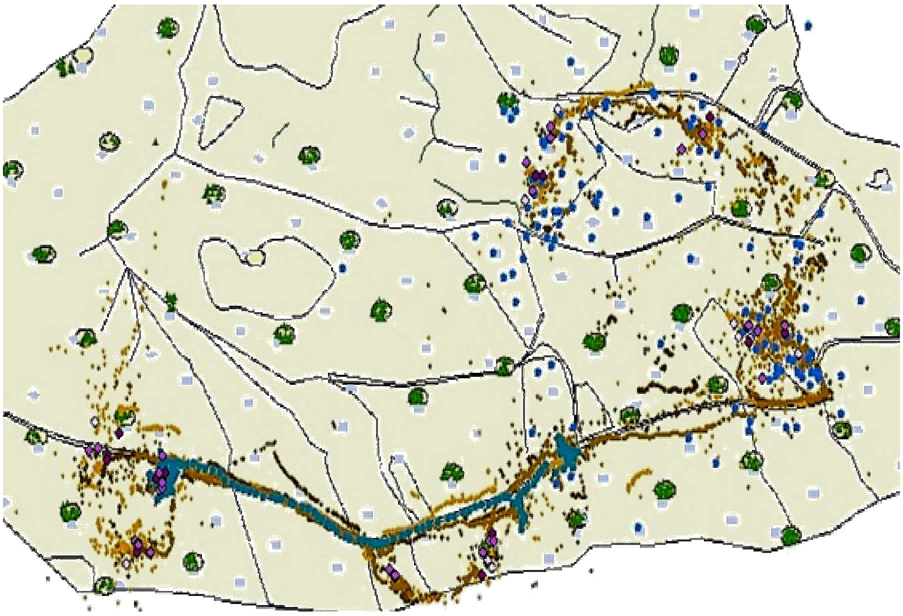

Figure 38: Aggregated 2D View from Device Logs.

After observation and analysis work, we were able to classify very high quality criteria, which implicate highly accurate GPS positioning values in this field test. If we cut all GPS values that hold less than eight GPS satellites at the actual positioning time, we get relatively low distinctions from the compared GPS datasets. This summarizes the number of GPS datasets (#DS) as a basis for calculation, the minimum distance (Min) in meters, the maximum distance (Max) in meters, and the average distance to the reference dataset (Avg) in meters. Furthermore we see the distances between comparing all GPS results and a shortened assortment of GPS values with eight and more satellites, which was indicated within our tests as a threshold of significant accuracy improvement.

	≥ 8 Satellites		**all**	
	gerda	karin	gerda	karin
# DS	9	16	686	701
Min	0,95	0,12	0,77	0,12
Max	33,70	32,40	351,91	401
Avg	13,47	13,41	27,55	23,53

Table 10: GPS Analysis - Nr of Satellites (martin to gerda/karin, values in m).

We instantly see in Table 10 that the average accuracy of datasets with more than eight satellites improved noticeably, the variances between maximum values are up to ten times better, and the variances of the average values are about a halve compared to all processed GPS values. For example, mobile device karin compared to the reference device (martin), we see that compared positioning decrease from 701 datasets with an average distance of 23,53 meters to 16 compared positions with an average discrepancy of 13,41 meters.

Now we modify the analysis and limit the compared values to a single reference GPS log and compared every point in succession to its predecessor to gain knowledge about continuously accuracy of received GPS values. We focused on distances between two positions in the same track log of device karin, which you can see in Table 11.

	≥ 8 Satellites		**all**	
	absolut	p. Sec.	absolut	p. Sec.
# DS	160	160	2214	2214
Min	0,25	0,001	-	-
Max	35,08	12,51	815,19	815,19
Avg	2,86	0,87	13,38	7,42
Med	1,12	0,82	1,87	1,18
StdDev	4,49	1,47	43,11	32,70

Table 11: GPS Analysis of Device karin's Values (in m).

In this case we took device karin’s values and compared them absolute (ignoring gaps in log files) and in an interval of one second (only a valid dataset per second is taken for calculation with its successor) over the logging time and calculated minimal, maximal, average distance, but also median and root mean square deviation and classified them again in all processed datasets and in datasets with eight and more satellites received.

After these interesting results we proceed (see Table 12) with a comparison of the distances of the GPS values of the devices karin and martin with exclusion of values through classification of distances (d). In detail, datasets are excluded with distances d ≥ 1, 2, 5, and 10 meters between both devices. Invalid values within all GPS logs are generally excluded from the analysis (because of several timeframes without receiving any GPS fix, neither a 3D, nor a 2D fix). Table 12 shows the results of the analysis for the datasets with distances (ranges) of < 10, 5, 2, and 1 meters.

	all	**Δ < 10**	**Δ < 5**	**Δ < 2**	**Δ < 1**
# DS	701	604	557	377	31
Min	0,12	0,12	0,22	0,22	5,31
Max	401,02	401,02	85,37	84,82	63,47
Avg	23,53	19,63	18,83	18,92	22,52
StdDev	30,09	20,93	13,73	14,07	16,98
Med	17,24	14,83	14,14	13,51	14,37

Table 12: GPS Analysis – karin’s and martin’s Values Extremum Filtered.

With focus on karin’s and gerda’s values we are able to see in Table 13 that values gathered from this classification steadily resulted in better deviation values between the devices when excluding data with distances d ≥ 1, 2, 5, and 10 meters and compared to all gathered GPS data.

	all	**Δ < 10**	**Δ < 5**	**Δ < 2**	**Δ < 1**
# DS	624	554	498	328	32
Min	0,25	0,25	0,25	0,25	1,53
Max	340,11	225,02	225,02	77,78	44,92
Avg	30,55	24,33	23,79	22,08	16,92
StdDev	38,34	20,19	20,23	17,76	13,04
Med	19,80	17,92	17,57	16,45	10,93

Table 13: GPS Analysis – Karin’s and Gerda’s Values Extremum Filtered.

We now compare the introduced classifications with focus on the different distances to define GPS dependences for GPS accuracy shown in Table 14. It is an analysis of distances between two subsequent positions for classification of actual GPS accuracy. First row shows the data with at least eight satellites, second and third row shows data with excluded extremes of more than five meters difference or more than 2 meters difference. Row four to seven are combinations with at least eight satellites and additional values. In detail it is an OR relation of values with exclusion of extreme values from more than five meters to more than one meter of difference.

	8 Sats	Δ < 5	Δ < 2	8 Sats | Δ < 5	8 Sats | Δ < 2	8 Sats | Δ < 1.5	8 Sats | Δ < 1
# DS	16	557	377	560	387	242	47
Min	0,12	0,22	0,22	0,12	0,12	0,12	0,12
Max	32,40	85,37	84,82	85,37	84,82	83,89	63,47
Avg	13,41	18,83	18,92	18,75	18,70	18,47	19,42
StdDev		13,73	14,07	13,74	14,02	14,67	15,44
Med.		14,14	13,51	14,00	13,40	12,68	13,79

Table 14: GPS Analysis – Criteria Comparison and Combination.

As summarized in Table 14, with a combination of GPS satellites received and additional data with limitation of distances we get a fair average between the number of calculated datasets and a minimum accuracy of calculated values. As specifically accentuated in Table 14, a combination of limiting dataset distances to d < 1m to 5m and satellites s ≥ 8 resulted in a relatively high accuracy of GPS values.

With this information we are able to define a base pseudo algorithm structure for a future automated POI estimation functionality.

Pseudo Code Implementation Example:

if: "Δ positions < 5m" OR "No. of Sats ≥ 8"

then: select actual positioning value

else: keep existing positioning value

The next analysis compares received GPS values with positioning values at specific points from Umweltbundesamt's permanent plots which have been measured precisely with GPS during the field test (accomplished by measuring the exact time at specific POI's with an own log file). The gathered positioning information from the recorded track logs of our three different devices were used to compare them to values given by the Umweltbundesamt. We configured the prototype interface using location-awareness and we logged the accessed permanent plots directly from the user's interaction (see also [Humm+06]).

In Figure 39 we see the accumulated occurrences of relative distances from our recorded GPS positions to the closest permanent plot (POI) investigated; 0 means the edited plot was the closest to the measured GPS position, 1 means the second closest permanent plot was edited and so on. In 72 out of 88 cases at the field test the edited permanent plot was equal to the closest permanent plot from the logged GPS location. Two times the second closest was edited, two times the third closest, four times the fourth closest, and even two times an extreme value occurred with the 11th closest permanent plot edited (referring to Hummel et al. [Humm+06]).

After analysis of the gathered information and the gained values we can now say, with some improvements, this prototype is robust providing sufficient positioning accuracy at the Zöbelboden monitoring area. This means exactly that nowadays used mobile devices and low cost GPS receivers can be adopted to support specific needs at rough working places and field situations.

We also have to keep in mind that additional antennas result in better signal strength or new, better GPS receivers and chip implementations can improve positioning accuracy. For example, SiRF Star II (used in this project) handles up to 12 channels and the newer chip SiRF XTrac III can handle up to 20 channels for receiving satellite signals while consuming less power. This does not mean we can receive 20 satellites at one time, but there are 20 possible channels for receiving positioning values which on the one side speeds up positioning time with more sensitiveness and on the other side it improves the received quality resulting in a higher accurate real-time positioning.

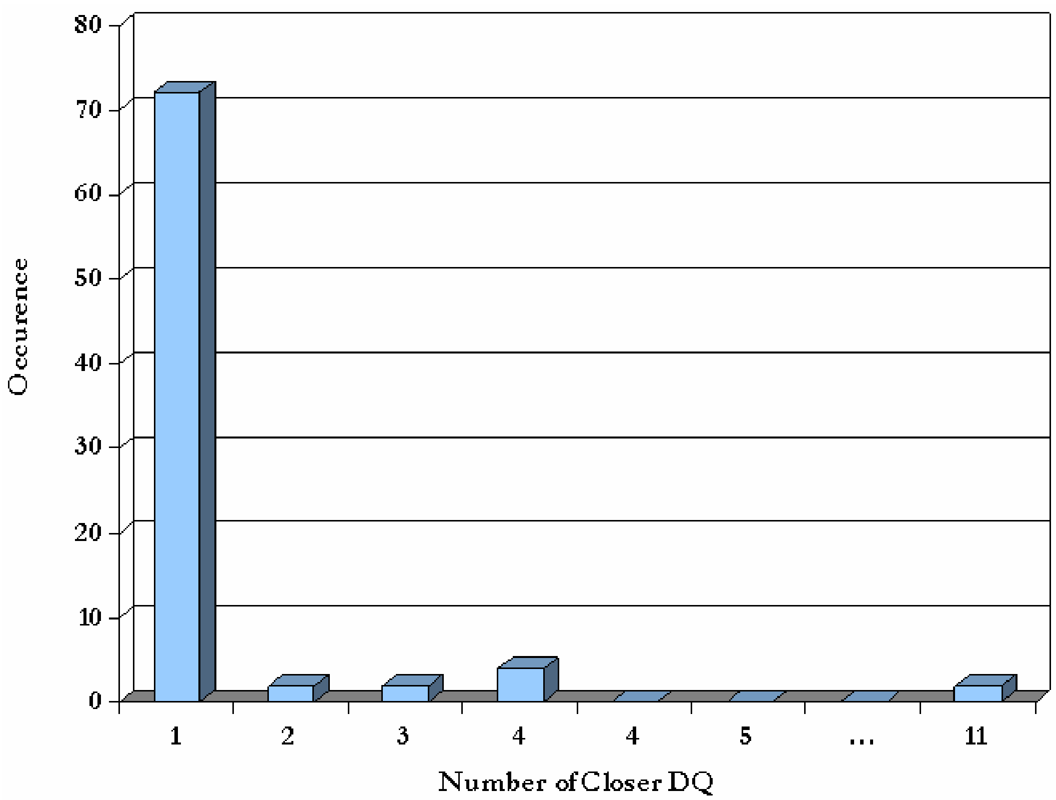

Figure 39: Distance of Investigated and Estimated Plots based on GPS values [Humm+06].

Evaluating Usability and Interface Design

The success of using location-aware and GIS capable mobile devices mainly relies on usability aspects, so usability is a key fact and constitutes a highly important issue of this prototype development. In addition to positioning accuracy we further experimented with usability aspects. For first insights, the usability test of ecological data collection in free field was performed within a separate experiment. This was done by usage of our prototype by an expert of Umweltbundesamt, working and fully measuring one permanent plot on Zöbelboden catchments. This field work was mainly defined by the monitoring process applied at Zöbelboden, for example when collecting tree disturbances and according data about affected objects in the observation area. Several interesting aspects about the prototype's usability and interface design were gathered at the field test in cooperation with

Umweltbundesamt's representatives. In some situations, the provided functionality of centering to the actual position causes some problems with extreme positioning values, which can occur if a strong forested area is passed. The automatic focus dropped the map's focus to a temporarily wrong estimated position. After analyzing this situations there are two possibilities to solve this issue. On the one hand cutting off extreme values (e.g., with a new introduced cluster algorithm for outlier detection) will prevent this and on the other hand it would be also an additional possibility to manually allow and disallow a changing focus of the map's projection of the mobile client. In context to automated navigation this can be improved by adding a dedicated exclusion of extreme values, so that map projection can only fluctuate in a pre-defined interval. Another important issue which was discovered at the field test is to enable multiple additional multimedia data (like different pictures from different views) at an object's position. Now it is possible to add one multimedia based file to a specific object or point of interest (POI) at the ESRI shapefile layer. Future development of this prototype should involve these two issues to provide a fully functioning and user friendly usable mobile client.

Umweltbundesamt's representatives acknowledged that the actual status of development represents a constructive approach for mobile workers. To summarize the outcomes we can say that the prototype states a very useful application for use in field situations for environmental monitoring. The prototype represents an easy to use, easy to understand, and easy to follow software. Multimedia based data and information can be easily integrated to the system and GPS positioning accuracy is most of the time sufficient for this kind of use case.

In context to further development other aspects of positioning concerning higher logics within the application can be realized through algorithm based positioning determination techniques, different statistical methods or intelligent exclusion or reasoning criteria which are even mentioned by Raffaetà et al. [Raff+02]. Further it is possible to enhance user's interaction during a data collection and monitoring process like interacting with a speech engine figured out by Doyle and Bertolotto [Doyl+06]. The system can be further improved by opening forms of monitored objects automatically if a specific previous defined distance to a desired object is detected or automated through a speech control engine which can be implemented in future as a speech based system ("human reception control" mentioned by Rauschert et al. [Raus+02]). In this way, mobile workers can be automatically guided through the target area, or they are able to use the mobile client's data collection functionality intuitively without the need of searching the displayed map for the monitored object for a manual selection.

8 CONCLUSION AND OUTLOOK

The requested objectives of this master thesis were: (i) geo-assisted gathering of ecological data in free field and (ii) providing reasonable usability to mobile workers. Our approach to solve the requested objectives was to define and implement a mobile GIS prototype and evaluate the approach in an individual field study. Within the prototyping process we used rapid prototyping and ESRI ArcPad for fast development with focus on gathering GIS, ecological, and multimedia data.

Additionally, we investigated outlier tests based on clustering of position for accuracy improvement. By using on our findings, we can say that positioning even with low cost GPS receivers can be significantly improved. The usability of the prototype was successfully evaluated in the field by an expert user from Umweltbundesamt.

In the field test in cooperation with Umweltbundesamt we measured the GPS accuracy and defined specific metrics, e.g., visible GPS satellites or use of distances between two subsequent positions, for classification of actual GPS accuracy.

Future developments of the prototype should include an intelligent positioning correction alghorithm based on our findings to select POIs precisely. As mentioned before this functionality is supposed to greatly improve the overall usage of mobile clients and especially user's interaction with automation of interaction. Further challenges are integration into a future UBA GRID infrastructure.

Although there are currently no important security aspects, we should consider security aspects as a next step for future work in this field in order to avoid possible threats that may occur when using the system at a regular basis. So security issues may be more interesting for future development and declare another important aspect for development which already was mentioned within the work of Claudia Eckert [Ecke05]. Further it is possible to easily automate user's interaction during a data collection and monitoring process. This will be possible by opening forms of monitored objects automatically if a specific previous defined distance to the object is registered. In this way, mobile workers will be easily able to use the mobile client's data collection functionality intuitively without the need of searching the displayed map for the monitored object for manual selection.

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10 APPENDIX

UN-ECE Integrated Monitoring Zöbelboden [www.umweltbundesamt.at]

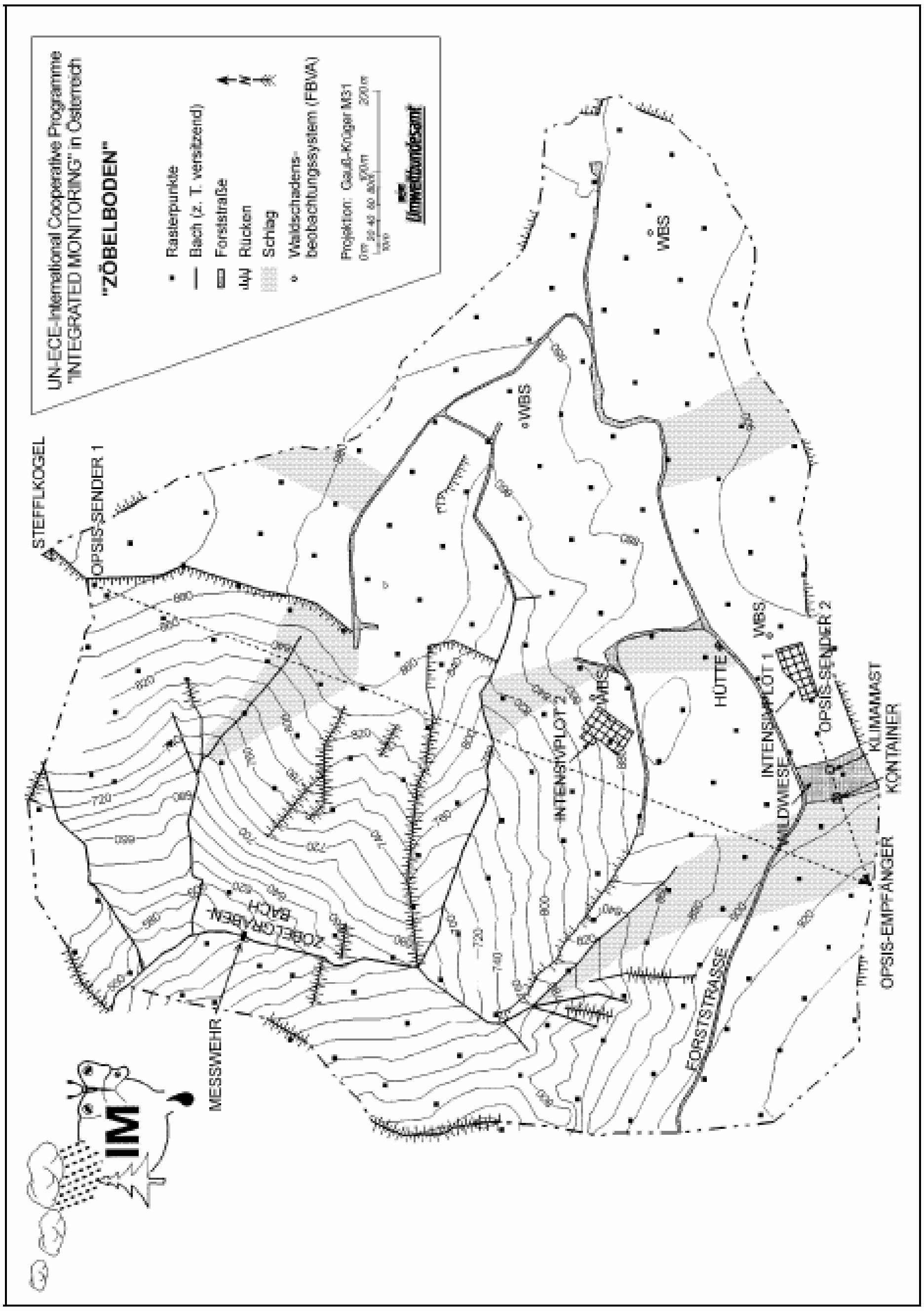


Figure 40: Detailed Map IM Area.

MORIS Specification (Chart Version) [www.umweltbundesamt.at]

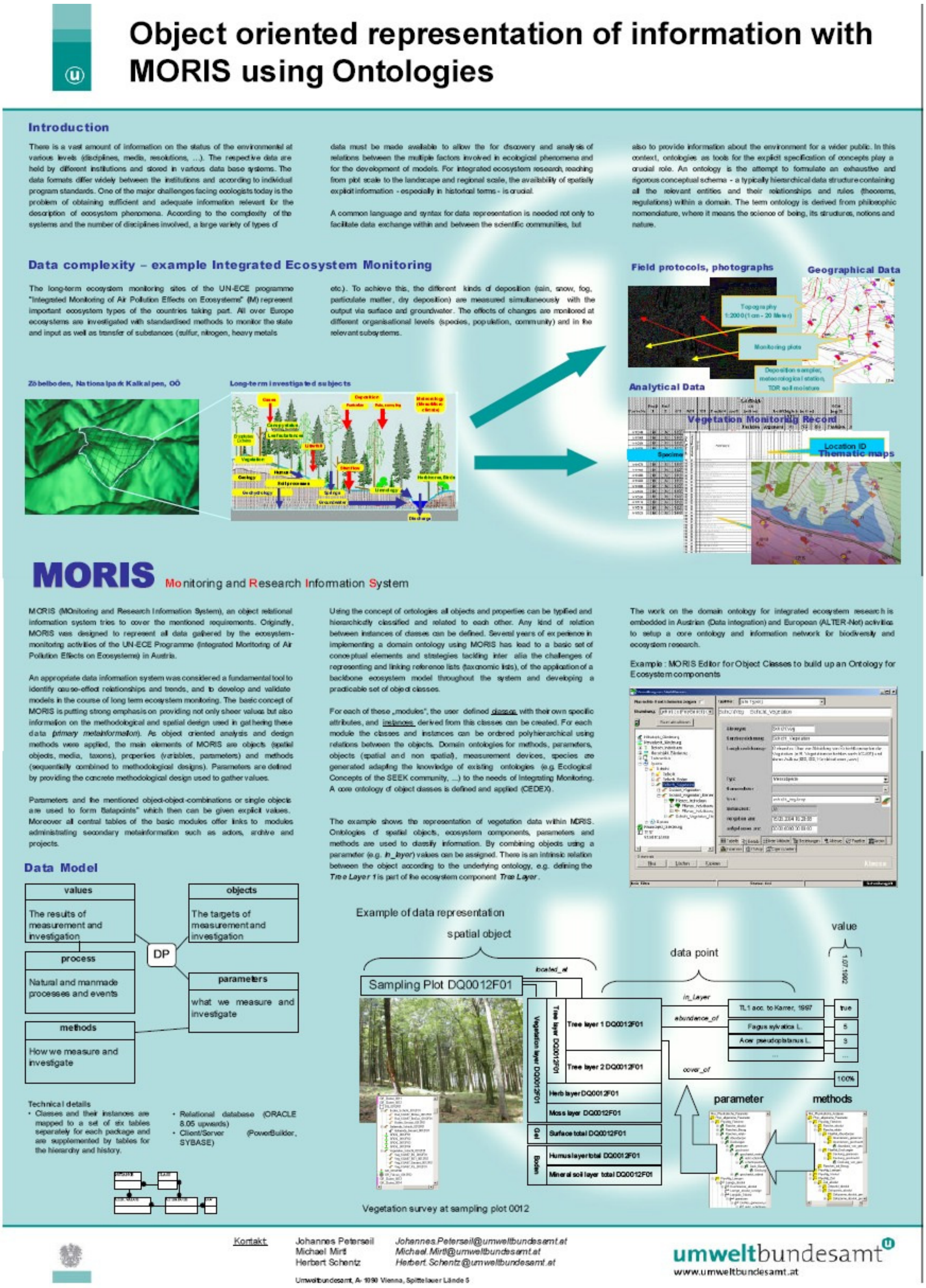


Figure 41: MORIS Chart.

ESRI Object Model [www.esri.com]

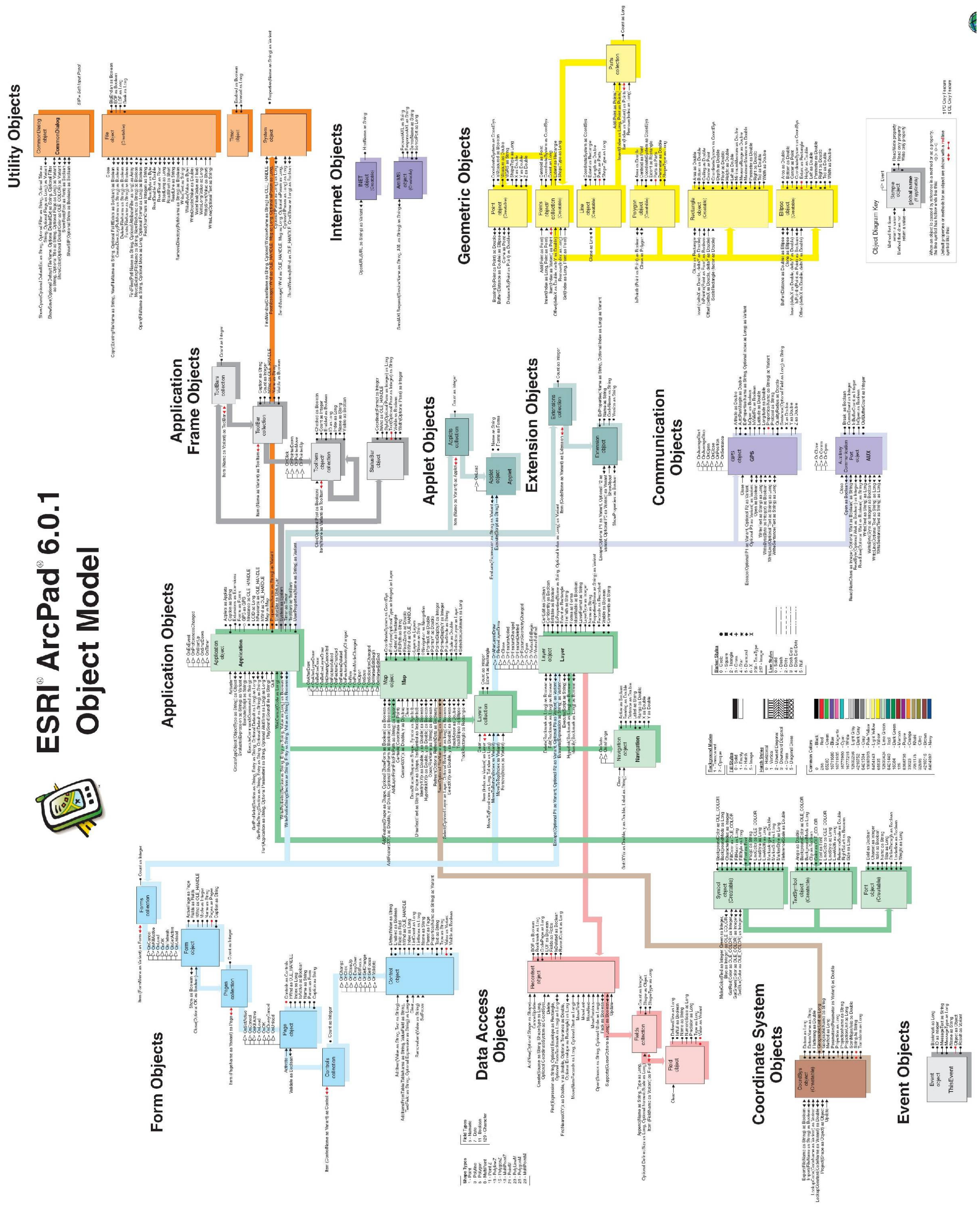


Figure 42: Object Model Framework.

ESRI Shapefile Specifications (Shortened Version) [www.esri.com]

SDE, ARC/INFO, PC ARC/INFO, Data Automation Kit (DAK™), and ArcCAD® software provide shape-to-coverage data translators, and ARC/INFO also provides a coverage-to-shape translator. For exchange with other data formats, the shapefile specifications are published in this paper. Other data streams, such as those from global positioning system (GPS) receivers, can also be stored as shapefiles or X,Y event tables.

Shapefile Technical Description

Computer programs can be created to read or write shapefiles using the technical specification in this section.

An ESRI shapefile consists of a main file, an index file, and a dBASE table. The main file is a direct access, variable-record-length file in which each record describes a shape with a list of its vertices. In the index file, each record contains the offset of the corresponding main file record from the beginning of the main file. The dBASE table contains feature attributes with one record per feature. The one-to-one relationship between geometry and attributes is based on record number. Attribute records in the dBASE file must be in the same order as records in the main file.

Naming Conventions

All file names adhere to the 8.3 naming convention. The main file, the index file, and the dBASE file have the same prefix. The prefix must start with an alphanumeric character (a–Z, 0–9), followed by zero or up to seven characters (a–Z, 0–9, _, -). The suffix for the main file is .shp. The suffix for the index file is .shx. The suffix for the dBASE table is .dbf. All letters in a file name are in lower case on operating systems with case sensitive file names.

Examples

- Main file: counties.shp
- Index file: counties.shx
- dBASE table: counties.dbf

Numeric Types

A shapefile stores integer and double-precision numbers. The remainder of this document will refer to the following types:

- Integer: Signed 32-bit integer (4 bytes)
- Double: Signed 64-bit IEEE double-precision floating point number (8 bytes)

Floating point numbers must be numeric values. Positive infinity, negative infinity, and Not-a-Number (NaN) values are not allowed in shapefiles. Nevertheless, shapefiles support the concept of "no data" values, but they are currently used only for measures. Any floating point number smaller than -10^{38} is considered by a shapefile reader to represent a "no data" value.

The first section below describes the general structure and organization of the shapefile. The second section describes the record contents for each type of shape supported in the shapefile.

Organization of the Main File

The main file (.shp) contains a fixed-length file header followed by variable-length records. Each variable-length record is made up of a fixed-length record header followed by variable-length record contents. **Figure 1** illustrates the main file organization.

Figure 43: Shapefile Specs (a).

Figure 1
Organization of the Main File

File Header	
Record Header	Record Contents
Record Header	Record Contents
Record Header	Record Contents
Record Header	Record Contents
. . .	
. . .	
Record Header	Record Contents

Byte Order

All the contents in a shapefile can be divided into two categories:

- Data related
  - Main file record contents
  - Main file header's data description fields (Shape Type, Bounding Box, etc.)
- File management related
  - File and record lengths
  - Record offsets, and so on

The integers and double-precision integers that make up the data description fields in the file header (identified below) and record contents in the main file are in little endian (PC or Intel®) byte order. The integers and double-precision floating point numbers that make up the rest of the file and file management are in big endian (Sun® or Motorola®) byte order.

The Main File Header

The main file header is 100 bytes long. **Table 1** shows the fields in the file header with their byte position, value, type, and byte order. In the table, position is with respect to the start of the file.

Figure 44: Shapefile Specs (b).

SiRFstarII GSC2x Technical Documentation [www.sirf.com]

SiRF

APPLICATIONS ➤Price-driven consumer ➤Automotive ➤General modules

SiRFstarII GSC2x Single Chip

Low Power and Lowest Cost SiRFstar Solution

PRODUCT OVERVIEW

A low-cost chip doesn't mean compromised performance. With its ROM-based software and one-third the power consumption of its predecessor, the GSC2x is poised to become the new standard for cost-sensitive consumer and automotive applications. Now you can build less expensive products using proven SiRFstarII™ technology and make Location Awareness a household word. Innovative architecture and packaging, combined with advanced process technologies, make it possible.

GENERAL SPECIFICATIONS

Supported Software

Standard

- GSW2.5 standalone GPS software in ROM

Premium

- SiRFDRive® 1.0 and 2.0 GPS/Dead Reckoning software for continuous accurate positioning
- SiRFXTrac® premium high-sensitivity GPS software
- SiRFInstantFix™ extended ephemeris service for very fast TTFFs

Package

- Type: 144-ball grid array (BGA) with a pitch of 0.65mm Pb free
- Dimensions: 7 mm x 10 mm; Height: 1.2 mm
- Expected total solution footprint: 250 mm2

KEY FEATURES

- Runs standard GPS software on internal ROM, or runs user applications and premium software on external Flash
- Digital and RF in a single package
- ARM7TDMI microprocessor throughput up to 40 MIPS
- 8 k cache for improved throughput
- On-chip 1 Mb SRAM for GPS navigation
- Two UARTs, high speed serial bus, battery backed SRAM, and 40+ GPIOs

Architecture Highlights

- Supports user task integration
- Signal acquisition using 1920 time/ frequency search channels
- SBAS (WAAS, MSAS, EGNOS) and DGPS support
- Cold start under 45 seconds

Low Power

- Under 100 mW at full power
- TricklePower™ mode reduces power to under 35 mW
- Push-to-Fix™ reduces power up to 98%
- Adaptive TricklePower intelligently switches between full and TricklePower

GSC2x BLOCK DIAGRAM

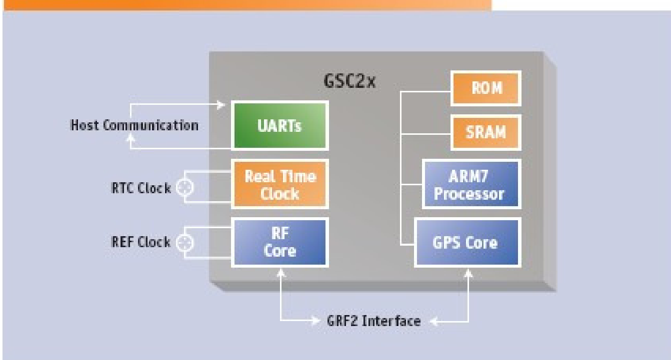


Figure 45: SiRF Tech Specs (a).

TECHNICAL SPECIFICATIONS

Horizontal Position Accuracy[1]		
Autonomous		<2.5 m
SBAS		<2.0 m
Velocity Accuracy[2]		
Speed		<0.2 m/s
Heading		<1°
Time To First Fix[3]		
SnapStart		<3 s
Hot start - Autonomous		<8 s
Warm start - Autonomous		<38 s
Cold start - Autonomous		<45 s
Cold start - SiRFInstantFix		<10 s
Sensitivity[4]		
Autonomous acquisition		-134 dBm
Tracking		-142 dBm
Tracking with SiRFXTrac		-148 dBm
Receiver		
Tracking	L1, CA Code	
Channels	12	
Max update rate	1 Hz	
Max altitude/velocity	<60,000 ft/<1,000 knots	
Protocol support	SiRF Binary, NMEA	
System Integration		
I/O Interface	UART	
External reference clock	13, 16.369, 16.8, 19.2, 24.55, 26, 33.6, 38.4 MHz	
RTC input	32.768 kHz	
Power[5]		
Continuous Autonomous operation		60 mW
TricklePower		35 mW
Size		
Package dimensions		7 x 10 x 1.2 mm
Design footprint		250 mm²

1. 50% 24 hr static, -130 dBm 2. 50% @ 30 m/s 3. 50% -130 dBm Fu 0.5 ppm Tu ±2 s Pu 30 Km 4. -142 dBm = 28 dB-Hz with 4 dB noise figure 5. Average, TricklePower 200:1.

HIGHLIGHTED ADVANTAGES

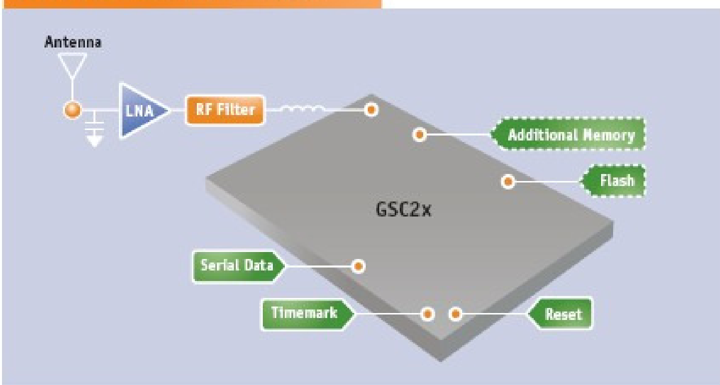
The GSC2x whittles the need for three chips to one or two by integrating the RF and baseband into one package and removing the need for external flash—a measure that also simplifies implementation for manufacturers.

Power is also dramatically reduced: full power operation is reduced from 180 mW on the SiRFstarIIe/LP to 60 mW on the GSC2x, and TricklePower is reduced from 80 mW to 35 mW. GSC2x internal software is highly flexible, allowing the use of a variety of configurations from blinking LEDs, varying baud rates, and protocols.

The GSC2x uses the SiRF® standard GSW2 GPS software for cost sensitive customers, with the option of using SiRFXTrac GPS software, a premium product for customers who want high-sensitivity GPS and also using SiRFInstantFix, an extended ephemeris service for very fast TTFFs. The GSC2x uses external Flash to take advantage of the in-built ARM CPU for applications such as a GPS handheld or to run the SiRFDRive dead reckoning technology for enhanced positioning accuracy and availability.

The GSC2x utilizes 0.13 micron CMOS process for baseband section and SiGe technology for the RF section.

GSC2x SYSTEM CONFIGURATION



ORDERING INFORMATION

Part Number	Description
GSC2x-7479	Single chip

For more information about this and related products, contact your SiRF representative, or call our sales force at (1) (408) 467-0410, or visit www.sirf.com.

For the location of your nearest authorized SiRF distributor, visit www.sirf.com.

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Sales@sirf.com

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(44) (1344) 668390
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Germany
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SalesGermany@sirf.com

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Taiwan
(886) (2) 8174-8966
SalesTaiwan@sirf.com

Japan
(81) (44) 829-2186
SalesJapan@sirf.com

India
(91) (80) 41465599
SalesIndia@sirf.com

August 2006, Rev. 1, Part Number 1065-1069

Figure 46: SiRF Tech Specs (b).

Gauss-Krüger Projection for Austria [www.statistik.at]

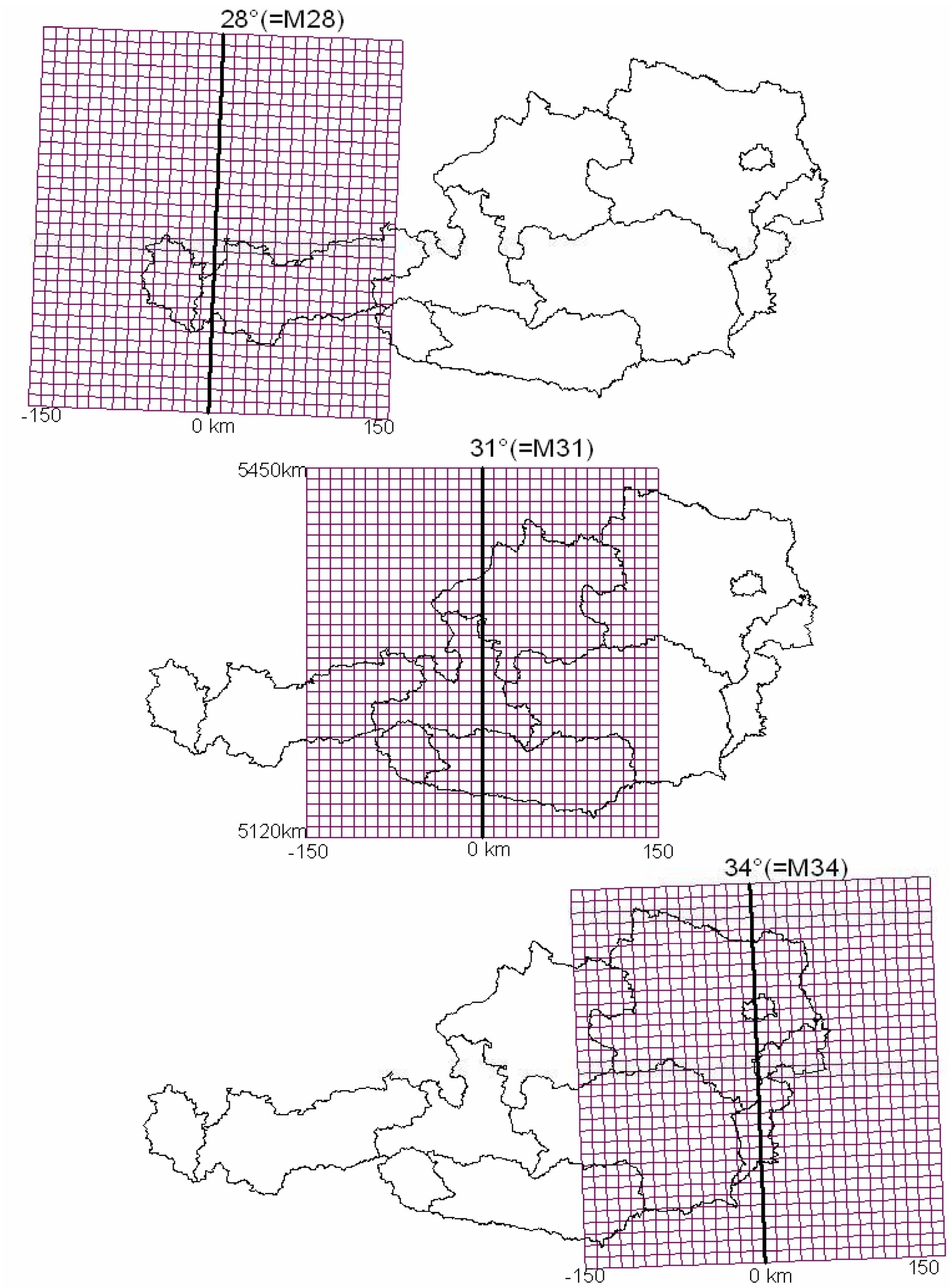

Figure 47: GK M28 / M31 / M34.