



A mobile GIS application for crop mapping development and evaluation



Date: GIPSY rapport 2004-9, version 2.0
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In cooperation with Synoptics Remote Sensing & GIS Applications bv
Project: 3e projectenronde ICT-Onderwijsteams (ICT 2002/3): "Wireless learning voor geo-informatie".
SURFtender 2001 ICT en Onderwijs, "GIPSY".

Preface

This case study was carried out with financial support of the SURF foundation in the Netherlands as part of the GIPSY project. The initial version of the application developed for this case study was tested and evaluated by a group of international students enrolled in the Geo-Information Science Master course 'Integratie cursus Omgevingswetenschappen' of Wageningen University. The development of the application itself and the supervision on the student work was carried out by the Spatial Information Laboratory (SPINlab) of the Vrije Universiteit Amsterdam in cooperation with Synoptics Remote Sensing & GIS Applications bv in Wageningen. A short evaluation on the student work and their final report can be found in chapter 4 of the Gipsy report titled 'Locatie Gebaseerd Leren en Computer Ondersteund Veldwerk'. The further development and testing of the application after the student work was carried out by the SPINlab and Synoptics bv on the basis of a combined initiative and effort. This report describes from a technological point of view the development, operation and evaluation of the crop mapping application. The authors wish to thank Synoptics Remote Sensing & GIS Applications bv in Wageningen for their active involvement, the providing of the source material to make this case possible and their cooperation in the testing of application and procedures. We wish also to thank Sytze de Bruin, course coordinator, and the partner teams at the Wageningen University and University of Nijmegen for making the first stage of the case study with the student participation possible. The cooperation with the National Aerospace Laboratory (NLR) for the online version of CropSpy is acknowledged. This text of this report will appear in 2004 in an adapted and summarized version in one of the chapters of the ESRI book about ArcPad titled: Mobile GIS the Arcpad way (in progress).

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Introduction

In this Gipsy case study Arcpad was used to develop an application on a handheld PC that assists fieldworkers in the mapping of crops in the Netherlands. The fieldwork is an important element in the whole process from the selection and classification of remote sensing images to the generation of the yearly updated digital crop map of the Netherlands¹ covering the year 2000 onwards. The digital crop map indicates what crop(s) were grown on a particular parcel of land and contains information on the shape and size of the distinguished fields within the parcels. Examples of crops mapped are grass, corn, potatoes, sugar beets, wheat, barley, flax, onions, vegetables, flower bulbs, etc. Local and national government bodies, water authorities, and agri-businesses use the crop map to monitor and control the interaction between water and agriculture for spatial planning and policy purposes. It is for example used for the allocation of possible flooding areas (to control or prevent peak floods), for the research on pesticides and pollution (e.g. estimation of nitrate, phosphate load), crop valuation and yield forecasts, disease and crop protection management, land administration, planning field works (mowing, dredging), manure leaching, etc.

The map is compiled by using state-of-the-art optical and radar satellite images dating from different phases of the growing season in combination with specifically targeted fieldwork and agricultural knowledge. Part of the fieldwork is required for the actual classification of the maps and a part is used to validate the result. As it is sometimes not possible to obtain high quality optical satellite data, due to atmospheric circumstances (especially cloud cover), it can be necessary to complement the satellite derived data with extensive field campaigns. This means that specialized fieldworkers with skills in both mapping and crop determination have to visit the concerned areas and record the crop data manually. The field boundaries within parcels between the different crops are usually determined with the help of the satellite images. If this is not possible the boundaries have to be determined on the ground as well. The map is delivered as a vector file (ArcView shapefile), and is fully compatible with the standard 1:10,000 topographical vector map of The Netherlands. The digital crop map is released every fourth quarter of the year.

Until now this fieldwork has been done by field teams who have relied on paper maps and input forms (see figure 1 a and 1b). Unless the advanced digital techniques used for processing satellite and vector data, the gathering of data has been so far a principally analogue process. As the areas to be covered can be very large (yearly ca. 10.000 parcels are visited by the field teams, 1 % of the total amount) this work can consume considerable time and is prone to errors. This is especially true because after the fieldwork all written information has to be introduced into the GIS database in order to make the data available in a digital format, risking all kinds of transcription errors. Also, depending on the skills, the background knowledge of the fieldworker and the phenological state of the crop, the determination of some crops can be difficult. In addition it is not always easy to determine the exact position in the field if there are few specific reference features around. Therefore it was decided to run a pilot fieldwork with the use of handheld computers, mobile communication and wireless data-exchange for feedback from the office, GPS and other digital equipment like digital cameras. It was expected that the use of automated input forms with time and GPS location stamping integrated with the GIS application on the handheld in combination with the mobile communication and wireless data exchange possibilities could increase the efficiency and solve most of the problems mentioned above.

¹ The 'PiriReis actual digital crop map' ('gewassenkaart') is produced by Synoptics Remote Sensing & GIS Applications bv in Wageningen, The Netherlands

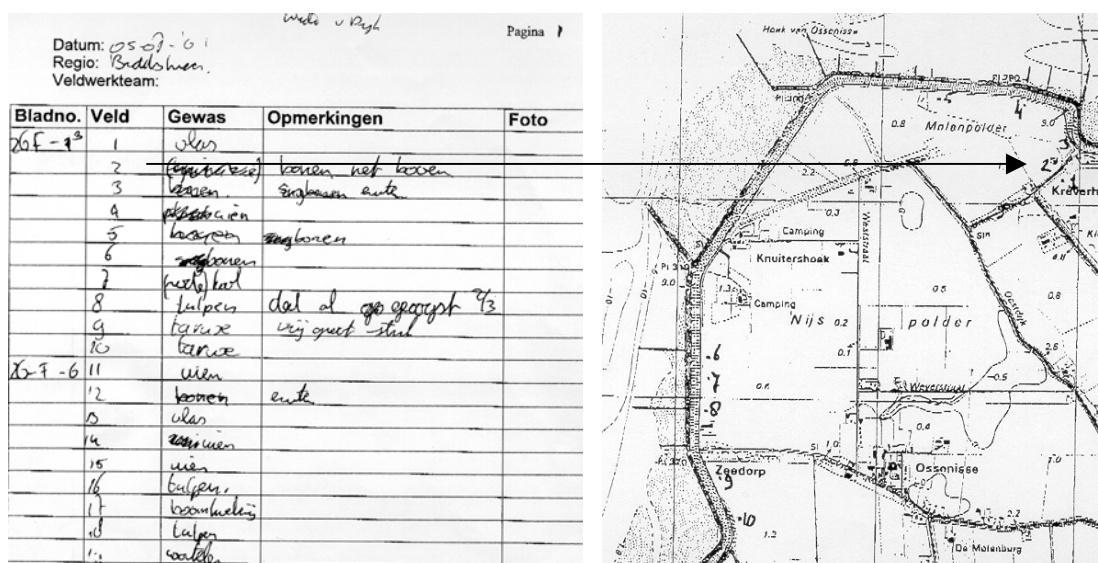


Figure 1, examples of paper field form and paper field map used for cropmapping in the Netherlands

Overview of the solution involving Arcpad

The solution involving Arcpad consists of three main components:

1. a mapping component
2. an information component
3. a storage and exchange component

Ad 1 The mapping component involves all the GIS data installed on the handheld and the customized standard mapping functionality of Arcpad for collecting point information. As the shape of the crop fields can be determined in most cases with the help of the satellite images, the mapping requirements of the application are very simple: the user has to be able to put a point on the map falling amply within the borders of a crop field. To this crop point attribute information can be linked via an entry form, like the crop type, comments, date and time, code of picture taken, etc. To put a point on the map the 'add point' button needs to be activated first. The entry form that pops up if a point is placed on the map is made with the ArcPad application builder (Arcpad Studio). In case the boundaries of one of the fields do not correspond with the boundaries according to the satellite image the user has the possibility to sketch the correct boundary observed in the field on the digital map using standard redline functionality of Arcpad (see figure 2). Another requirement of the application is that the positions of the points placed on the map can be changed easily if necessary. All these requirements have been fulfilled using the standard functionality and customization possibilities of Arcpad and the Arcpad Application builder. Particular for the mapping component is that for each crop mapped also the x,y position of the observer is automatically written to the attribute table of the mapped point. Storing this position makes it possible to compare in a later phase if the position of the observer corresponds with the x,y position of the mapped crop.

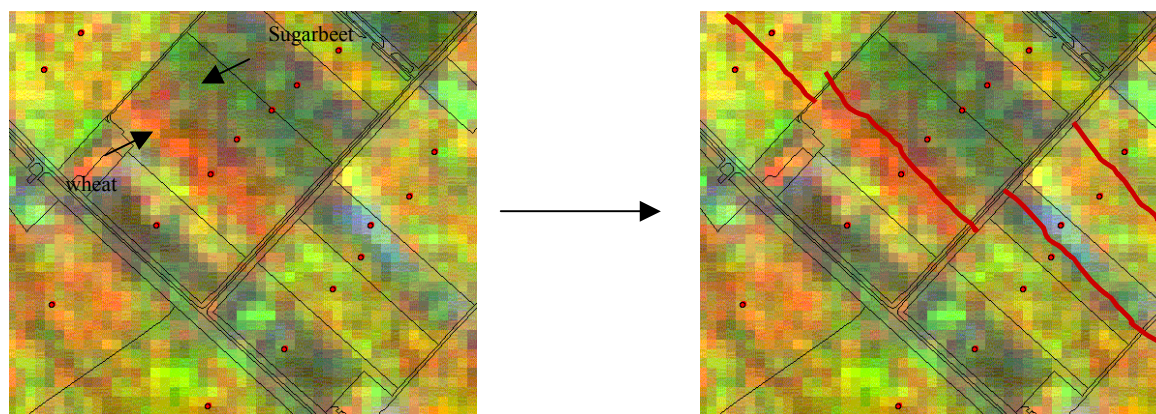


Fig. 2 : Example of use of red line tool

Ad 2 As soon as the user has tapped the screen to place a crop point on the map a 'quick' list pops up with 7 of the most prevalent crops in the fieldwork area from which he/she can choose one. If the observed crop is not among these 7 the user can choose 'other', which brings up the total crop list classified in different crop families. As some of the fieldworkers might be less skilled or experienced than others they can press the 'view' button which brings up a html based classified list with pictures and descriptions of different crops. In this way the user can access crop information anytime from within the Arcpad environment (see figure 3a-3c)).

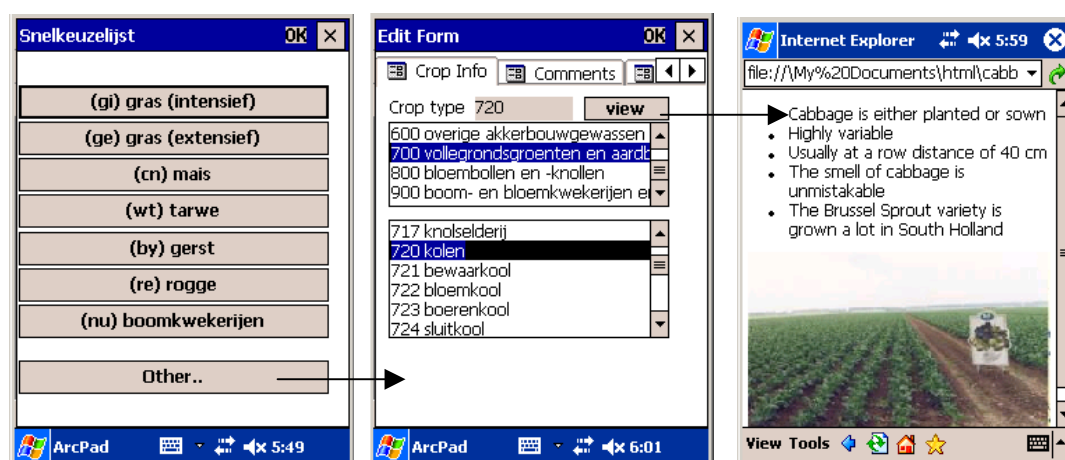


Fig. 3a, 3b, 3c, quick-list, picklist and view information tool

After choosing the right crop the fieldworker can either press OK to add the point to the map or proceed to the next page of the form where comments can be made or a reference to a picture taken can be recorded (in case the user works with an integrated or a Bluetooth camera the user can browse from the form directly to the file location of the picture to reference it). An overview of the recorded information is given below.

Automatically recorded:

- Map coordinates of crop point (x,y)
- GPS coordinates of fieldworker (x,y,z)
- GPS data quality parameters (number of visible satellites, hdop)
- Date and time of point recording
- Project year, mapsheet, fieldworker (if a session was started)
- Wireless upload of point information (sent or not sent)

Entry by fieldworker:

- Name of crop to be classified- "croptype" code
- Comment about the crop to be classified (facultative)
- Code and file location of picture taken with digital camera (facultative)

Ad 3 A critical component of any digital data collection method is a reliable data storage. To prevent data loss by lack of battery power or technical malfunction the application saves the collected data therefore on the removable memory card instead of saving it in the internal memory of the handheld which has proven to be risky. As an extra safety measure the user has the option to let the application send each time a point is collected the coordinates and attribute information directly via the wireless telephone network to a database on a dedicated webserver. The database on this web server on its turn serves as an input for a real-time ArcIMS webmapping service² displaying the background maps and images with the collected points on top. Even though this characteristic is not critical for the success of this application it gives the possibility to exchange data remotely between different field teams and the office. This makes monitoring and controlling of the whole field collection process possible, which might lead to different more efficient working processes and workflows in the near future. Other wireless communication and exchange possibilities are the use of ftp, e-mail and oral communication via the mobile telephone network. In case of doubt the fieldworker can for example send a digital picture of a certain crop via ftp or e-mail to the office and ask by phone or e-mail for advice.



Fig. 4a, 4b Use of the application on the bicycle (combination of XDA and Garmin 12 with cable)

Software and hardware environment

On the fieldworker end of the application, the cropmapper was equipped with a PDA, a GPRS-enabled telephone to double as modem, and a GPS unit. During the student field trials and the first and second professional test, an O2 XDA was used. During the third professional test, a more powerful iPaq h5550 was used instead. In all scenarios the client software was ArcPad 6.0.1. In addition, the browser function of the CE operating system was used for information display purposes.

On the office side, a server under Windows 2000 Advanced Server runs ESRI ArcIMS 4 behind an MS IIS web front. Incoming http postdata is received by an ASP script on the webserver and stored into an MS Access database table. This table is subsequently processed by the dbase2shape³ utility that updates a shapefile with the data from the table. A shell script ('batchfile' under dos) invoking the command line java tools for ArcIMS then refreshes the webmapping service, forcing it to use the newly updated version of the shapefile. There are two implied dependencies here: a Java Runtime Environment must be present for the ArcIMS command line

² As the data on the webserver is collected in a simple access database this data can also be input for other types of web mapping services. An alternative web service was on our request developed by the National Aerospace Laboratory NLR of the Netherlands, see <http://www.neonet.nl/gipsy>. If an organisation doesn't want to publish the data via the web it is also possible to display the data directly in a desktop GIS via a transformation to a common GIS format and adding the maplayer that is stored on the webserver via a mapped network drive.

tools to be installed, and a Python environment is required to execute dbase2shape.

Because both the translation from table into shapefile and the reloading of the shapefile by ArcIMS can both be run on either a looping timer or a trigger condition, this construction is an effective shoestring solution with some flexibility and room for additional intermediate stages between steps. The interval between data upload and the map being updated in our settings was at most 20 seconds, but would normally be shorter.

GIS environment

The GIS environment into which Arcpad is integrated consists basically of a ArcGis database with satellite data superimposed with topographic information (see figure 4). The topographical map of the Netherlands scale is a vector map, scale 1:10.000 ('Top10 vektor') of the topographical survey in Emmen from which the parcels, the roads and houses are the most important features for the work procedure. This vector map is used for reference and orientation purposes and for the definition of parcel boundaries. The satellite data consists of a series of satellite images of different growing seasons in one and the same year combined in multitemporal images which provide an independent source of information for the type and position of crops in the Netherlands. Satellite images used are Landsat TM images and Envisat radar images.

For use in Arcpad a selection of the most important infrastructure (roads, canals, houses, etc.) is made from the topographical map and saved in ArcView shape format. All maps and images are georeferenced to the Dutch national coordinate system the 'Rijksdriehoekstelsel'. A simple legend with few colours is constructed for use in Arcpad. Scale dependency is set to prevent slow response times when zooming out or panning to a small scale. In ArcPad the satellite image and/or the derived polygon map with the crop fields is used as a backdrop image to secure the correct placement of the collected observations (see figure 4). To limit the size of the data set the satellite images which are in Erdas Imagine format are compressed ca. 5 to 10 times to 'MrSid' format. The top layer of the dataset is the 'croplayer' a point shape file which is already in edit mode so points can be added to this layer.

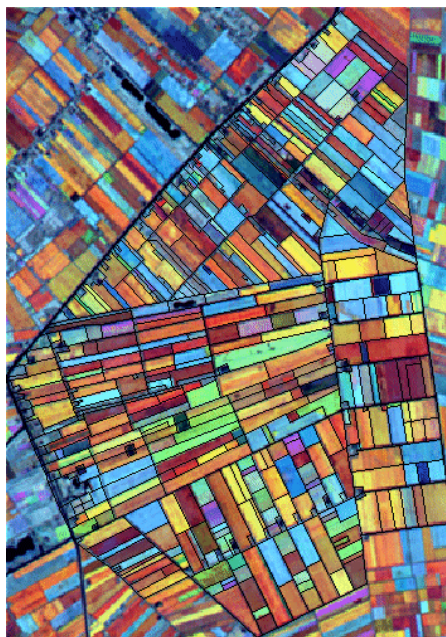


Fig. 5. Multi temporal image of an agricultural area in the East of the Netherlands (Landsat TM 29 May, 19 June, 10 July) overlaid with vector information (Top10 vektor)

³ Joel Lawhead, Nvision Solutions Inc.

The final crop map is delivered as a vector file (ArcView SHP), and is fully compatible with the standard 1:10.000 topographical vector map of The Netherlands (see figure 5). The map is released every fourth quarter of the year.

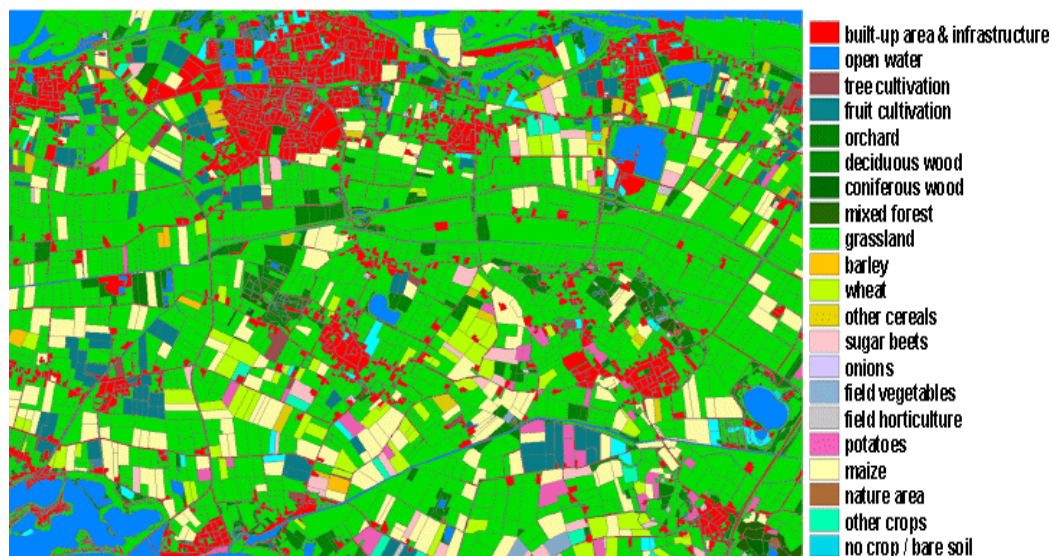
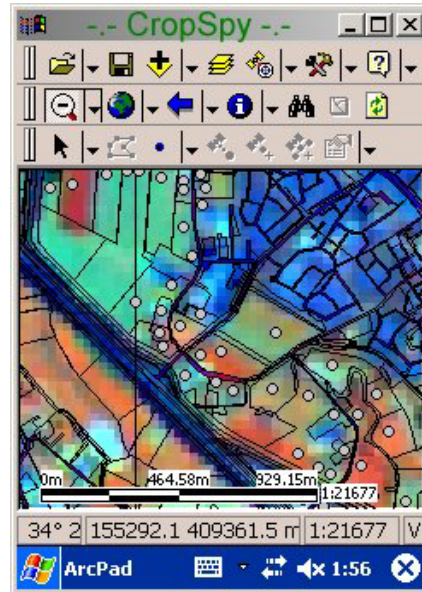


Figure 6a, 6b. Cropmap © Synoptics bv of "Land van Maas en Waal", Province of Gelderland. Topographic vector map ©Topografische Dienst Emmen.

Workflow of the solution from the user's perspective

During the spring and summer season the map producer selects suitable satellite images for the process leading to the yearly crop map of the Netherlands. During the course of this process it becomes clear for which areas additional fieldwork has to be carried out. After a fieldwork area is selected maps and images are prepared for integration in the Arcpad application (see above). The data set in the main memory of the handheld is kept as small as possible to keep working speeds high. Additional reference material, maps, check lists and so on are loaded to a separate storage card. Arrived in the field the field team starts a session by starting Arcpad, GPS, Bluetooth connections, telephone and loading the prepared Arcpad project and activating the appropriate icon from the menu bar and fills in the name of the fieldworker and some project data. After activating GPS in Arcpad and zooming in to the work area the fieldworker is ready to start adding crop points to the map. As the fieldworker has arrived in front of a crop field to be mapped, he/she needs first to identify the crop, using the crop information list on the handheld if necessary. If this doesn't bring a solution the fieldworker can take a digital picture of the crop for determination afterwards or send it via ftp or e-mail to the office to get assistance. When mapping the selected field the fieldworker stands



preferably on the road in front of the middle section of the field to take care that the GPS position of the fieldworker will be on a more or less perpendicular line from the road to the point placed ca. 5 to 15 meters from the road (see figures 6a and b). This is to make sure that points are securely placed inside the fields in a consequent way.

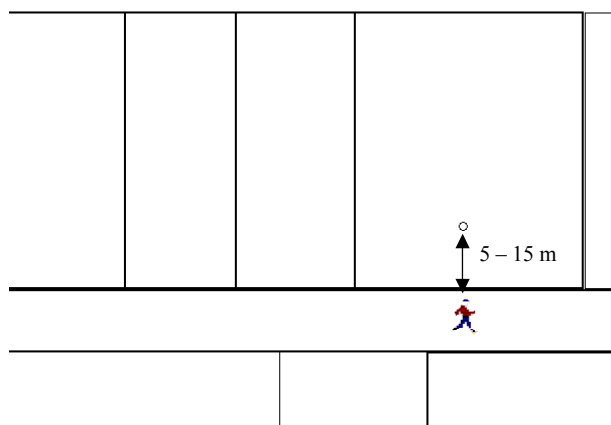
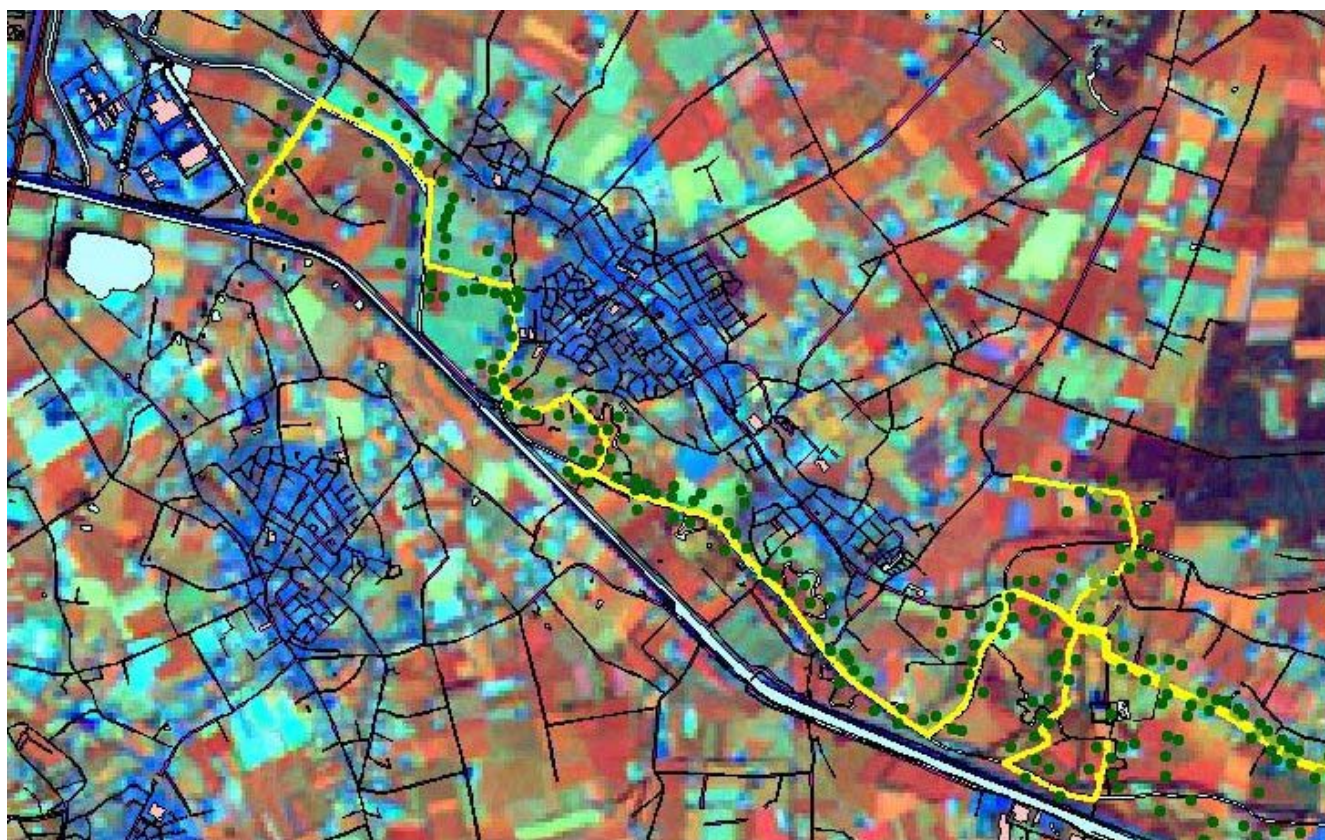


Fig. 7a and 7b : Choosing the crop point location



By placing a point on the map the entry form is brought up and a crop needs to be selected from the quicklist or by pressing 'other' from the complete croplist (see figure x above). If the fieldworker wants he/she can finish the operation and proceed to the next field by clicking on OK, otherwise he/she can fill in more form pages like the comments page to write down for example a comment about the phenological state of the crop and write down the code of the picture taken (this can be done semi-automatically by pressing the window box and browsing to the picture location if the picture is taken by an integrated/plug-in camera or has been transferred to the device with a wireless connection). All other data like time, date, project code, x,y coordinates, etc. are automatically stored in the attribute table of the collected point (see figure 7b). After pressing OK the point is added to the map and stored on the removable storage card (smart disk card) and is sent directly via the GPRS connection to the web server if this connection is active. In that case the user gets a confirmation message back from the webserver if the point data has been received correctly, otherwise the user will be notified that the transfer did not succeed. In that case the application will attempt to send the point data together with the next point added to the map. If the transfer has succeeded it is possible for the office and the fieldworker to browse to the webmapping service of the application on the web or to overlay the updated map with the collected crop points on top of the dataset by adding the Internet mapservice in Arcpad and select the appropriate layer. For the fieldworker this might be useful if he/she wants to see where another field team has been collecting data. If a crop point has been placed on a wrong location the user can simply drag it to a new location by selecting it and activating vertex edit (the user has to press a location outside the point area on the map until a menu pops up with the option 'feature moving', by activating this option the point can be dragged to a new location). The whole process of identifying crops and mapping them is repeated till the fieldwork is finished after which data and pictures from the handheld pc and camera will be downloaded and transferred to the central database where the data of different field teams will be integrated in a consistent way and linked to the polygon map with crop boundaries which was prepared earlier on the basis of the satellite images in a point in polygon operation. After this the whole map will be checked for errors and boundaries will be changed if the field teams observed and noted differences with the boundaries on the satellite images. The

resulting maps will be used in the further procedure including classification and validation of satellite images leading to the final product the digital crop map of the Netherlands.



PROJNUM	MAPSHEET	CROPTYPE	COMMENT	GPSX	GPSY	GPSZ	GPSSATS	GPSHDOP	GPSQUAL	TIME	DATE	PICTURE	AGENT	CROPNAME	SENT
Test 3	45DN	608		159944.409	407147.448	66,6	6.0	1.3	1	15:58:32	11/20/2003		Karin	gras (intensief)	TRUE
Test 3	45DN	160		159732.116	407223.265	63	0.0	0.9	1	16:02:08	11/20/2003		Karin	mais	TRUE
Test 3	45DN	609	beeldentuin	159273.995	407500.987	81,1	8.0	1.8	1	16:04:24	11/20/2003		Karin	gras (extensief)	TRUE
Test 3	45DN	943		155516.479	409308.723	53	4.0	2.4	1	16:07:37	11/20/2003		Karin	vruchtbomen	TRUE
Test 3	45DN	983	wild stukkie	159510.342	406689.603	61	4.0	7.3	1	16:15:12	11/20/2003		Karin	natuurontwikkeling	TRUE
Test 3	45DN	421		158641.892	408746.338	54	7.0	1.1	1	16:19:28	11/20/2003		Karin	suikerbieten	TRUE
Test 3	45DN	982		158644.427	408749.492	41	7.0	1.2	1	16:23:15	11/20/2003		Karin	naaldbos	TRUE

Figure 8a and 8b, collected points (green) and tracklog (yellow) and result table of field work in Brabant Heeswijk

Customization of ArcPad

Necessary customizations to ArcPad were trivial, as the purpose of the case study was simple point data collection. The most important addition was that of a specialized point editing form, developed using the earlier experiences gained from the first field tests and specifications provided by professional fieldworkers. This was all with the aim of streamlining the data entry process for optimal speed, as points per time unit were the critical success factor. To minimize the amount of work a fieldworker had to perform at each individual point, entry fields of which the values would remain constant across large areas or over longer periods of time was moved into a session form, which was essentially an interface for assigning values to a set of user-defined variables that were automatically copied as needed into the record for each registered point upon creation and/or modification.

Easy access to the session variables and data upload functions did necessitate an extra toolbar to put the relevant buttons within one-click reach. As the addition of more toolbars goes at the expense of the visible map area however, the net added value of having functions available without going through menus needs to be evaluated in future field tests before this practice can be made a recommendation.

There were a few extra features not related to the user interface worth mentioning here:

Rather than having Arcpad modifying only one shapefile containing all our data, a provision was made so that a point-for-point backup could be simultaneously kept on a separate storage medium. This is important when the primary copy of the file is in RAM memory that stands at risk of being erased in case of sudden power failure or system crash.

Integration with GPS

The application relies on a good registration of geographical coordinates to locate the position of the user and subsequently the location of the fields to be mapped. The requirements for accuracy however are not that high as the main concern is that a point can be placed somewhere in a field with a minimum size of ca. 20 x 20 meter. As the mapping takes place outside the urban areas or forest areas there is usually a good reception of the satellite signals and accuracies between 5 and 15 meter are easily reached. Arcpad is used in combination with a Garmin 12 connected with a cable, or with a GPS jacket or plugin or wireless (Bluetooth) GPS depending on the type of handheld used. The 'FindGPS' extension for ArcPad downloaded from the ESRI Support Center is used to find automatically the right port and the baud and parity settings for the connected GPS. As mentioned before the application writes each time the user places a point on the map automatically the position of the user to the attribute table of the collected crop point, so two positions are recorded each time: the position of the crop point and that of the user. The GPS tracking functionality was used to record the data collection pattern so data collection strategies can be analyzed and possibly improved later on (see figure 7a).

Problems and solutions

No problems have been encountered during the fieldwork in the use of Arcpad or with the developed application. Main problems encountered were unstable Bluetooth connections and connection problems to the telephone/GPRS network. Another point of concern is the increased consumption of battery power when the handheld uses an active Bluetooth connection for Bluetooth GPS or phone or when the integrated phone of the handheld is active and data is transferred via the GPRS network. Especially the last configuration drained the

battery of the handheld quickly (in 1 ½ - 2 hours with the XDA). The only handheld device which had a very stable Bluetooth connection was the iPaq 5550, which however has problems accessing the Internet from Arcpad. It is possible to overcome the battery problem by using devices with a swappable battery or by using peripheral Bluetooth devices –next to the handheld pc- which use their own energy source, or of course by having a mobile recharging possibility, via the car, solar cells or a dynamo.

Business and educational benefits achieved

The development of this application was the result of a SURF project⁴, the 'Gipsy' project, a project concerning innovative education and has served two main objectives. In the first place the application was developed for use in one of the case studies of a master course in remote sensing and GIS integration and secondly to promote knowledge exchange with a specific commercial company in this field. The application has been tested several times during its development phase. The first serious test took place in June 2003 in the province of Flevoland with a group of 6 students who had some GIS experience but no particular experience with mobile and wireless applications neither with crop mapping. Apart from the minimum data quality requirements the most important criterium for the success of the application from the point of view of the map producer was the number of crop points collected per time unit depending on the means of transport (by foot, bicycle, moped or car). Even though the results were very satisfactory regarding the ease of use and the data quality, the number of collected crop points turned out to be disappointing. This was related to both the lack of experience in crop recognition of the students and probably to the fact that the fieldwork formed part of a practical subject in the students Masters program. Their main concern was therefore not to collect as many points as possible but to evaluate and improve the application. It was therefore decided to develop the application further on the basis of the experiences in this fieldwork and to repeat the fieldwork with one of the professional fieldworkers of the map producer. This second test was carried out by bicycle in autumn 2003 in the South of the Netherlands near the city of Den Bosch. As expected the results of this second test were very positive as the number of points collected was as high or slightly higher than with the conventional method. Apart from the higher reliability and verifiability of the data the biggest improvement was however the speed and ease of post processing the data which saved more than half of the total costs (see table 1). A third test was carried out with some further improvements early November to test the application in a wireless field architecture. After overcoming some technical problems related to a too weak radio signal of the integrated phone in the handheld the data collection in the Province of Brabant could be real-time followed and discussed over the phone from the office in Wageningen. In this case the coordinates of the collected points and attribute data were directly uploaded to a table on the SPINlab webserver which could be accessed via the WorldWideWeb in Wageningen. In a later phase the whole field architecture was completed by adding the ArcIms webmapping service which automatically displayed the newly added crop points to the display. This last element of the architecture has been successfully tested in a 'cropmapping' fieldwork outside on the university campus while the data collection could be real time followed inside the building via the developed webmapping service. In table 1 a comparison is made of the time and cost involved of conventional fieldwork and computer assisted fieldwork carried out by either scholars or professional fieldworkers. The results show clearly that total field work costs can be decreased considerably especially because of the decrease of post processing costs. At the same time it is assumed that the quality of the collected data will be higher through the use of GPS, standardized input and the low risk for transcription errors.

Even though several tests were carried out the results in table 1 are only indicative as the tests have not been carried out with scholars but with students with different objectives. Further the test with the professionals is only carried out by bicycle therefore the number of fields mapped per day on the bicycle had to be extrapolated for a fieldwork with a car. Finally the table does not include costs for equipment, software, development, maintenance and training of handheld devices and applications.

Table 1

4 SURF is the higher education and research partnership organisation in the Netherlands for network services and information and communications technology (ICT).

Time and costs for an average field work of 5000 fields	Analogue classic (car)		Digital scholars (moped)		Digital professionals (car)	
	Time units	Cost (100 %)	Time units	Cost (100 %)	Time units	Cost (100 %)
Preparation time	0.5	3 %	4	12 %	4	9 %
Management time	1	7 %	1.5	13 %	0.5	27 %
Field work	20	40 %	40	75 %	15	64 %
Post processing time	50	50 %	0	0 %	0	0 %
Percentage of classic fieldwork		100 %		90 %		45 %

Note: The estimations of involved time and cost in this table are partly based on real figures and partly on assumptions (this is especially true for the scholars). Costs for equipment, software, development, maintenance and training of handheld devices and applications are **not** included. More fieldwork should be carried out to make a reliable comparison.