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Report on task JNTB898 on the Finnish support programme to IAEA safeguards

T. Ilander, A. Kansanaho, H. Toivonen

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Nuclear Safety

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ABSTRACT

Environmental sampling is the key method of the IAEA in searching signatures of a covert nuclear programme. However, it is not always easy to know the exact location of the sampling site. The satellite navigation system, utilizing a small receiver (GPS) and a PC, allows to have independent positioning data easily. The present task on the Finnish Support Programme was launched to create software to merge information about sampling and positioning. The system is built above a desktop mapping software package. However, the result of the development goes beyond the initial goal: the software can be used to real-time positioning in a mobile unit utilizing maps that can be purchased or produced by the user. In addition, the system can be easily enlarged to visualize data in real time from mobile environmental monitors, such as a Geiger counter, a pressurized ionisation chamber or a gamma-ray spectrometer.

PREFACE

Satellite navigation has been used for in-field applications by the Finnish Centre for Radiation and Nuclear Safety since 1993. Because of this experience, training in the use of GPS positioning and desktop mapping was chosen as a task under the Finnish Support programme to IAEA safeguards. A lecture and a field experiment were held on a training course on environmental monitoring at the IAEA headquarters in June 1995. The contents of the task were published by Kansanaho et. al "GPS positioning and desktop mapping" STUK-YTO-TR 88, Helsinki 1995. From this document the general information about desktop mapping and GPS positioning is transferred to the present publication. The description of the software is updated and new elements, such as production of maps, are added.

CONTENTS

1 INTRODUCTION

Satellite navigation is a simple method to determine current position anywhere in the world. When the satellite navigator data are displayed using a computerised mapping system, anyone can easily spot the location exactly.

A suitable map of the area of interest is the key of successful navigation. During the last couple of years, the production of digital maps has increased and now it is possible to purchase these maps for many applications. An advanced user of a mapping software can also handle the production of digital maps, starting from high-quality printed maps.

A satellite navigation system, known as SAHTI, produced by STUK for real-time navigation and environmental measurements. It includes a GPS-receiver and a laptop computer, equipped with tailored software above a commercial mapping package. The software is produced using Visual Basic 3.0 Professional and MapBasic 3.0.

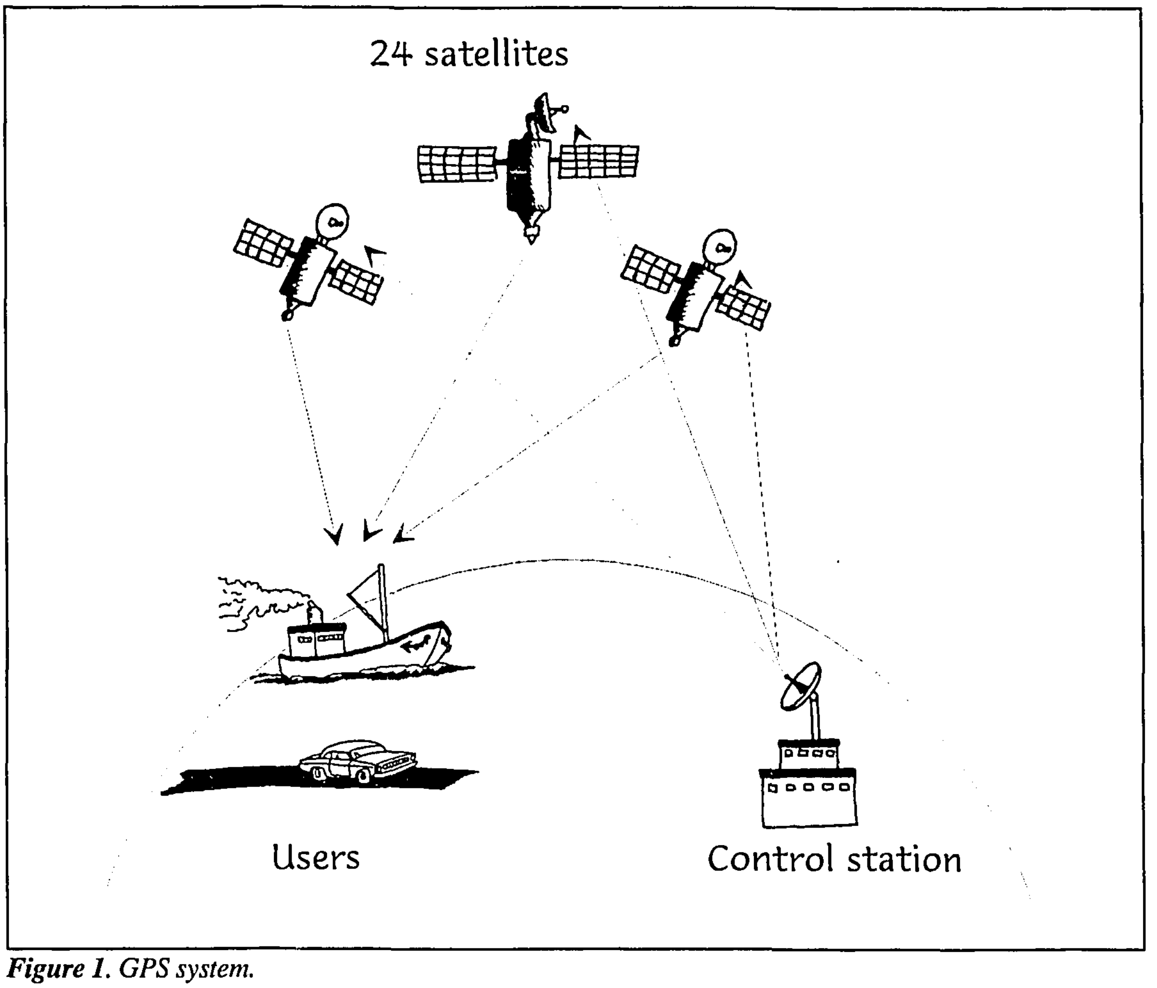


Figure 1. GPS system.

2 GPS-SATELLITE NAVIGATION

The Global Positioning System (GPS) is a satellite navigation system designed, built and controlled by the US Department of Defence. The GPS system is based on 24 satellites which circle the earth at an altitude of 20,000 km. These satellites are controlled by the Ground Control Segment of the system. It's main tasks are to calculate new parameters of the satellite orbits and to correct the satellite clocks. The exact time is essential for the whole system, since the positioning is based on measurement of time delays in signals from satellites down to earth. A successful navigation requires that the receiver can "see" at least 3 satellites. However, a position, which is calculated from signals of 4 or more satellites gives higher accuracy.

To utilize the GPS system, the user needs a GPS receiver, which picks up the satellite signals and calculates current position. The accuracy of 100 metres (95 % probability) is available for all users (C/A code, civil code), whereas the US military can reach an accuracy of 10 metres (P code, military code). Accuracy of C/A code is usually enough for navigation and environmental monitoring. For special purposes higher accuracy can be achieved locally by utilizing differential correction techniques. In some countries, e.g. in Finland and Sweden, a radio-transmitted differential correction signal is available, and thus an accuracy of 2 m is possible even in real-time applications.

GPS receivers are of different sizes, from a PCMCIA card up to briefcase-size models. The smaller instruments are less precise, but still useable for navigation and for visualisation of environmental monitoring data. GPS receivers return the current position in longitude-latitude co-ordinates based on WGS-84 datum (World Geodetic System). In most GPS-receivers position data can be passed into a computer using a serial interface. SAHTI system supports two receivers, Trimble SV-6 and Trimble Mobile GPS (PCMCIA).

The Trimble Mobile GPS is using a protocol known as TSIP (Trimble Standard Interface Protocol) in communications. The data are sent in binary packets. Thus it is not readable without knowing the data structure exactly. The byte order for a floating point number in Visual Basic is reversed. Therefore the values of co-ordinates and time (expressed as single precision floating point numbers) are calculated using IEEE 745 standard for floating point arithmetic's.

The receiver SV-6 uses a protocol know as TAIP (Trimble ASCII interface protocol) in communications. The data are sent from the receiver as ASCII characters. As default the receiver sends position data every 5 seconds.

3 DESKTOP MAPPING

3.1 MapInfo for Windows

Desktop mapping software is a powerful tool for presenting data of geographical significance. Data points are displayed on a digital map with exact location. In addition to normal data analysis, Desktop Mapping offers geographical analysis (measuring distances, areas etc.). It is possible for the user to spot and display the location on earth correctly from the position data of the satellite navigator. This, however, requires that a high quality digital map is used as a base map.

A desktop mapping software, known as MapInfo for Windows, was selected for the SAHTI system. MapInfo is not capable of navigation by itself. However, MapInfo is fully programmable through the MapBasic-language. This enables the user to produce customised applications utilizing all MapInfo's functions.

3.2 Base maps and co-ordinate systems

MapInfo for Windows can handle both major types of digital maps, vector maps and Raster images. Vector maps consist of individual objects, like lines, regions etc. Vector maps are stored on disk in special MapInfo format. Raster Images are standard picture files (TIFF, BMP, GIF etc.). Both types of maps are commercially available. The best way to find them is to ask the local National Survey Board for advice. The commercial suppliers for digital maps can also help to find MapInfo compatible maps.

Once a plane map is created, a mathematical model, known as projection (Transferse Mercator, Lambert etc.), is used to transform the locations of features on the earth's surface to locations on a two-dimensional map surface. A co-ordinate system is created by specifying the parameters for the projection used. One of the parameters is known as datum (WGS-84, ED-50, ED-79). It defines which ellipsoid is used as well as the location of the origin. An ellipsoid estimates the shape of the globe. When a digital map is being selected for a base map, the co-ordinate system of the original map has to be found.

Co-ordinates returned from GPS will not show the correct position on the map if the co-ordinate system of the map is not based on WGS-84 (the difference may be hundreds of metres). There are mathematical conversion formulas defined to transform co-ordinates from one system into another (accuracy of a few mm). However, these formulas include usually very complicated mathematical functions. Since the accuracy of GPS is only 100 m, a more simple method for co-ordinate correction should be used. SAHTI system can only perform mathematical corrections between Finnish co-ordinate systems. Therefore, in global use the correction must be performed in another way (see later).

3.2.1 Vector map as a base map

Vector maps are usually produced from printed paper maps using a special digitizing table. MapInfo handles vector maps as database tables where one column in a data record refers to a geographical object (poly line, region, symbol etc.), that corresponds to a real feature on the earth's surface. A data record can therefore contain information about the object (inhabitants of the town, number of houses etc.). Vector maps are especially useful when large areas are viewed.

They can also be re-sized on the screen without any limits. However, inaccuracies and "shortcuts" in digitizing become disturbing when the map is zoomed down to the finest details.

A wide range of vector maps is commercially available. The accuracy of these maps depends on the material they have been produced from and on the person who has performed the digitizing. The price of these maps depends on the accuracy of the map. MapInfo allows the user to change the co-ordinate system of a vector map. Disk space and memory of the PC determine the level of details on a map, since every detail is a single drawn object. MapInfo can show several vector map layers simultaneously and also include or exclude layers when a map screen is re-sized.

The user can also define his own co-ordinate systems for MapInfo. This, however, requires a good knowledge of MapInfo and co-ordinate systems. If vector maps are used for GPS-navigation, suppliers should be asked to provide their maps with WGS-84 system. See Figure 2a) for an example of a vector map.

3.2.2 Raster image as a base map

Raster images are mainly scanned images of printed maps. They are ideal base maps if the area of interest is fairly small in diameter (< 10 km). All the details in a printed map are included in the Raster image. If a colour scanner is used, true colours of the printed map can be applied, too. Raster images are used only as backdrops onto which transparent vector layers are superimposed.

Because the Raster image consists of small dots, re-sizing is limited both ways by the resolution of the image. The co-ordinate system, in which the original material is created, cannot be changed either. If a Raster image is based on a system other than WGS-84, a co-ordinate correction may have to be performed to display the co-ordinates from GPS at the right position in the map window. A simple correction is presented in section 5.3.

A SPOT satellite image and an aerial photograph are other Raster images, which are potentially useful for safeguards purposes. SPOT satellite images are supplied with the requested co-ordinate system and they are already in digital form. Aerial photographs do not have any built-in co-ordinate system. Using these as base maps requires either GPS-measurements on the spot or some reference map where the co-ordinates of the corresponding objects are found. Figure 2 b) is an example of a Raster image.

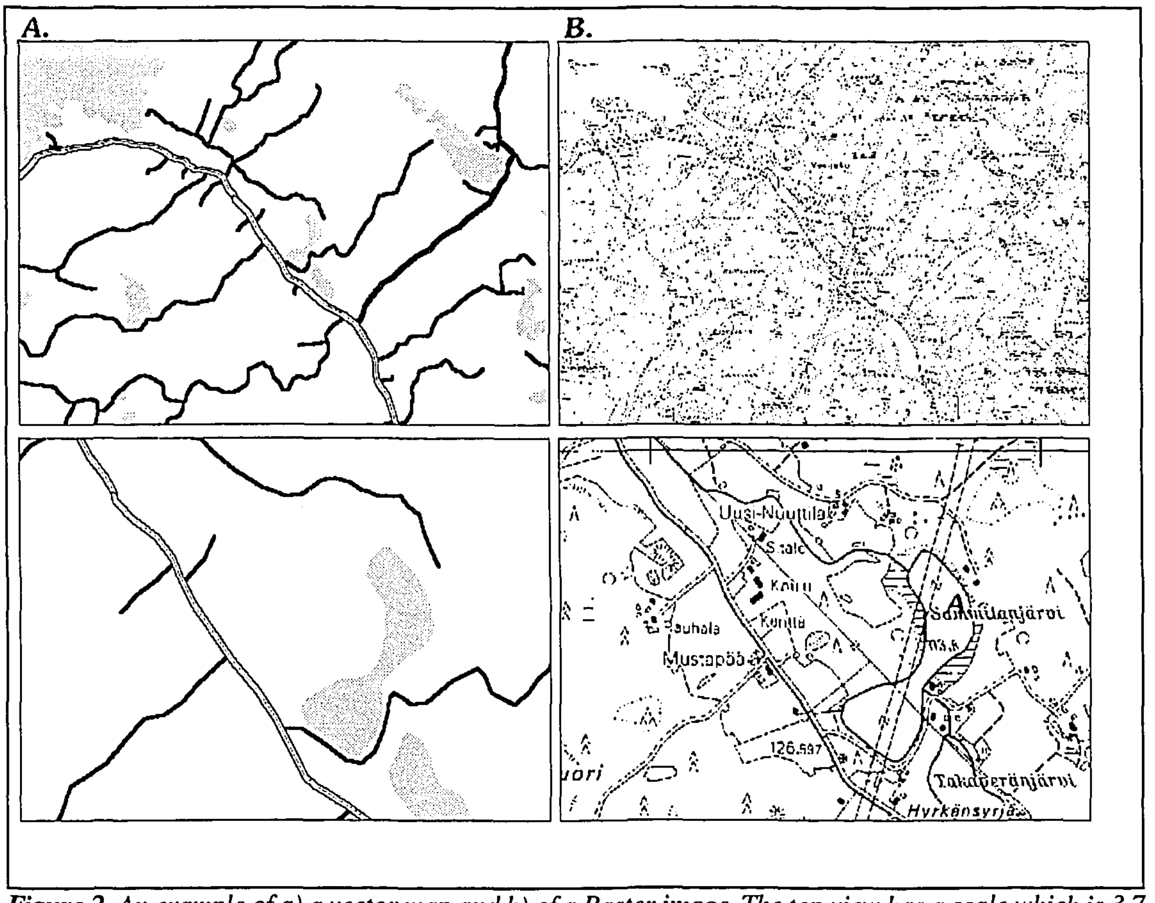


Figure 2. *An example of a) a vector map and b) of a Raster image. The top view has a scale which is 3.7 times larger than the bottom one.*

4 PRODUCTION OF MAPS FOR MAPINFO

MapInfo uses two types of base maps, vector maps and Raster images. Vector maps are usually produced from printed paper maps using a special digitising table. Raster images are usually scanned images of printed maps. Both types of maps are commercially available. But if they are not available of the area of interest, the user must produce own maps from the paper copies that are available.

4.1 Using scanned images as base maps

If no digital map is available of the area of interest, MapInfo allows the user to produce own material. Using a scanner is the easiest way is to create a Raster image of a paper map. MapInfo supports several formats for a Raster image; TIFF, GIF, JPEG and PCX. One of these should be available in any scanner software. Fixing the Raster image into exact position is performed by selecting at least three control points and giving their exact position for MapInfo. The procedure depends on the original material. Three most common cases are studied below; detailed examples are found in the appendices.

4.1.1 A map with co-ordinate system supported by MapInfo

In this case the paper map contains all information needed. The parameters that make the co-ordinate system vary depending on the projection used. Once the co-ordinate system of a map is found, the user should refer to MapInfo Reference manual to find out which parameters must be given for the projection in question.

At least three points must be picked for MapInfo as control points in Raster image registration. The co-ordinates of these control points in the co-ordinate system used are needed. If the co-ordinate system is not WGS-84, some correction must be performed for exact positioning. See Chapter 5.3 for determining the correction. An example of fixing a map of Finland in the Finnish co-ordinate system is given in Appendix 3.

4.1.2 A map where the scale and origin longitude are known, but other co-ordinate system parameters are unknown

Most of the plane paper maps are created in Transfer Mercator projection (also known as Gauss-Gruger). Any Transfer Mercator projected map can be fixed correctly, if the origin longitude and map scale are known.

The origin longitude is a parameter, which gives the central meridian for the map projection. The Central meridian (for example 27.00000oE) is running parallel with map's Y-axis. Usually the information of the central meridian is printed, but if not, the map has to be studied carefully or the supplier must be contacted.

MapInfo must be set to use the same central meridian in Transfer Mercator projection as found in the original map. The user may have to define a new co-ordinate system. The control points are measured carefully so that they stand on a map forming a rectangular with sides running parallel to the map axis. The distances from one carefully chosen control point, the main point, are measured with a ruler and converted into metres using the scale factor of the map. The location of the main point is eventually located exactly using GPS. The co-ordinates in metres are then calculated for other control points and the map can be exactly positioned. A detailed example of fixing a Raster map of Tallinn area is given in Appendix 3.

4.1.3 A map where the scale and coordinate system are unknown

Sometimes the only map of the area is a tourist map or a large scale atlas map. Fixing of these maps exactly is impossible. MapInfo enables, however, the user to point the locations of selected control points in a map window. At first, some spots in the environment, which correspond to certain objects on a printed map, must be selected and positioned using SAHTI. Suitable spots are bridges, road junctions, field corners etc.. SAHTI creates a new map layer with a symbol corresponding to one of the chosen spots in the nature. The number of the spots should be from 10 to 15 and they should be spread out over the whole map area. When all the spots are recorded and added on the map layer, fixing of the Raster image is performed by pointing each control point in the Raster image with corresponding symbol on the measured map layer. An example is given in Appendix 3.

4.2 Production of own vector maps

If only Raster maps of the area of interest are available, MapInfo allows the users to produce vector maps of their own. The maps are digitized with MapInfo drawing tools (Poly line, symbols etc.). Digitizing is usually performed from a Raster base map with drawing tools. For digitizing roads, the *Poly line* drawing tool is selected. The roads then are followed on the screen by the mouse. The corners are marked by clicking the mouse. A building can be placed on the map by using the *Symbol* tool. After all the objects wanted are placed on the map, the layer is saved as a map. An example is given in Appendix 4.

5 SAHTI SATELLITE NAVIGATION SYSTEM

SAHTI system is built by the aerosol laboratory of the Finnish Centre for Radiation and Nuclear Safety (STUK). Radiation measurement results and GPS co-ordinates have been combined in the laboratory since 1993. These applications were based on retrospective desktop mapping. Following the same ideas, a real-time navigation system, SAHTI, was developed for in-field measurements. The same approach is now applied to safeguards purposes under the Finnish support programme to IAEA. The system consists of a GPS-receiver (Trimble, Mobile GPS or SV-6) and a laptop computer. The software is produced using Visual Basic and MapBasic programming languages.

5.1 Overview of SAHTI software

The main body of the system, the SAHTI control panel, performs co-ordinate acquisition, stores time and co-ordinates into a file and passes the information to the mapping application. This program is known as SAHTI.exe. A MapBasic program, known as SAHTI.mbx, runs within MapInfo and displays the position on a selected base map. Some display settings can also be performed in SAHTI.mbx program. A third part of the system is known as IMPORT.exe, which handles the viewing of previous measurements. Figure 3 shows the layout of the whole system.

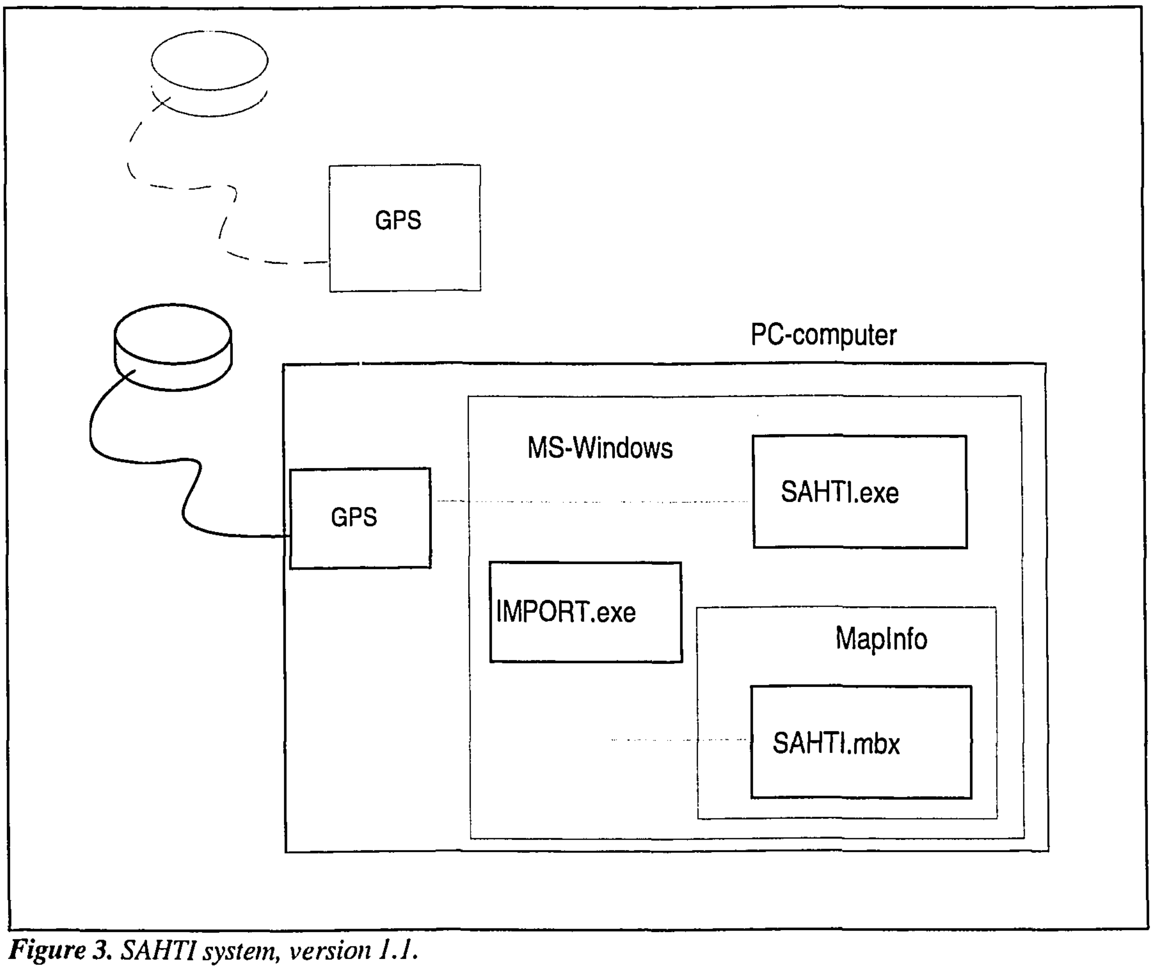


***Figure 3.** SAHTI system, version 1.1.*

5.1.1 SAHTI control panel

The program is produced with Visual Basic. It communicates with a GPS-receiver through a serial interface. Position, time and status of the receiver are displayed in the SAHTI window. The navigator is configured automatically by SAHTI.exe to send the positioning data once every second. Position data are received through a serial interface with the speed of 9600 bps (Mobile GPS) or of 4800 bps (SV-6). Mobile GPS sends information of health of the receiver every 20 seconds, whereas SV-6 sends the same information every second.

SAHTI system can be configured through Basic Setup in Options menu. Changes are performed by typing alternative values in the textboxes. Some parameters cannot be changed in Basic Setup window. These parameters are changed by editing the GPS.INI-file in Windows directory. A copy of the file must also be in the MapInfo directory for SAHTI.mbx. Figure 4 shows the layout of SAHTI.exe.

In Basic Setup window the user can define default parameters which are used in SAHTI system:

MAP DIR shows the MapInfo's directory.
MBX FILE shows, which MapBasic program is used.
DEFAULT DATA FILE shows the directory and the name of the file where the data is saved.
DEFAULT FILE ID shows the first 4 characters of the positioning file name.

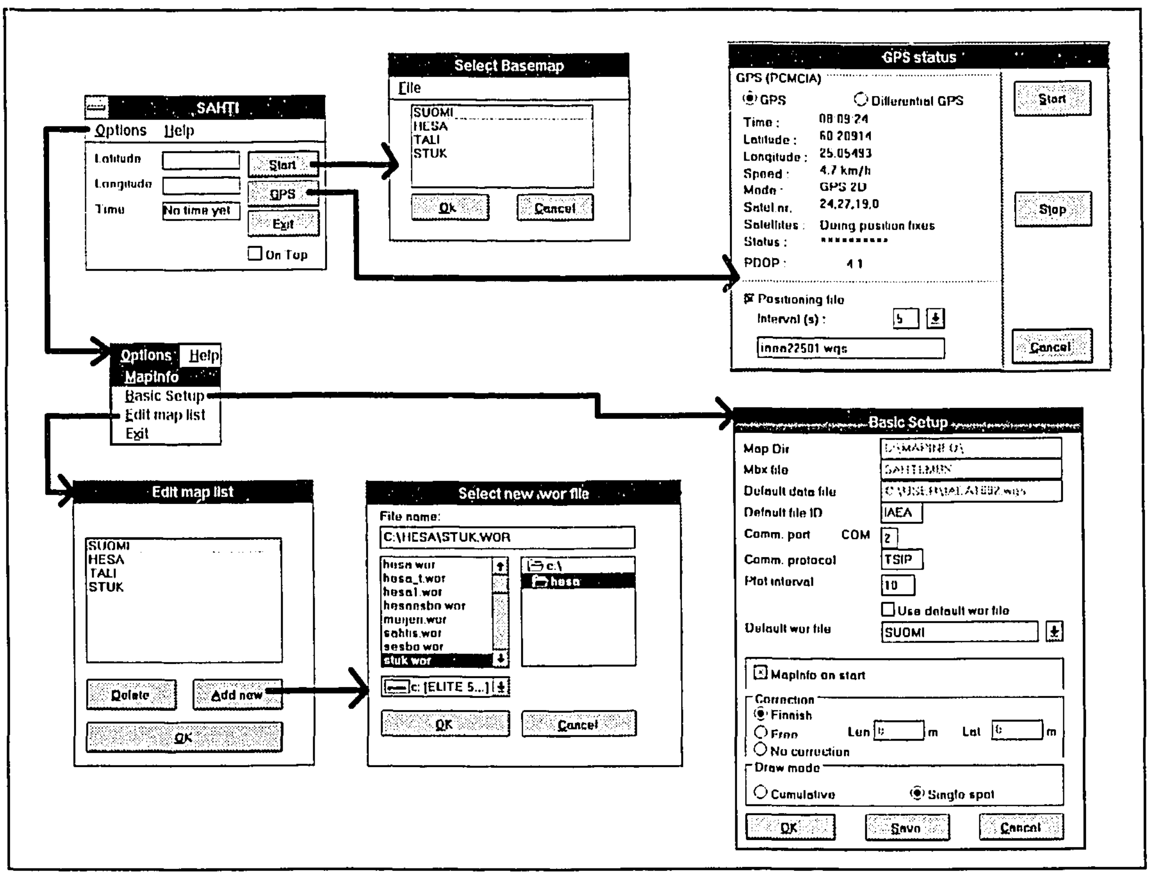


Figure 4. SAHTI.exe. Selecting an item in the "Options" menu shows new windows in which the system can be modified (Basic Setup, Edit map list). Selecting item "MapInfo" confirms the use of MapInfo in the system and it starts automatically when positioning is started by clicking the "Start"-button. Every time the co-ordinates are updated, information is passed to SAHTI.mbx, using Windows DDE-link. Detailed status for GPS positioning can be viewed by clicking the "GPS"-button.

COMM. PORT defines which serial port is being used.

COMM. PROTOCOL defines the protocol used (TSIP/TAIP).

PLOT INTERVAL defines the interval how often the map is updated (seconds).

USE DEFAULT WOR FILE defines if the default MapInfo workspace is used when positioning is started.

DEFAULT wor file is the name of the default MapInfo workspace.

MAPINFO ON START defines if MapInfo is started together with the positioning.

CORRECTION defines which correction mode is used.

DRAW MODE defines if cumulative or single spot drawing is used.

If the value of a field is changed, SAHTI system checks validation of the new value. If the new value is not valid, a message is displayed and the old value is returned. Changes can either be saved to be permanent or to be used just in the present session. When SAHTI is started the system reads the settings from the GPS.INI file and uses them as default.

The co-ordinates and time are saved to an ASCII file defined by the user. The names of the directory and the file are given in the Basic Setup window. The file name consist of four user defined characters and date in DDMM format (STUK2106.WGS). The extension WGS stands for WGS-84 system co-ordinates. The file name can also be changed in the GPS Control panel window. The file contains information about the source (PCMCIA/ DGPS), date, time, longitude, latitude, speed, satellite identification numbers and altitude. The file is saved to the directory defined in Basic Setup. Detailed file format and description for the data fields are given in Appendix 5.

Selecting "GPS"- button shows the GPS control panel. A more detailed status of the GPS receiver is shown. If any errors occur while trying to get the positioning data, it's shown on this window. The following changes or selections can be made: (1) positioning start or stop, (2) name of the ASCII file for the positioning data and (3) frequency (interval) for data saving.

The following information is received from the GPS navigator (see Figure 5):

Time is the time received from the GPS. SAHTI system changes also the time of the PC accordingly.

Latitude and *longitude* are degrees in WGS-84 system.

Speed shows speed in km/h.

Mode shows the GPS system mode. Mode refers to two-dimensional or three-dimensional positions. A 2-D position fix provides latitude and longitude. Altitude is assumed to be fixed. Only three satellites are required to provide 2-D position. A 3-D position provides the altitude in addition to latitude and longitude and requires four satellites.

Satel nr. field shows the identification numbers of the useable satellites.

Satellites field tells the status of the GPS receiver.

Status adds a mark ("¤") on status field every time it receives data from GPS.

PDOP field tells the accuracy of positioning. PDOP (Position Dilution of Precision) is a figure of merit expressing the relationship between the error in user position and the error in satellite position. Values considered good for positioning are small. Values larger than 7 are considered poor. If PDOP is too high, an error message is shown in Satellites field and no positions can be received from GPS.

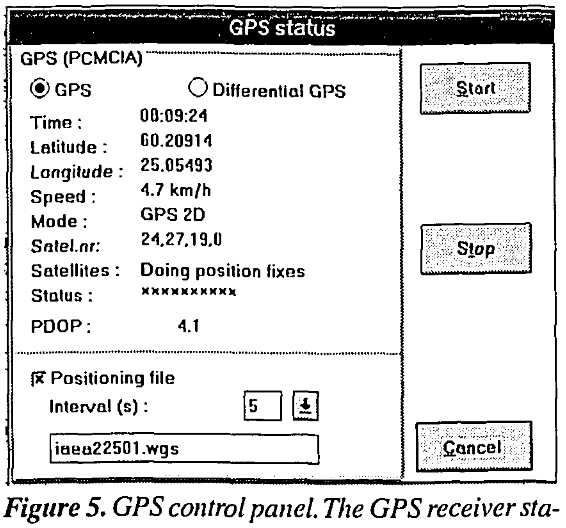


***Figure 5.** GPS control panel. The GPS receiver status is seen during the positioning. "¤" mark is added to the status field every time the system gets data from the GPS receiver. Positioning can be started and stopped from the panel.*

5.1.2 GPS application for MapInfo, SAHTI.mbx

SAHTI.mbx is a MapBasic application that displays the position as a symbol in the right position. A drop-down menu, "GPS", is added in MapInfo's menu bar when SAHTI.mbx is executed. Figure 6 shows the layout of SAHTI.mbx.

Edit Symbol brings out a MapInfo's symbol picker dialogue where the drawing style of the position symbol can be changed.

Corrections opens a dialogue where the desired correction method can be selected. *Finnish correction* is a simple mathematical correction from WGS-84 to the national co-ordinate system, KKJ. *Free correction* moves the symbol by the given amount of metres. Positive values move the symbol towards East (Lon) and North (Lat). When *None* is selected no correction is performed.

Draw mode sets the display either in cumulative or non-cumulative mode. The text on the window shows the current mode when the dialogue window is loaded.

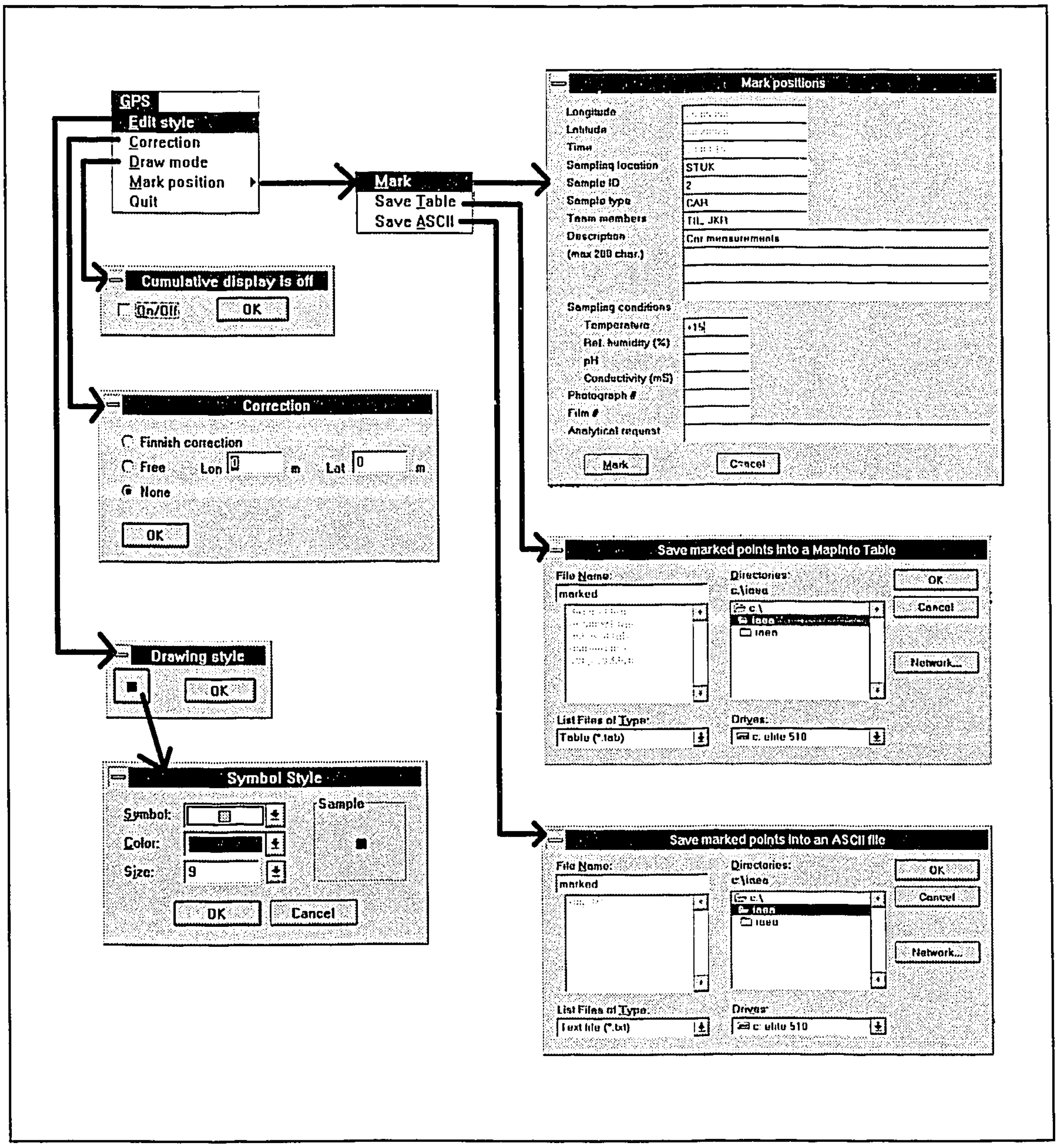


Figure 6. *A layout of SAHTI.mbx. A drop-down menu appears in MapInfo when SAHTI.mbx is executing. Several functions are performed by selecting an item in the drop-down-menu.*

Mark positions ables to mark the locations with special interest. Information is recorded and saved. Draw mode must be non-cumulative. The procedure is repeated until all desired points are marked. *Mark* shows a dialogue for entering information of the point and updates the table "FixPoint" with the information for location of interest. *Save Table* opens a dialogue for saving the marked locations as a MapInfo table. *Save ASCII* opens a dialogue for saving the marked locations as an ASCII file.

If the draw mode is changed into cumulative mode while positions are being marked, the table "FixPoint" is saved and closed. The table is saved in user defined directory with the name "FIXPOINT.TAB". It is recommended to save the marked positions with the name defined by the user before the draw mode is changed.

Import previous opens navigating sessions and displays them. This option executes program IMPORT.exe. The map is automatically updated.

5.1.3 Previous data viewer, IMPORT.exe

IMPORT.exe program executes automatically when "Show previous" is selected in MapInfo's "GPS" menu.

An ASCII file is opened for reading through a standard Windows File Open dialogue. The coordinate correction which is used for a certain map is applied when old data is imported. A new MapInfo table, named by the user, is opened and the data are automatically updated in MapInfo's map window. Figure 7 shows the layout of IMPORT.exe.

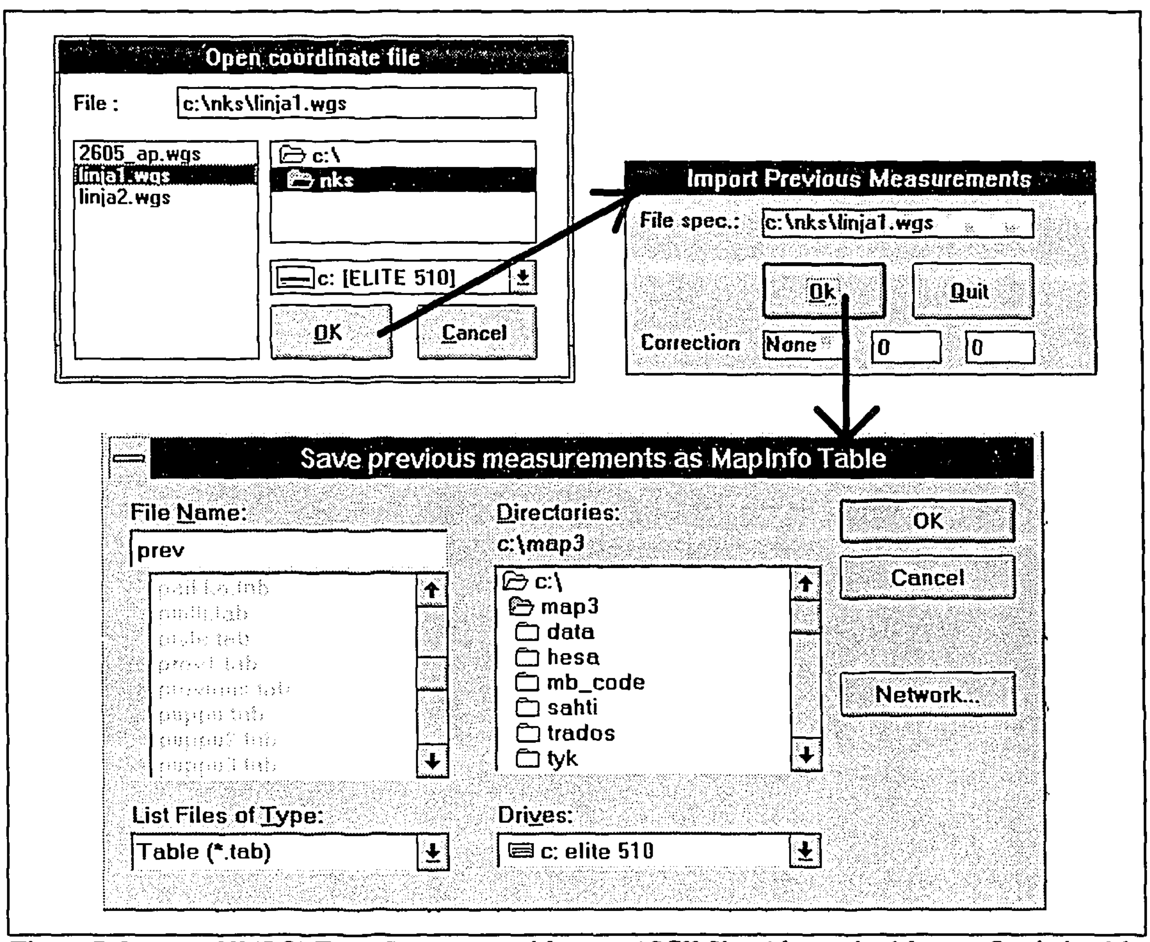


***Figure 7.** Layout of IMPORT.exe. Data are read from an ASCII file with standard format. Symbols of the old measurements are automatically added in the current Map window and a new table, named by the user, is opened.*

5.2 Starting positioning

Before starting the system, the user should ensure that there are digital maps available of the area of interest. Digital maps can also be produced from paper maps by using a digital scanner and MapInfo.

Once the maps have been purchased or produced, a MapInfo workspace for navigation must be prepared. A workspace is a set of map layers, which are displayed in the way the user wants. Preparation of MapInfo workspace is presented in Appendix 1.

Before starting the navigation, it should be checked that the antenna can see enough open sky (not too many buildings or trees around). Because of signal attenuation, the accuracy of positioning might be lower or the receiver might not get signals from the satellites at all.

When the program has been started, it may take some 3 to 8 minutes before the co-ordinates appear on the screen. The system works in real time when the navigator has found three useable satellites for calculation of the first position. The co-ordinates are updated in the SAHTI window with the interval selected by the user. The title of the window shows the status of the navigator. There is a label with caption "HEALTH", appearing and disappearing on the bottom of the SAHTI window, showing that the communication is working. When a sufficient number of satellites is noticed by the GPS-receiver, the label on the bottom of the window reads "OK" and the status of the navigator changes to "Doing Position Fixes". If MapInfo is used, a symbol appears in the map window, showing the current position every time the co-ordinates are updated. All the co-ordinates are stored in a file, defined by the user. The file name consists of four characters given by the user, the date with four characters and an extension (e.g. IAEA1906.WGS). When the position symbol moves away from the area shown in the current map window, the view is automatically updated so that the last position symbol is shown in the middle of the map window. Navigation is finished by quitting "GPS"-menu in MapInfo and selecting "Exit" in SAHTI program. Step-by-step instruction of using SAHTI system is presented in Appendix 2.

5.3 Confirming the position on the map

If the base map is used for the first time, the user should confirm that the position obtained from the GPS-receiver corresponds to the location found on the base map. This is especially important if the co-ordinate system is not based on WGS-84, or has not been completely defined. Confirmation is performed by letting SAHTI system to run in one spot for a long time with the plot interval of 10 seconds. The "Draw mode" must be set in cumulative mode (setting in MapInfo, GPS menu). After about an hour, the centroid of all measured positions is estimated and the distance between the measured centroid and the location on the map is measured using MapInfo's ruler tool. The centroid corresponds to the real location in the nature with an accuracy of 30 metres or better.

If the centroid of all measurements is less than 50 m away from the corresponding position on the map (measured with MapInfo's ruler tool), the map fits in its correct position well enough and no correction is needed. If the centroid is clearly further away from corresponding position on the base map, a correction must be performed.

There are some simple methods to perform the correction. The easiest method is a linear correction, where the symbol is forced by a certain number of metres towards the right direction. In MapInfo's GPS menu there is a submenu for corrections. Linear correction of given number of metres is performed by selecting "Free correction" and typing the distances into the text boxes beside. The same correction parameters are applicable over 100 km away from the spot on which the correction was defined. The same linear correction parameters should be used every time when the map is used. Therefore the correction should be carefully recorded. "Finnish correction", in the corrections window, is a local correction applied only in Finland with the Finnish base maps.

Especially for Raster images, there is another method. Once one spot has been determined with GPS reliably (long time acquisition), the distance between the position according to GPS and the correct position on the map is measured with MapInfo (with the ruler tool). Raster Image Registration in MapInfo is changed to bring the map object at the same position with the measured one. This is performed by adding (or subtracting) the differences into X and Y co-ordinates of Raster Image control points, respectively. The advantage in moving the whole map is that it only has to be performed once. There is no need to remember any correction parameters either.

5.3 Information for environmental sampling

SAHTI system provides a tool for book-keeping of information in sample collection. Locations of special interest can be marked and saved in either ASCII or MapInfo table format.

The draw mode must be non-cumulative. *Mark* is selected from GPS-menu and a sample collecting dialogue appears. After filling the fields and pressing OK, a red spot appears on the map and a new table "FixPoint" is opened.

After marking all the wanted points, the table can be saved as an ASCII file or MapInfo table. The ASCII file has "," as a field separator (Excel file). This function can also be used for fixing a Raster image with unknown scale and co-ordinate system. Figure 8 shows the layout of the Sample collecting dialogue.

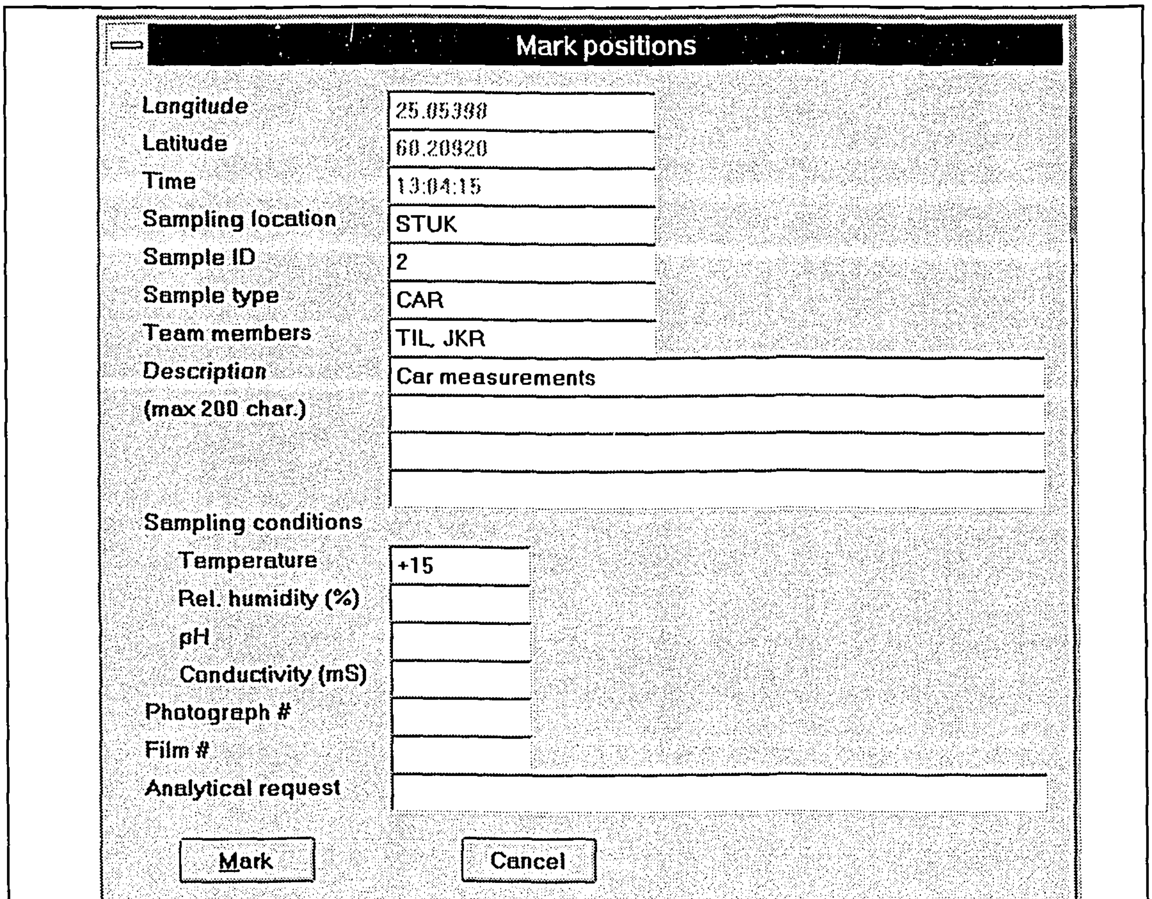


***Figure 8.** Sample collecting dialogue. The fields can be filled while marking the spot or they can be edited afterwards. After marking the spot a browser window appears in MapInfo with the sample collecting data.*

MAPINFO WORKSPACE

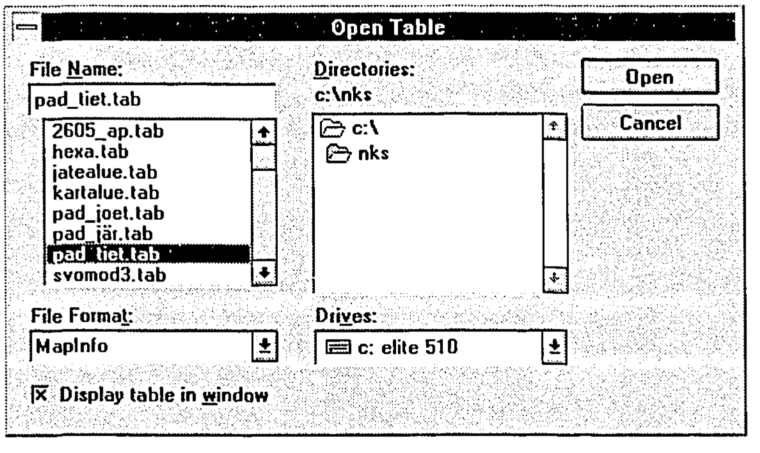
MapInfo's workspace is a selection of maps in one or more map windows. Names of maps and display settings (colour, region fill style, etc.) are stored into a file with an extension ".WOR". You can include in your workspace several map layers (vector and Raster). It is recommended that the bottom layer in the map window is a large vector map, e.g. map of World or Europe. The preparation includes the following steps:

1. Make sure that all the maps you want to include are stored on the hard disk of your computer.

2. Start MapInfo.

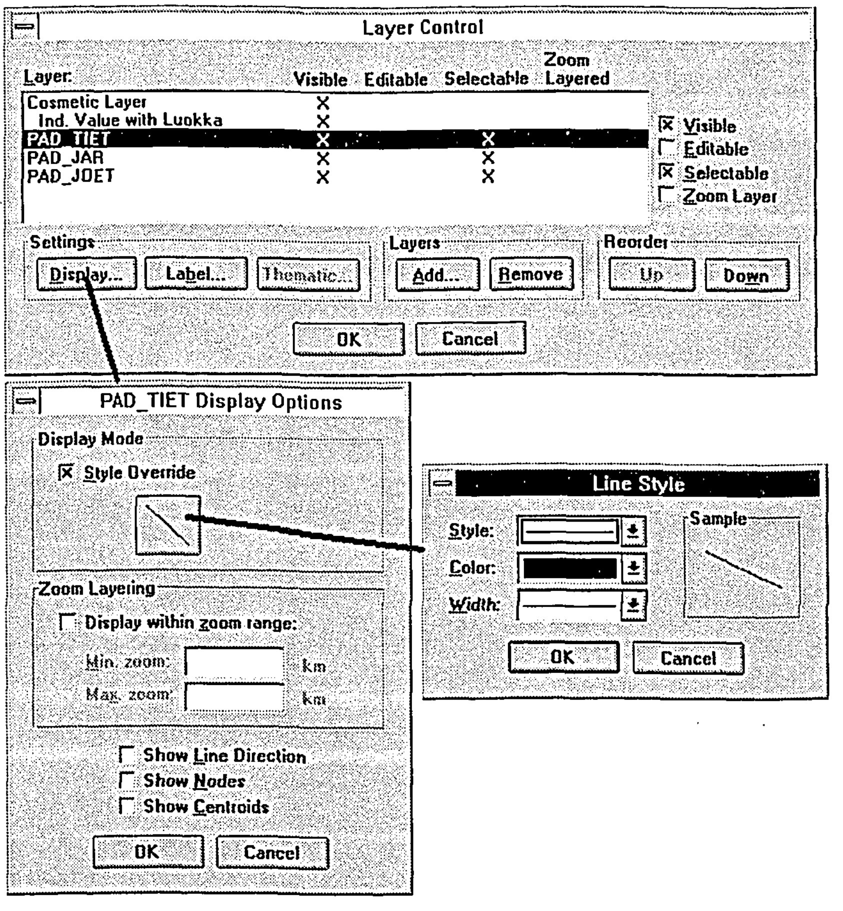
3. Select Open a Table in File menu. Through the dialogue which appears, open a map which you want to include in your workspace (largest map first, e.g. map of world). Repeat until all desired maps are opened.

- File > Open Table



4. If any vector layers are included, you can change the display style.

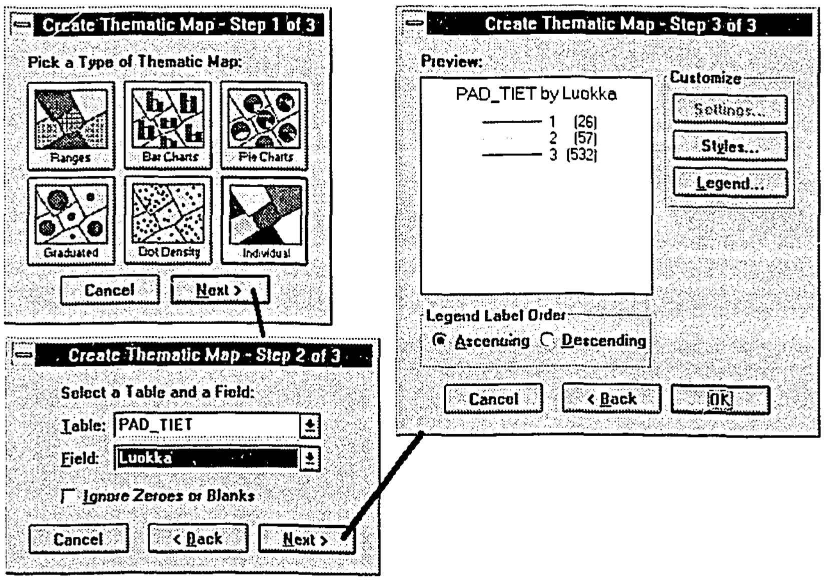
- Map > Layer control > Display > Display mode



Here you can change the style of the objects in the layer (style override)

The style of the display can also be changed by creating a thematic map for one field of the table.

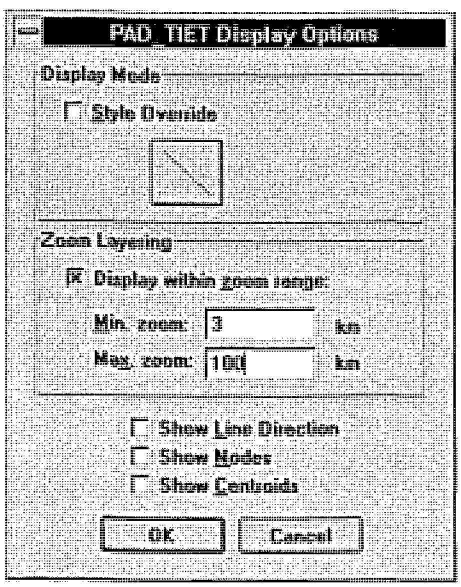
- Map > Create Thematic map



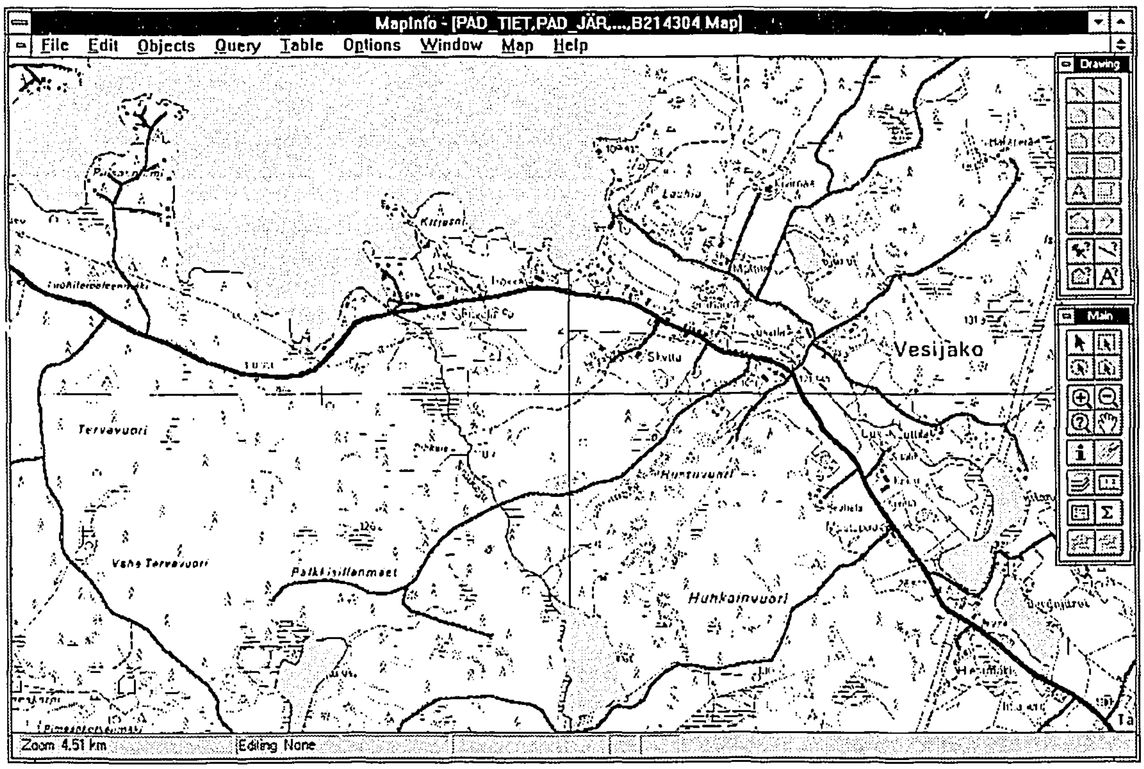
Here the objects are coloured or styled according to the value of the selected variable (e.g. the colour of the road corresponds the road classification)

5. Set the display limits for each layer. This means to set the smallest and the largest zoom level where the particular map is visible. Vector layers with large number of details and Raster layers must become visible only when the scale (the zoom) of the map window allows all details being seen.

- Map > Layer control > Display > Zoom layering

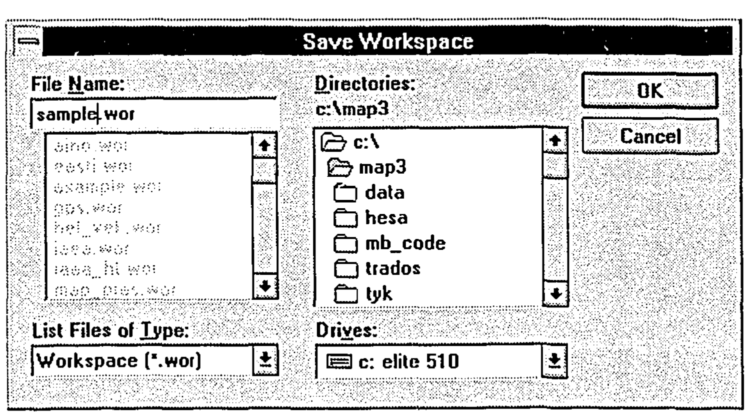


6. Zoom and move the map so that the area of interest is in the middle of the map window.



7. When all modifications are made, save the workspace

- File > Save workspace...

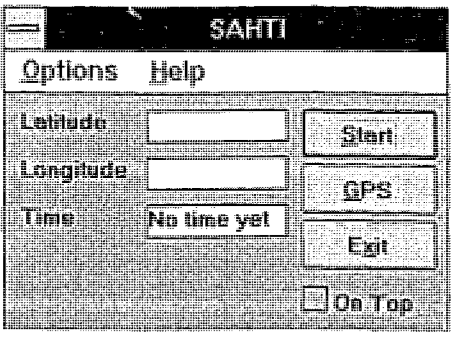


STEP-BY-STEP INSTRUCTIONS OF USING SAHTI SYSTEM **APPENDIX 2**

STARTING SAHTI NAVIGATION SYSTEM

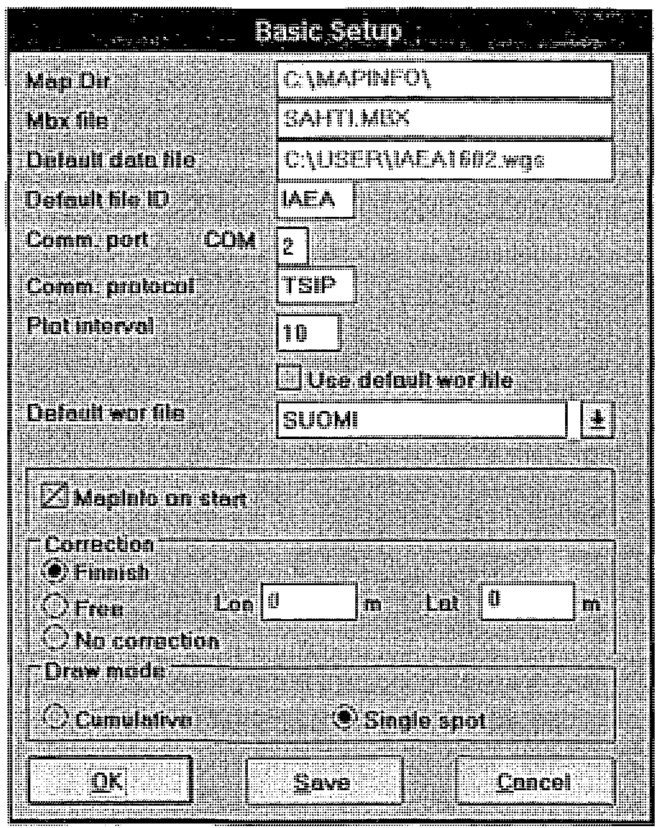
The following example assumes that a suitable MapInfo workspace is prepared earlier. Starting the system is performed according to the following steps:

1. Check that the GPS PCMCIA card is in the slot and attach the antenna cable to the connector in the card.
2. Check that MapInfo's security key is attached to the parallel port of the computer (this is unnecessary if you have an unprojected version of MapInfo).
3. Turn on the computer and make sure that the PCMCIA card is set up properly by automatic PCMCIA card drivers (a sound signal).
4. Place the antenna on an unobscured surface. Check that there is not many high buildings or trees covering open sky.
5. Start Windows and program "SAHTI" (program group GPS, for example).
6. A window as follows appears



7. Check the "Basic Setup" for the following parameters.

- Options > Basic Setup

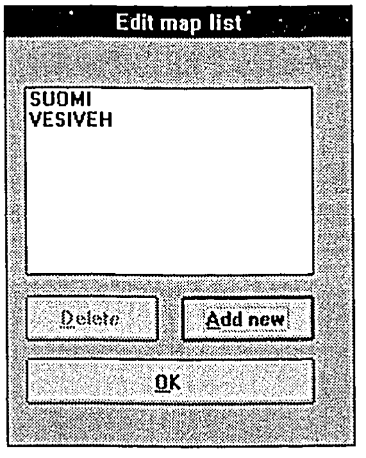


Map directory is the directory, where MapInfo and the required MapBasic programs are stored.

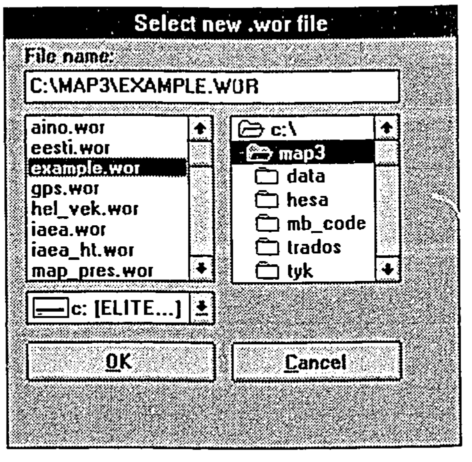
Suitable plot interval is between 2-10 (the interval of passing data to MapInfo, approximately in seconds).

8. If the system is used for the first time, you must add a new MapInfo workspace.

- Options > Edit Map list



Selecting "Add new", shows a standard Windows file open dialogue, through which a prepared MapInfo workspace (Extension ".WOR") is added to the system.



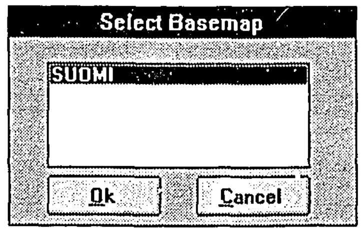
9. Click the check box "On Top" to set the SAHTI window to stay always above the map layers.

10. Confirm that you are using MapInfo to display the position on a digital map.

- Options > MapInfo

11. Start navigation by clicking the "Start"-button.

12. If "Use default wor file"-option is not selected from Basic setup window, SAHTI shows a list of workspaces defined earlier. Select a suitable base map from the list. MapInfo starts then automatically with the selected workspace.



If the default workspace is defined earlier, no list is shown and MapInfo starts automatically after clicking "Start"-button.

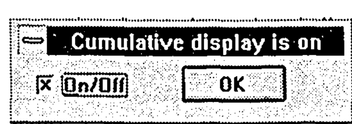
The co-ordinates should be updated first time at the latest after 5 minutes. If there is no update, check that GPS is receiving signals from satellites (status on top of the SAHTI window) and make sure that the antenna is placed properly.

CO-ORDINATE CORRECTION

Once the navigation is working properly, the co-ordinate correction must be set as defined for the base map. If the correction is not defined yet, it should be performed to obtain higher accuracy navigation. Section 4.3. explains the principles of co-ordinate correction. Defining the correction is performed as follows:

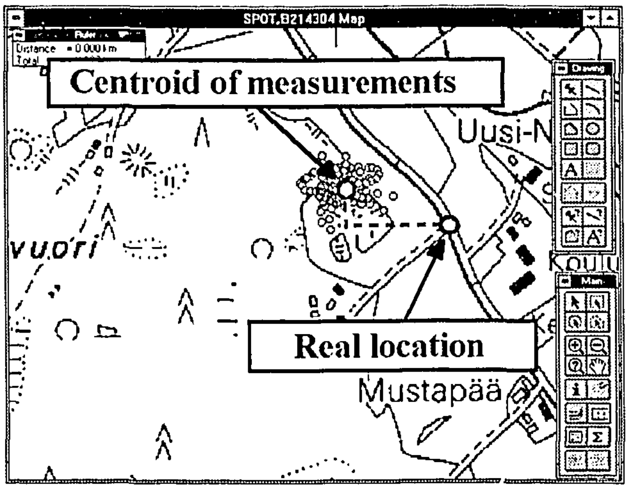
1. Set the draw mode to cumulative through GPS menu in MapInfo

- GPS > Draw mode



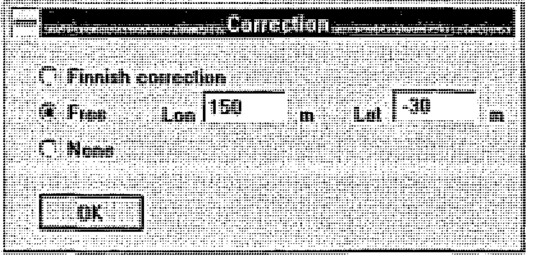
Click on the check box to change the mode to cumulative.

2. After about an hour, re-scale the map window so that all measured positions are seen (zoom tools in main tool box). The centroid of all measurements is estimated and the distance between the measured centroid and real location on the map is measured using MapInfo's ruler tool (in the main tool box). In this example we assume that the distance is 150 m west and 30 m north.



3. Linear correction: Select "Corrections" in GPS menu.

- GPS > Corrections



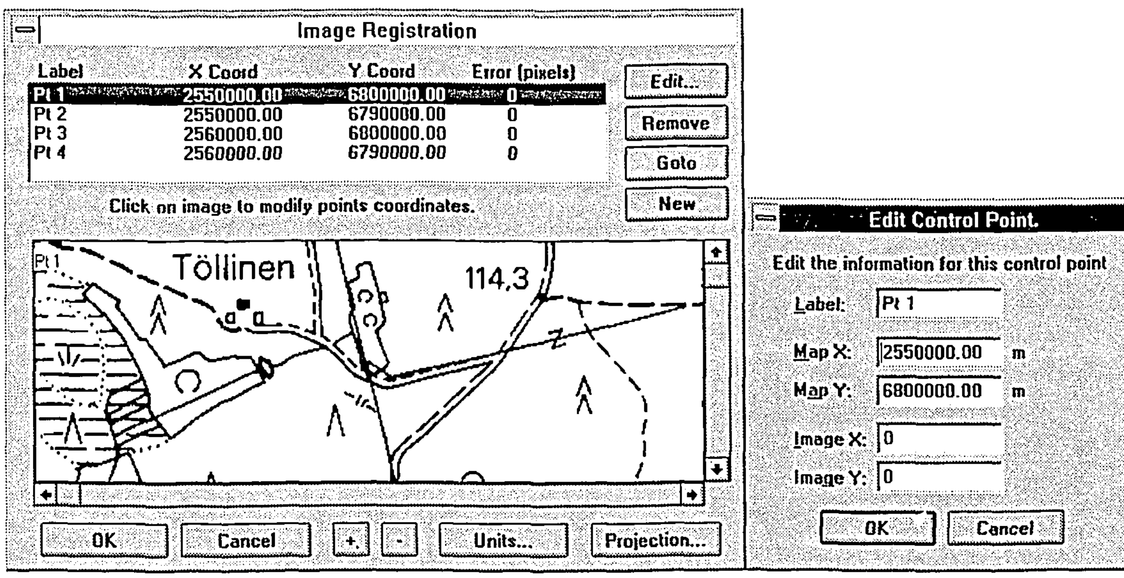
Choose "Free correction". Type 150 in the text box with label Lon and -30 in the text box with the label Lat. Click OK button.

APPENDIX 2 STEP-BY-STEP INSTRUCTIONS OF USING SAHTI SYSTEM

4. Method for a Raster image as a base map

A Raster image can be moved into right position by changing the values for Raster Image Registration in MapInfo. This is possible if the co-ordinates of control points are expressed in metres, feet etc. In this example you must subtract 150 from X co-ordinate and add 30 m to Y co-ordinate.

- Table > Raster > Modify Image Registration



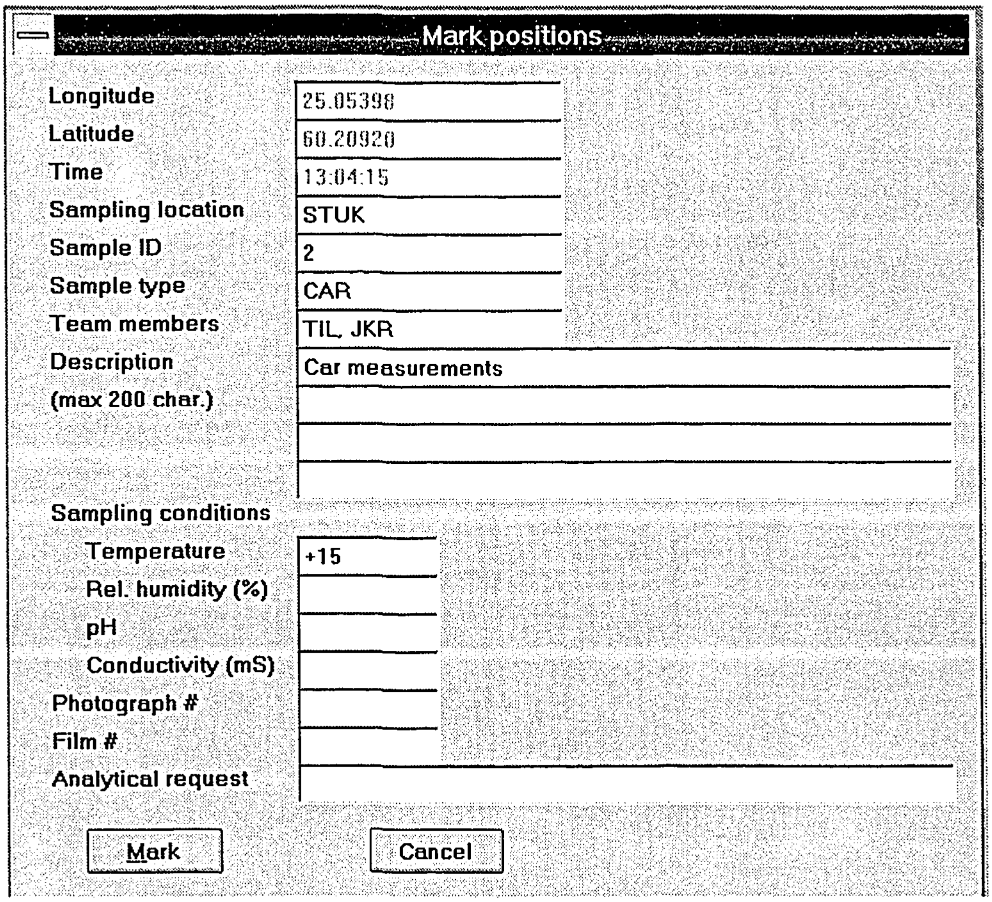
STEP-BY-STEP INSTRUCTIONS OF USING SAHTI SYSTEM **APPENDIX 2**

MARK POSITIONS

Locations with special interest (e.g. sampling point) can be marked and co-ordinate information saved in ASCII file and MapInfo table. At first the draw mode must be non-cumulative. Marking and saving goes as follows:

1. Wait that the co-ordinates update while you stay on the interesting spot. Select "Mark" in GPS menu.

- GPS > Mark positions > Mark



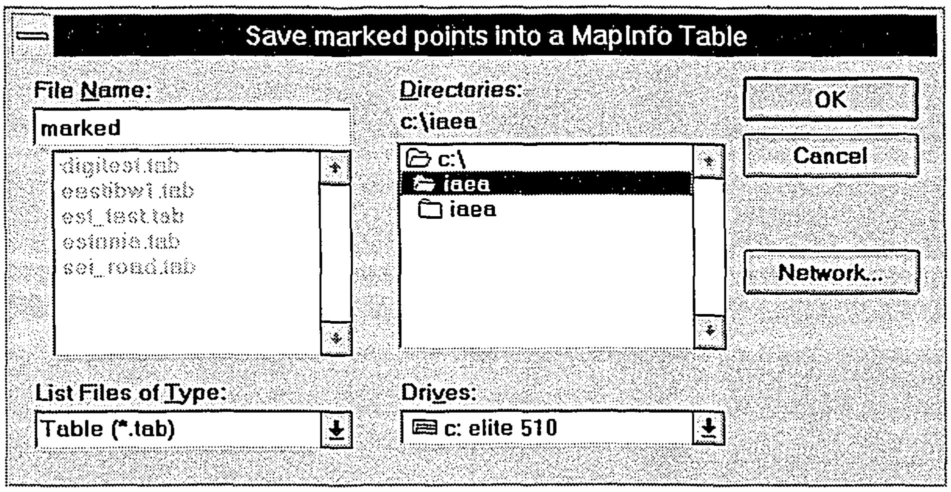
A dialogue where you can type sample location and other notes appears. Click OK and a red spherical symbol, referring to the marked location, appears in the map window.

2. Repeat the procedure above as many times as needed.

APPENDIX 2 STEP-BY-STEP INSTRUCTIONS OF USING SAHTI SYSTEM

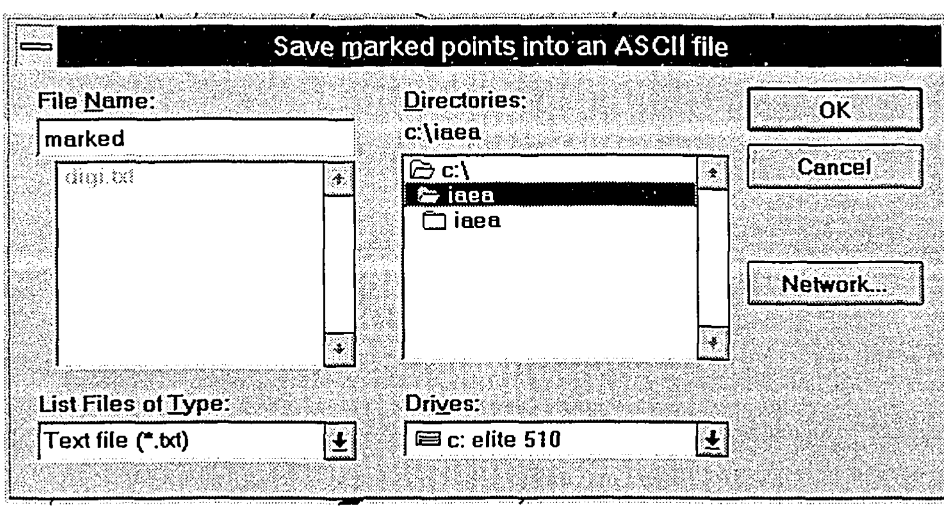
3. Save an ASCII file selecting "Save an ASCII file" in GPS menu.

- GPS > Mark positions > Save an ASCII File



4. Save a MapInfo table selecting "Save a Table" in GPS menu.

- GPS > Mark positions > Save a Table



FINISHING THE NAVIGATION:

1. In MapInfo select "Quit" in GPS menu.

2. Click buttons "Stop" and then "Exit" in SAHTI window.

APPENDIX 3

A MAP WITH CO-ORDINATE SYSTEM SUPPORTED BY MAPINFO

If the co-ordinate system is known and supported by MapInfo, it easy to fix a Raster image as a MapInfo table. A scanned Raster image, a Finnish base map B213406.tif, is used as an example. The co-ordinate system is the Finnish KKJ system and the co-ordinate units are metres. The control points are fixed in corners of the image and the co-ordinates are read from the paper map.

First the Raster map is opened in Raster image format.

Open -> Table

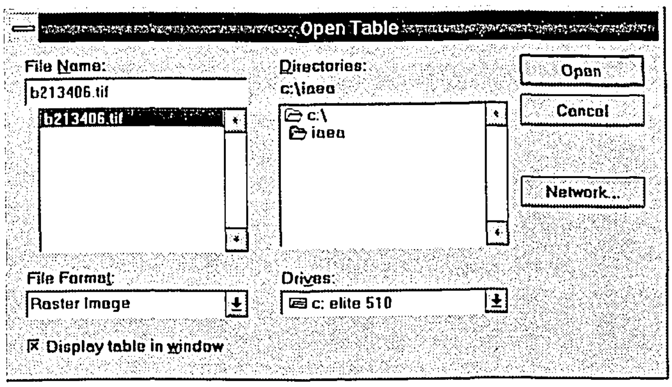
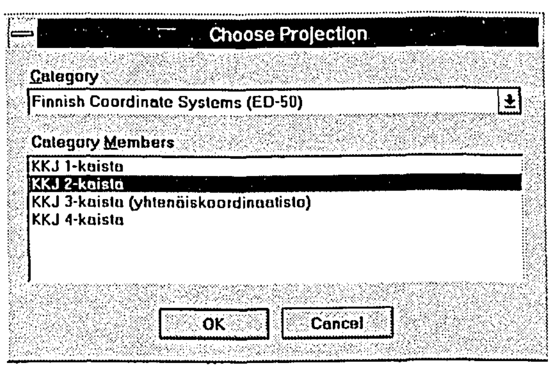
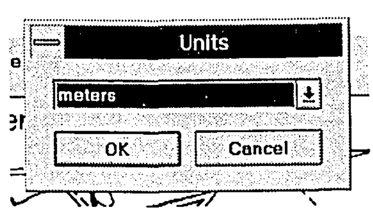


Image registration window appears. The projection of the map must be selected before fixing the control points.

The "Finnish co-ordinate systems (ED-50)" is selected as a category and "KKJ2-kaista" is selected as a category member from "Choose Projection" window.

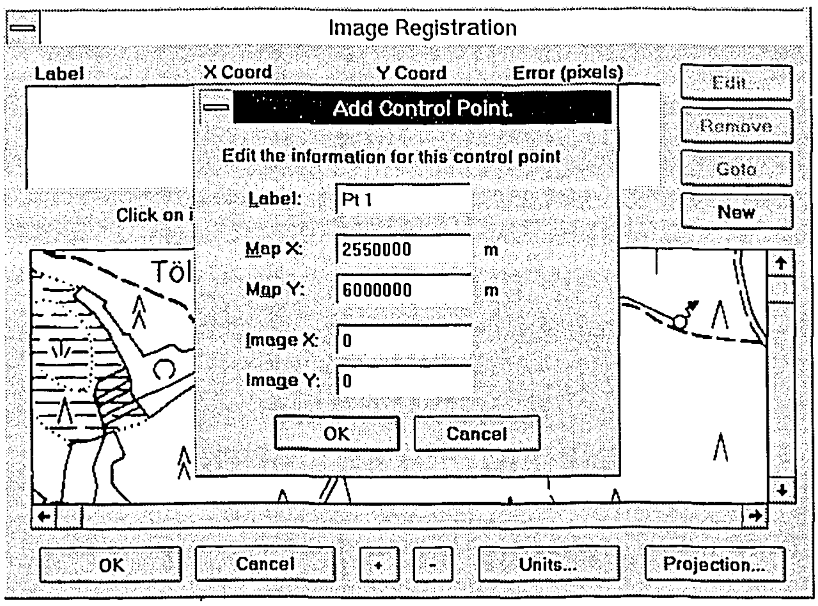


The units are changed to metres from Units window.



APPENDIX 3 — PRODUCING MAPINFO MAPS FROM RASTER IMAGES

The left upper corner of the image is marked as the first control point. A red cross appears at the point. In Add Control Point window the co-ordinates are given in Map X (longitude) and Map Y (latitude) fields. This step is repeated for all four corners of the image. Image registration now shows the control points and their co-ordinates. The points that are not exactly on a correct line are shown in the Error column. In that case the points can be adjusted.



MapInfo creates a file, where the co-ordinates for the control points of the Raster image are. The file is an editable ASCII file with extension "tab". The file contains the Raster image name, all the control points and projection.

Example of file B213406.tab:

```
!table
!version 300
!charset WindowsLatin1
```

Definition Table
File "b213406.tif"

```
  Type "RASTER"
  (2550000,6800000) (0,0) Label "Pt 1",
  (2550000,6790000) (0,5000) Label "Pt 2",
  (2560000,6800000) (5000,0) Label "Pt 3",
  (2560000,6790000) (5000,5000) Label "Pt 4"
  CoordSys Earth Projection 8, 29, "m", 24, 0, 1, 2500000, 0
  Units "m"
```

APPENDIX 3

A MAP WHERE THE SCALE AND ORIGIN LONGITUDE ARE KNOWN, BUT OTHER CO-ORDINATE SYSTEM PARAMETERS ARE UNKNOWN.

A scanned image of Tallinn, Estonia was produced for use as base map. The origin longitude (25.00 E, vertical longitude line) was found by studying the map. Scale (1:200000) was also given on the map. An UTM -projection (Universal Transverse Mercator) for central meridian 25.00 E was created in MapInfo by editing the file "mapinfow.prj". The following two lines were added into the file:

```
"— Estonia maps (WGS 84) —"
"UTM ESTONIA-25 (WGS 84)", 8, 104, 7, 25, 0, 0.999995, 500000, 0
```

The first line is a title, which is displayed when selecting the projection. The second line includes parameters for a co-ordinate system: 8 is for the projection (Transverse Mercator), 104 is for the datum (WGS-84, used in GPS), 7 is for the units (metres), 25 is the origin longitude (same as in the original paper map), 0 is for the origin latitude, 0.999995 is for the scale factor (1—1/200000), 500000 is for the false easting (co-ordinate in meters on longitude 25.00 E) and the final 0 is for the false northing (co-ordinate in meters on latitude 0.00 N).

One control point was chosen on the map, referring to the location of a hotel car park. Another control point was measured horizontally 3.5 cm left on the map (equals 7 000 m). The third point was measured vertically 3.5 cm down on the map (equals 7 000 m). See Figure A1.

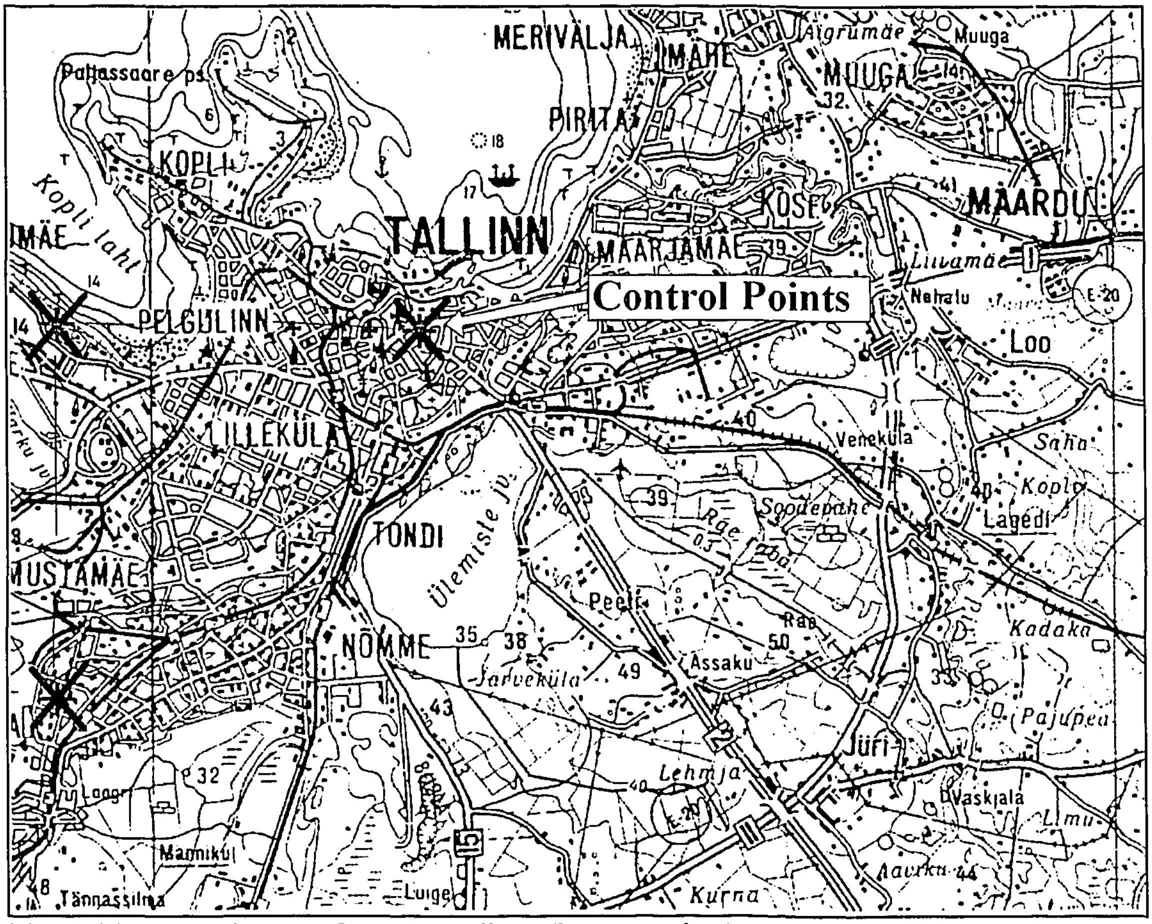
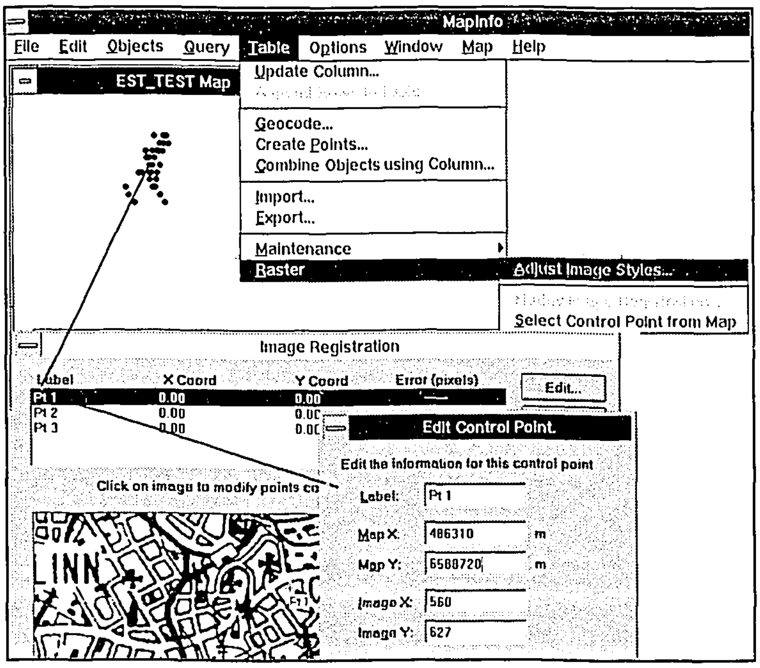


Figure A1. Scanned image of a map of Tallinn. Three control points are marked with "X" (see text).

APPENDIX 3 PRODUCING MAPINFO MAPS FROM RASTER IMAGES

A GPS was left for over an hour to perform positioning and all the measurements were displayed in MapInfo. A scanned image, stored as "EESTIBW1.TIF" was opened as Raster Image in MapInfo. In the Image Registration the projection was chosen (EESTI-UTM25, defined earlier), and the map units were set for metres. The control points were added according to Figure A1. The co-ordinates of point 1 were found using MapInfo's feature for selecting the corresponding control points from the map on the screen. Points 2 and 3 were calculated by subtracting 7000 m from co-ordinates of point 1.



The scanned image is opened in MapInfo as a Raster image. The projection is changed into UTM-25 (defined earlier) and the Units are set into metres. The control points which were chosen on the original map are added with mouse. The control point number 1 refers to the hotel car park. The plotted GPS measurements show the location of the car park, which makes it possible to select a control point from the map by clicking mouse when the cursor is in the right place. The co-ordinates for the control points 2 and 3 are calculated by subtracting 7000 m, respectively (measured from the original paper map).

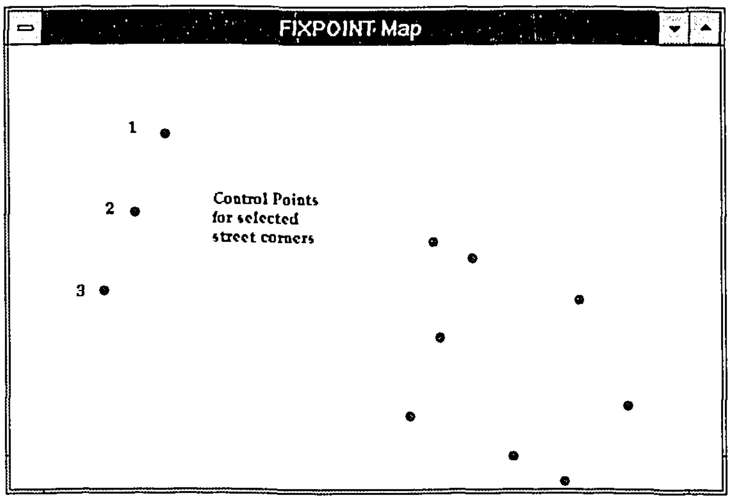
PRODUCING MAPINFO MAPS FROM RASTER IMAGES **APPENDIX 3**

FIXING A MAP WHERE THE SCALE AND CO-ORDINATE SYSTEM ARE UNKNOWN.

1. A scanned image from Helsinki area is used as a Raster base map. Eleven street corners are selected as control spots.

2. Positioning is started with the option Single spot display.

3. GPS receiver is moved to the first spot (Pt 1) and SAHTI system is running until the co-ordinates are shown on the map.
4. Mark option is selected from GPS menu in MapInfo. A dialogue for sample collection appears. Only Location field is filled. A red symbol on the map shows the location of the GPS receiver. The receiver is moved to the second position and the procedure is repeated until all the selected spots are marked.



5. Table Fixpoint is saved and the positioning is finished.

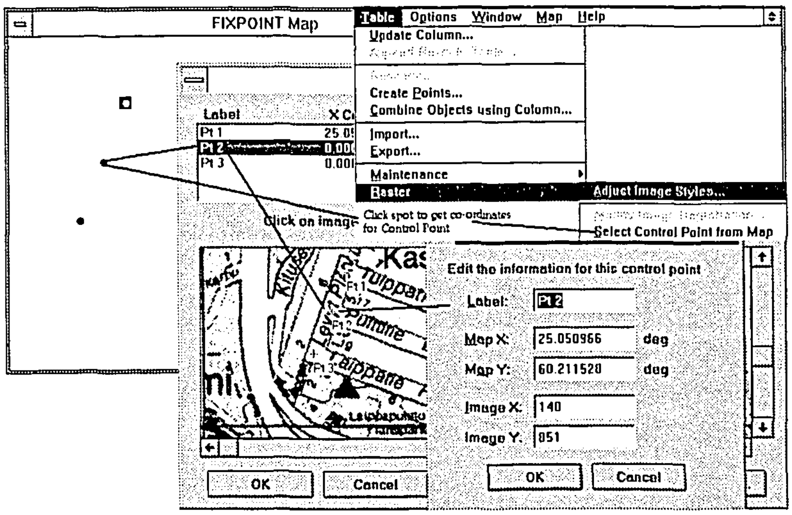
APPENDIX 3

6. For fixing the map, the table Fixpoint is opened again. A scanned image Laippa.bmp is opened as a Raster image. The projection is selected as Unprojected co-ordinate system.

7. All the control points in Raster image are marked in the Image Registration Window.

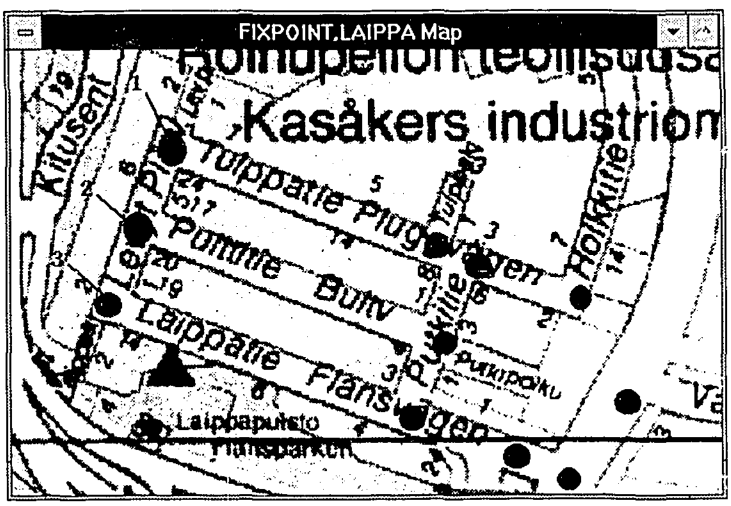
After marking all the spots the first control point is selected from the list.

Select Table-> Raster->Select Control Point From Map.



8. Move the cursor to the first spot on the Fixpoint map window. Click the symbol and "Add control point" window appears with the co-ordinates of the spot. Press OK and repeat this with all the spots.

9. When all the control points are registered, press OK, and the Raster image is shown in the same map window as Fixpoint table.

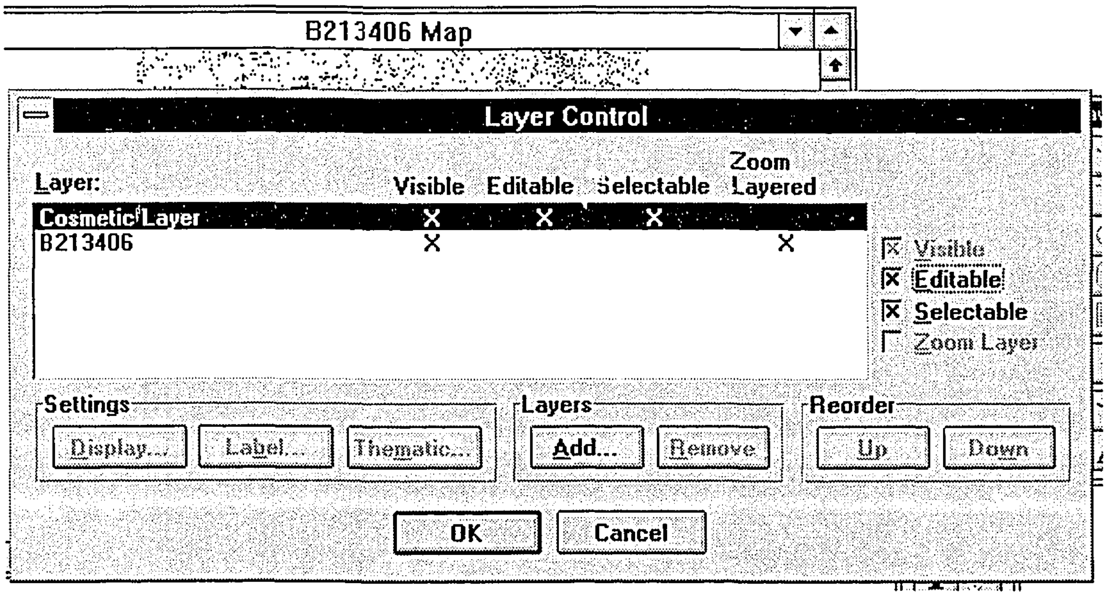


PRODUCING VECTOR MAPS

MapInfo has tools for digitizing a map from a paper copy. This requires a special digitizing table. If this is not available, smaller maps can be digitized from Raster maps that already are MapInfo tables. Digitizing is performed with MapInfo drawing tools by fixing the roads and other objects of interest. This example shows how to digitize roads from a Finnish Raster base map.

1. Open table B213406 and zoom the area so that roads are clearly seen.

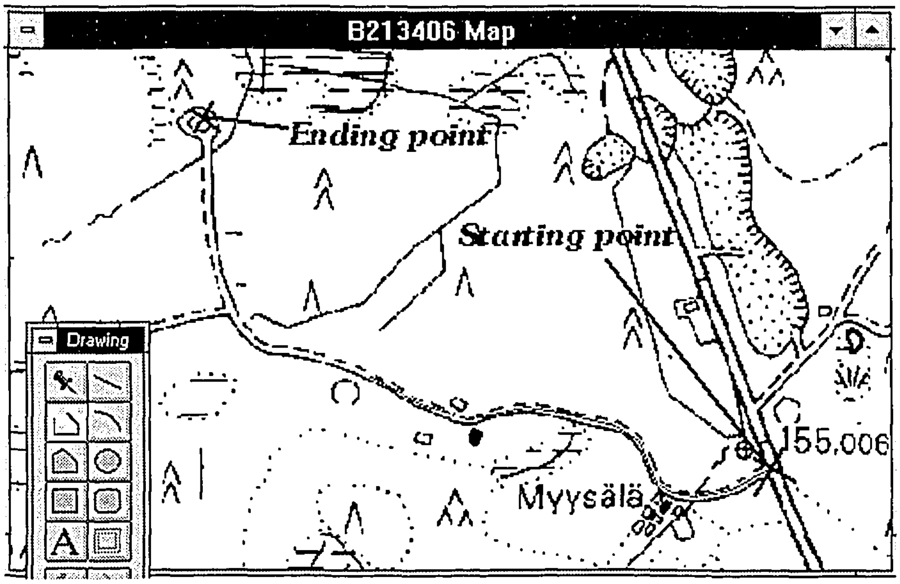
2. Select Map-> Layer Control and set Cosmetic Layer editable.



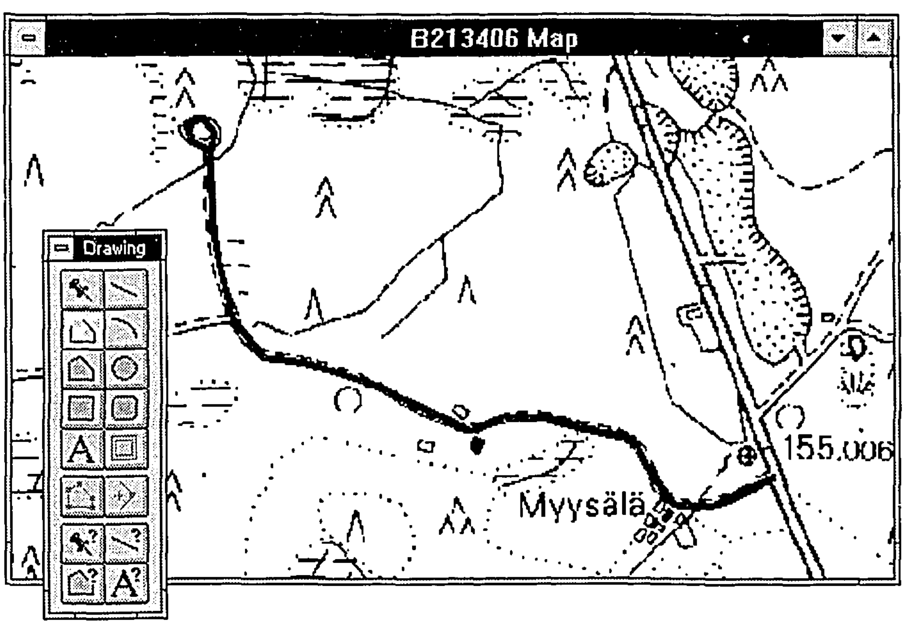
3. Select Options -> Line Style and increase the width of the line to be seen easily.

APPENDIX 4

4. Select polyline drawing tool from the toolbar and move the cursor to the beginning of the road you want to digitize. Follow the road and click the mouse in the curves so the line follows the road.



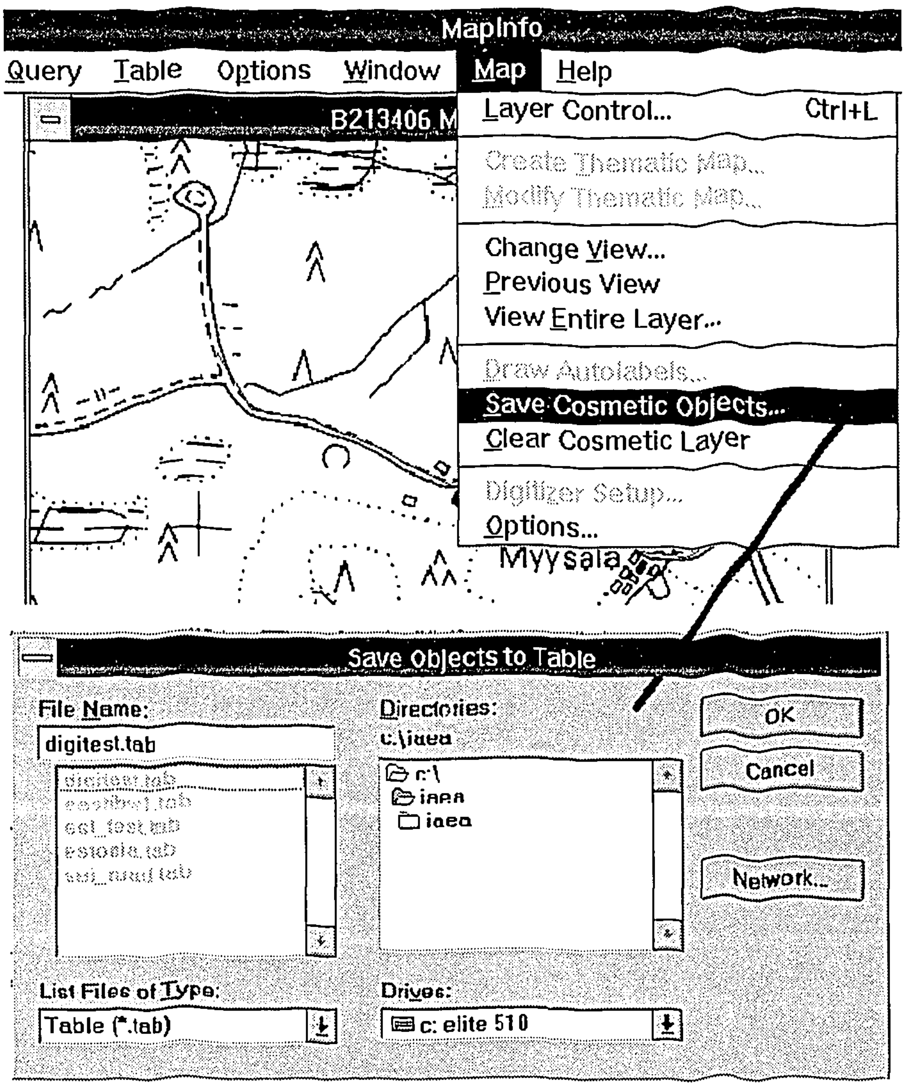
5. Double-click in the end of the road to show the digitized object.



APPENDIX 4

6. When all the wanted objects have been digitized, they are saved as a MapInfo table.

Map->Save Cosmetic Objects..



APPENDIX 5

DATA FORMAT

The data file consists of positioning data. All separate fields are in their own line. The first characters of the line are the line header separated with ":" from the actual data field. If some data fields are missing, there is no line for that data field. For example if line PC_DATE is missing, the data for that line was not available. The format is flexible and new variables can be added if required.

The file format is :

ID:	- identification for the measurement (GPS(PCMCIA)/ DGPS)
GPS_DATE:	- date of the satellite system
GPS_TIME:	- time of the satellite system
PC_DATE:	- date of the computer
PC_TIME:	- time of the computer
GPS_DEV:	- device of positioning (GPS/ DGPS)
GPS_MODE:	- mode of positioning (g,d,f,i) g = GPS, d = DGPS, f = read from file, i = interpolated
GPS_HEALTH:	- health information from the satellite
GPS_PDOP:	- PDOP parameter
GPS_SATELLITES:	- satellite identification numbers
GPS_SPEED:	- speed (km/h)
GPS_ALT:	- altitude (m)
LONWGSG:	- longitude in WGS84 from GPS
LATWGSG:	- longitude in WGS84 from GPS
LONWGSD:	- longitude in WGS84 from Differential GPS
LATWGSD:	- longitude in WGS84 from Differential GPS
LONWGSF:	- longitude in WGS84 read from file
LATWGSF:	- longitude in WGS84 read from file
LONWGSI:	- interpolated longitude in WGS84
LATWGSI:	- interpolated longitude in WGS84
# WGS84	- comment line
NEXT————-	- beginning of next position data

POSITIONING FILE FORMAT

APPENDIX 5

Example of the file:

```
ID:GPS (PCMCIA)
GPS_DATE:960126
GPS_TIME:090925:25
PC_DATE:960126
PC_TIME:090925:25
GPS_DEV:GPS
GPS_MODE:g
GPS_HEALTH:0
GPS_PDOP:0.0
GPS_SATELLITES:27,16,16,0
GPS_SPEED:4.6
GPS_ALT:33
LONWGSG:25.05337
LATWGSG:60.20868
NEXT------------------
ID:GPS (PCMCIA)
GPS_DATE:960126
GPS_TIME:090933:33
PC_DATE:960126
PC_TIME:090933:33
GPS_DEV:GPS
GPS_MODE:g
GPS_HEALTH:0
GPS_PDOP:0.0
GPS_SATELLITES:18,27,16,16
GPS_SPEED:0.0
GPS_ALT:23
LONWGSG:25.05338
LATWGSG:60.20868
NEXT------------------
```

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