2018

WSL Monoplotting Tool

User Manual

Swiss Federal Institute for Forest, Snow and Landscape Research WSL

05.07.2018

SUMMARY

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1 INTRODUCTION

The Monoplotting-Tool (MPT) allows georeferencing of landscape oblique photographs (terrestrial or aerial), to be used for quantitative measurements and analysis. Thanks to a mathematical model it is possible to combine the georeferenced image with the Digital Elevation Model (DEM), to connect each point (pixel) of the image with the corresponding world coordinates. Thus, a georeferenced photograph becomes a true three-dimensional geographical map.

The first part of this manual (to chapter 4) presents the user interface, the necessary geographical data and the data structures.

The second part (from chapter 5) explains in detail the different functions of the MPT and their usage: chapter 5 presents the basic functions and data management from georeferenced geographic or photographic documents; chapters 5 and 6 describe the steps required to prepare and georeference documents and to georeference (calibrate) an image using the camera calibration process.

Finally, the most important technical terms are explained in a glossary, with in addition the corresponding literature.

2 DATA TYPES

The Monoplotting Tool uses both standard GIS data and MPT-specific data.

Standard GIS data includes both vector data and raster data. Raster data consists in pixel data such as pixel maps, orthophotos, and elevation models, where each pixel contains the information relative to the corresponding coordinates (color, altitude, …). Vector data are represented by mathematical structures and are mainly suitable for the presentation of spatially discrete objects such as administrative boundaries, biotope types or corridor boundaries.

MPT-specific documents can be distinguished in georeferenced documents (*m_map* and *m_photo*) and data documents (*m_data* and *shp*). The terrestrial or air oblique images play a central role here: they are the specialty and the added value of the MPT over existing GIS packages.

In the MPT, the calibrated/georeferenced oblique images, as well as the conventional GIS raster data are synchronized and connected to the DEM: the three-dimensional coordinates corresponding to the current mouse position are simultaneously shown on all georeferenced documents.

2.1 COORDINATE SYSTEMS

The coordinate system has to be the same for each georeferenced map or DEM used in a MPT project, and must be a projected orthogonal coordinate system.

2.2 GEOREFERENCED GIS-MAPS

Georeferenced maps consist in raster files, linked to a spatial reference model. This reference model contains information about the reference coordinate system, i.e. X and Y coordinates. In the Monoplotting Tool, such *georeferenced GIS maps* are used to georeference the oblique images.

It is recommended, as far as possible, to generate map pyramids in a GIS system (ArcGIS, QGIS, …), because the MPT can manage such pyramids but cannot not generate them.

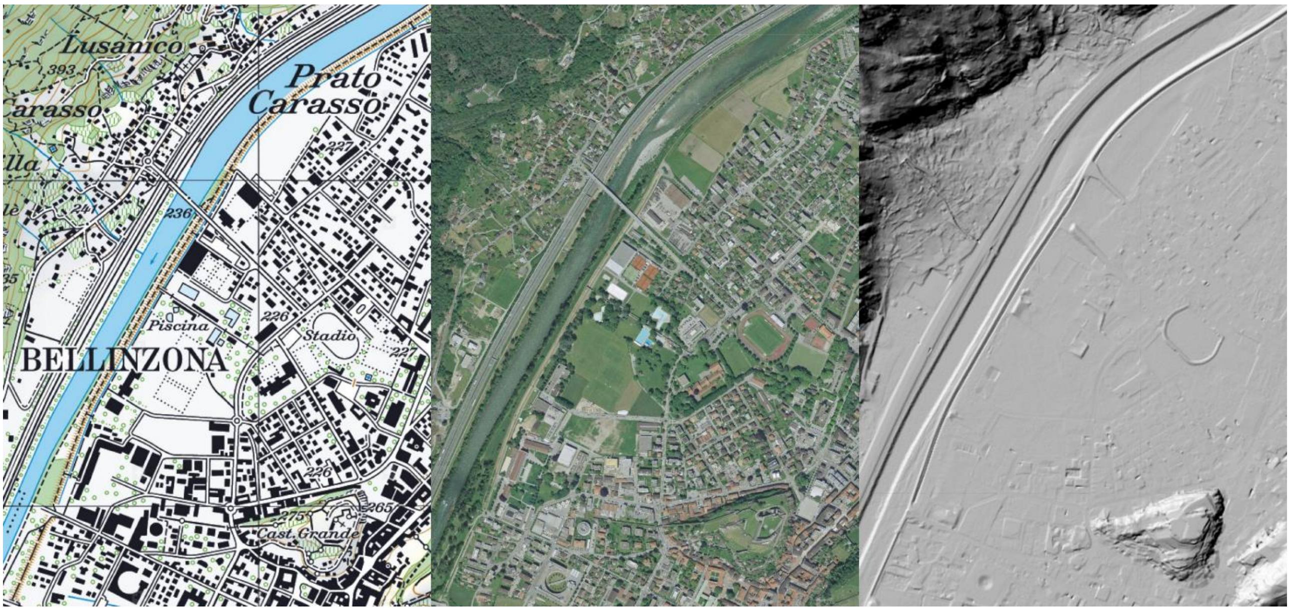


Figure 1 - Example of GIS-data of the same area: pixel map (left), orthophoto (center) und DEM with hillshade (right) (source: swisstopo.ch).

2.2.1 Pixel maps (geotiff/jpg/...)

Pixel maps are digital georeferenced maps in pixel format. Each pixel contains both image information (i.e. surface coverage) and spatial position (X-/Y-coordinate).

2.2.2 Orthophotos (geotiff/jpg/...)

An orthophoto is a digital georeferenced aerial photograph. The orthophoto is usually more accurate and easier to use than pixel cards and is therefore to be preferred.

2.3 DIGITAL ELEVATION MODELS

Digital elevation models are georeferenced files, with in addition a Z-coordinate for the third dimension (altitude). You therefore have both longitude, latitude and altitude information. Basically, a distinction is made between a digital terrain model (DEM) and a digital surface model (DOM).

2.3.1 DEM

The DEM (Digital Elevation Model) describes the terrain surface / water surface without vegetation or anthropogenic buildings. The DEM is usually used for representations such as the steepness of the terrain

2.3.2 DOM

The DOM (Digital Surface Model) also describes the terrain surface / water surface. In contrast to the DEM, however, the anthropogenic buildings and vegetation surfaces are recorded in the DOM. The use of the DOM is particularly useful for the representation of areas in which anthropogenic buildings dominate.

2.3 MPT GEOREFERENCED DOCUMENTS

Geo-referenced MPT documents (*m_map* and *m_photo*, siehe chap. 4.3) are raster data that allowing to determine the three-dimensional coordinates of each point of the image.

2.3.1 Map file (**.m_map*)

The *m_map* format consists of already georeferenced files (pixel maps and/or orthophotos) with planar coordinates (*\map*) combined with the DEM (*\dtm*).

2.3.2 Photo file (**.m_ photo*)

The *m_photo* format contains the link to the georeferenced oblique image (\ *img*), the calibration data (**.cmr* file) and the DEM (\ *dtm*).

2.4 MPT DATA DOCUMENTS

The MPT data documents (*m_data* and *shp*) are three-dimensional, vector GIS elements that are defined or processed by the user.

2.4.1 MPT-specific data documents (**.m_data*)

In this monoplotting format *m_data* all *geofeature* such as polygons, polylines, points and heights can be created, imported / exported, measured and stored. Unlike traditional *shp* data formats, such elements can be created, edited and stored in the same file.

2.4.2 ESRI shapefile (**.shp*)

Conventional ESRI shapefiles (X, Y, Z coordinates) can represent polygons, polylines, and points. Unlike *m_data* formats, an ESRI shapefile contains only on type of geographic element. Shape files can only be used in the MPT if they also have the Z-coordinate.

3 FOLDER STRUCTURE

This chapter describes the folder structure in which the software should be organized. This is a suggested but not the only possible way to organize the data.

3.1 GENERAL DESCRIPTION

The folder structure provided by the software consists of a *MPT data workspace*, which is the main folder for all monoplotting projects and documents (see chapter 4). The GIS main folder contains the project folder, which is thematically subdivided into the folders data, dtm, img and map. In Table 1 - Suggested MPT data structure.

, this structure is presented with a brief description, while die Figure 2 illustrates the composition of the Monoplotting file formats discussed in more detail in chapter 5.

3.2 RECOMMENDED PATHS

In the MPT, the data structure can basically be defined by any user as desired. However, we recommend using the data structure listed here to organize the data according to their origin and characteristic.

Workspace			***Description***	***Data type***
MPT/ MPT data workspace	project folder	.\	MPT georeferenced map documents	m_map
		.\	MPT georeferenzierte photo documents	m_photo
		.\data	MPT 3D vector data documents (points, polygons, polylines and heights), created or imported in MPT	m_data shp
		.\dtm	Digital elevation models (DEM and/or DOM)	tif
		.\map	Georeferenced GIS raster data (maps and/or orthophotos with planar coordinates)	
		.\img	Oblique images to be georeferenced, and corresponding camera calibration data (*.cmr)	tif, png, jpg, ... cmr

Table 1 - Suggested MPT data structure.

3.2.1 <MPT data workspace>

Data is stored relative to the project folder, if it is under this folder; otherwise they are stored relative to the *MPT data workspace*, so that the MPT projects can easily be exchanged between different users and computers.

In Figure 2 shows the recommended structures and their contents.

3.2.2 <project>

The project folder contains project data such as the MPT georeferenced basic documents (*m_map* and *m_photo*) and the data documents (*m_data* e *shp*). In this folder the subfolders with the MPT data documents and the GIS basic data are:

3.2.2.1 data

Folder with user data documents (*m_data* and *shp*).

3.2.2.2 dtm

Folder with the project's Digital elevation models (usually a DEM in TIF format).

3.2.2.3 map

Folder containing the raster maps used in the project (usually small files with pixel maps). Larger files such as orthophotos can be stored in the central folder so that you can access them from multiple projects without having to copy them to the respective project folder each time.

3.2.2.4 img

Folder with oblique images used in *m_photo*; If you work with several images at the same time, we recommend saving each image in a separate folder.

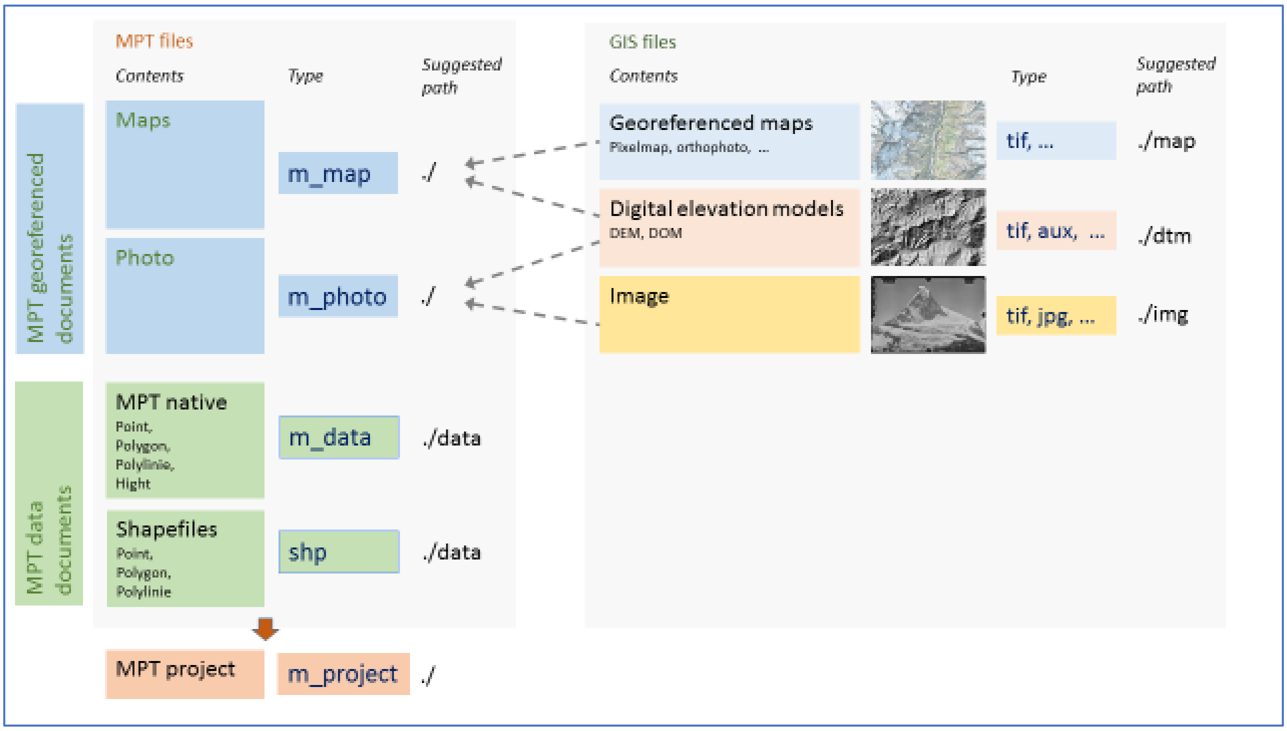


Figure 2 - MPT data structure.

4. MPT BASIC USAGE

The documents used in an MPT project are stored in project files (**.m_project*); reopening a project the documents are restored in the position corresponding to the last save.

In a project, you can basically use any number of documents (the limit is set by the hardware used). All documents can also be used in other MPT projects.

In this chapter we explain the basic usage, i.e. managing and using geo-referenced geographical documents, already calibrated in the MPT (*m_maps* and *m_photos*). The creation and georeferencing/calibration of these documents are explained in chapters 5 und 6.

4.1 THE MAIN WINDOW

When you start the program, the main window opens.

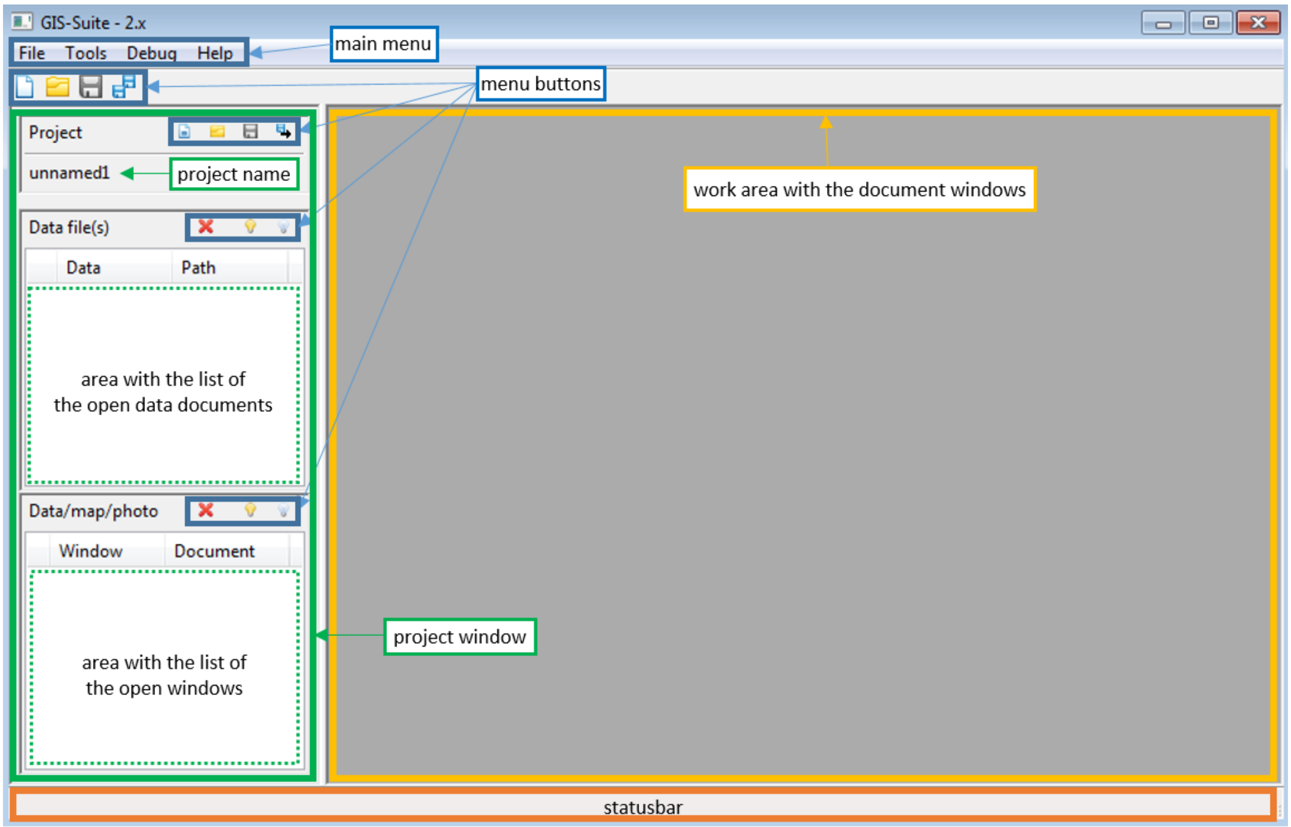


Figure 3 - MPT main window at program start.

4.1.1 Main menu and toolbar

The main menu and the toolbars with the various menu buttons give access to the available commands. The most important commands have their own button, so you do not have to search the command in the different menus.

4.1.2 Statusbar

The status bar shows information about the current state of use of the program (e.g. information about the menu used) or the coordinates corresponding to the current mouse position.

4.1.3 Project window

The project window shows the project name, the list of opened data documents and the list of open windows. There are also the commands for the project management (new/open/save, see 4.5.1).

4.1.4 Work area

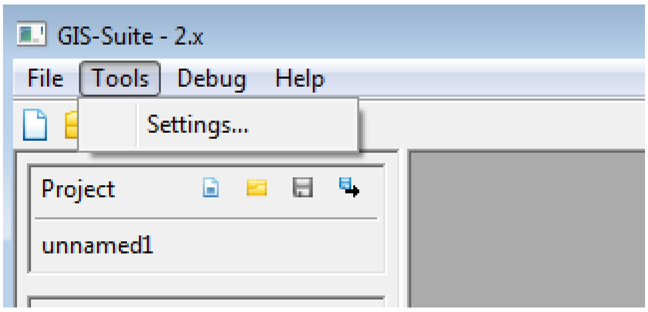
In the work area you find the windows with the current open documents.

4.2 Basic settings

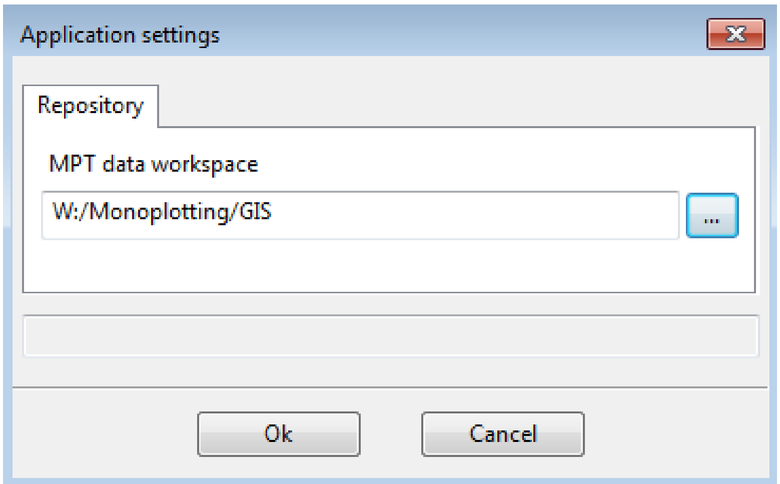
At the first program start, it is important to define some basic configurations.

Currently the *MPT data workspace* is the only needed definition (see chapter 3.2.1).

Go to the menu *Tools->Settings...*:



Select the desired folder and press *Ok*:



4.3 Georeferenced documents

4.3.1 General information

Georeferenced documents are raster data files that contain and deliver geographic information from a particular area consisting in maps (standard GIS maps, *m_map*, see chapter 2.3.1), and image documents (oblique images, *m_photo*, see chapter 2.3.2).

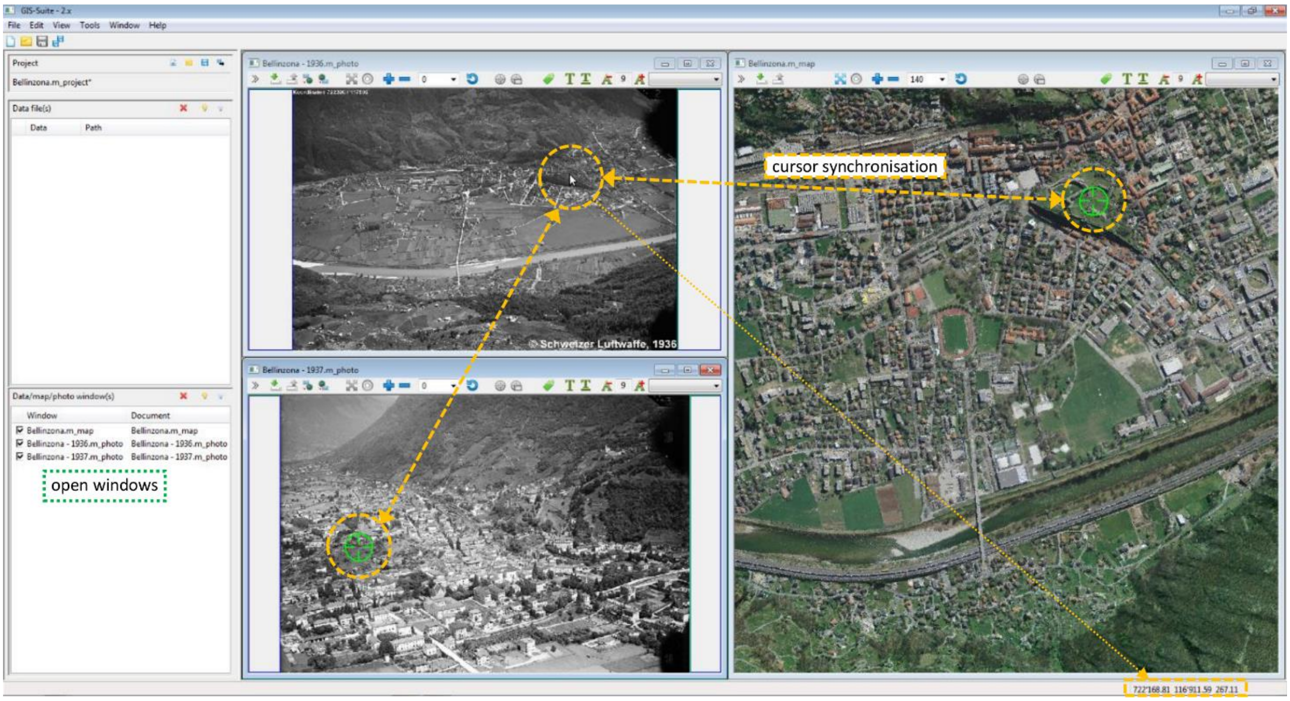


Figure 4 - MPT main window with geo documents: two oblique photographs and an orthophoto.

Map and picture windows can be used in the MPT exactly in the same way as three-dimensional geographic maps. The coordinates corresponding to the mouse position are displayed in the status bar and the corresponding positions are indicated by a green symbol in the other open geo-windows. The only difference between the two types of documents is the ability for image windows to import/export pixel-coordinate data and to convert the data from/to pixel/world coordinates.

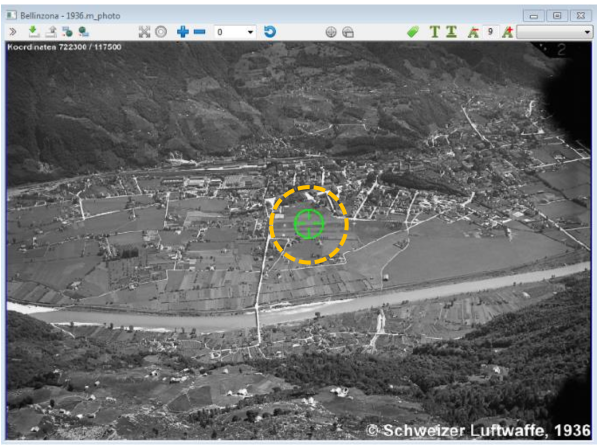
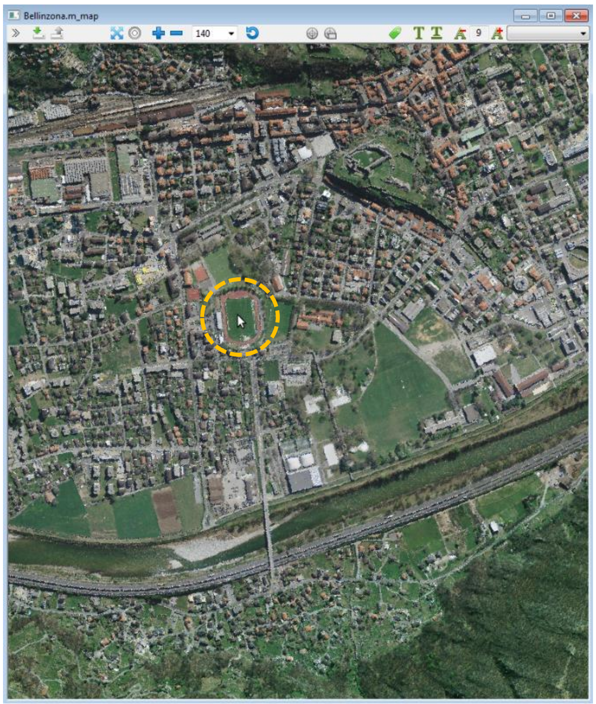
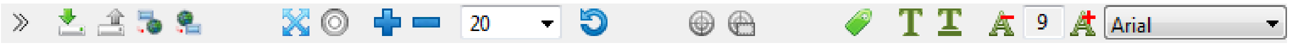


Figure 5 - Oblique photograph and map (orthophoto) windows. The map can be rotated to get the same orientation of the image, which greatly simplifies the comparison between image and map (source: Schweizer Luftwaffe and swisstopo).



4.3.2 Maps/images menu and tool buttons

The following commands are available in the menu and in the corresponding toolbars to work with map and image documents:



- open/close the map/photo definition bar
- import data (see chapter 4.7.3)
- export data (see chapter 4.7.2)
- (*) shapefile pixel to world coordinates conversion
- (*) shapefile world to pixel coordinates conversion
- zoom window to fit the map/photo
- center view
- view zoom in
- view zoom out
- 20 view rotation
- zoom back to the previous view
- fit to all objects
- fit to the selected objects
- show/hide labels (object's name)
- define text foreground color
- define text background color
- 9 font size
- Arial font face

(*) only image windows

4.3.3 Cursor synchronization

Moving the mouse in a (georeferenced) geo-window (maps or image), the corresponding position (if available and visible in the window) in the other georeferenced geo-windows will be displayed with a special green cursor icon (see Figure 4 and Figure 5). The cursor synchronization should help the user to orient himself in the different landscape pictures (also from different ages).

4.4 Data documents

Data documents contain user-defined data. These data can be stored both in the MPT data format (*m_data*, see chapter 2.4.1) or as ESRI shapefiles (*shp*, see chapter 2.4.2). MPT data files can contain all available object types (points, polylines, polygons, heights), while shapefiles can have only one object type (points, or polylines, or polygons).

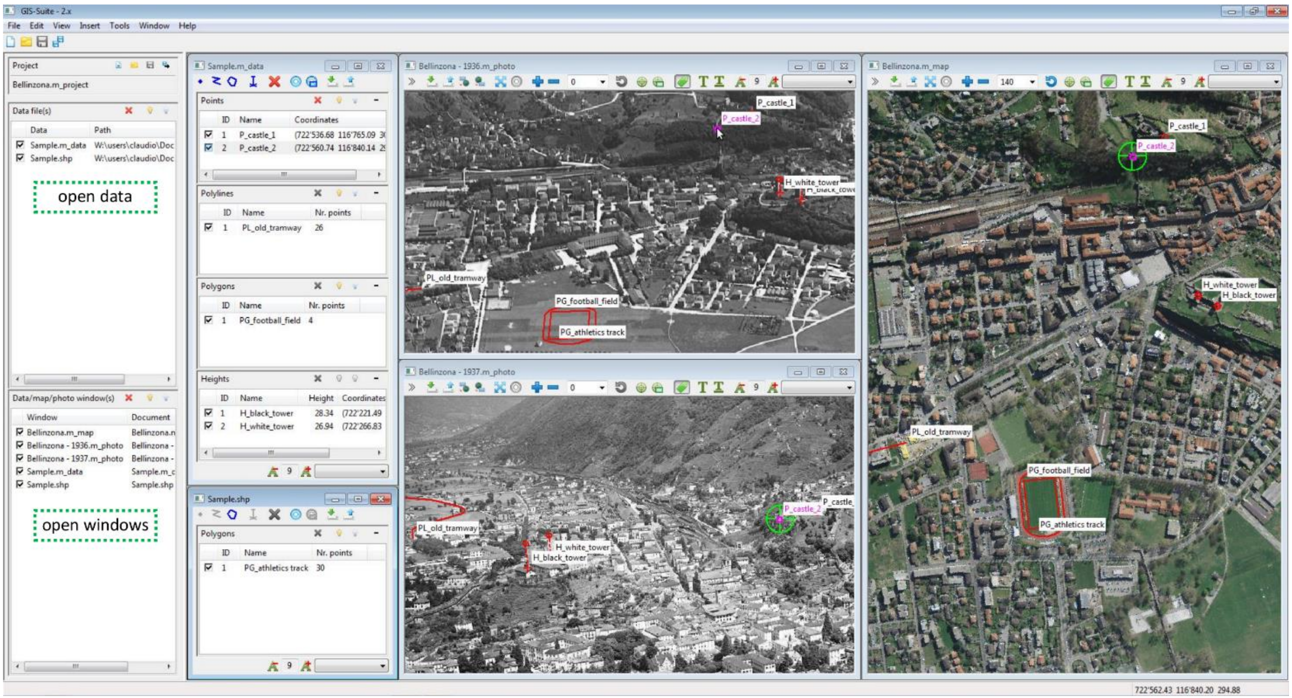
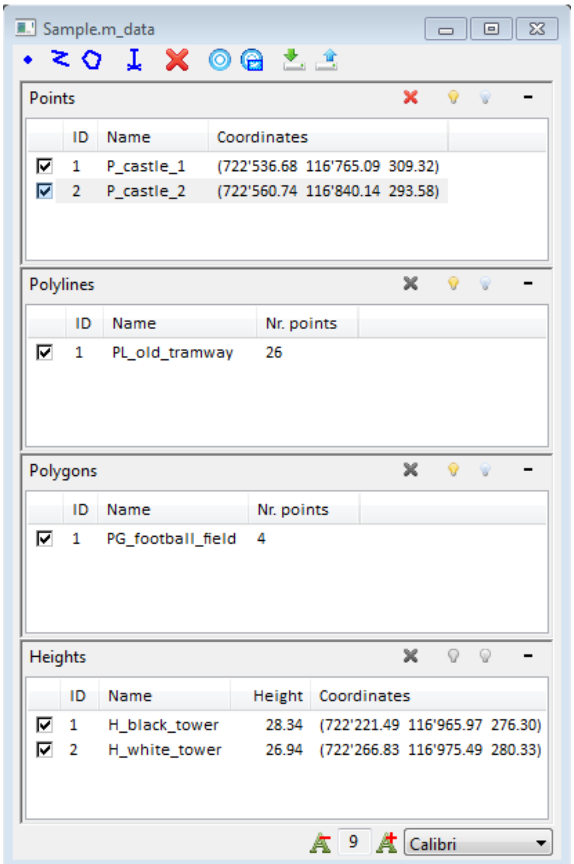


Figure 6 - MPT main window with two historical oblique images, an orthophoto and two user-defined data documents.

4.4.1 Data window

Data window is designed to manage data objects (select, insert, edit, delete). Windows with MPT data format have four sectors for points, polylines, polygons and heights. Shape data windows have only one with the corresponding object type.



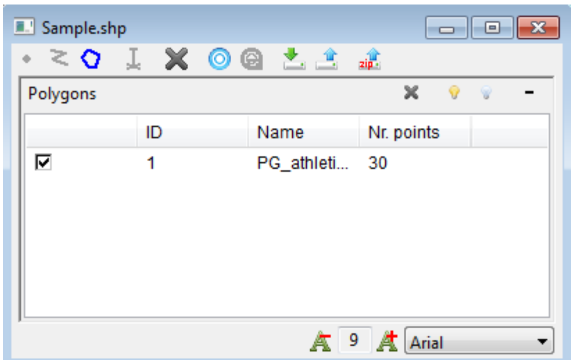


Figure 7 - Data window in MPT data format with objects of all four data types (left), and a shapefile data window with a polygon (right).

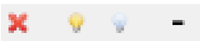
4.4.2 Data **menu and tool buttons**

The following commands are available to work with data documents:

- .... point definition (see 4.6.1)
- .... polyline definition (see 4.6.2)
- .... polygon definition (see 4.6.2)
- .... height definition (see 4.6.3)
- .... delete all selected objects
- .... fit all georeferenced views to all objects
- .... fit all georeferenced views to the selected objects
- .... import data (see 4.7.3)
- .... export data (see 4.7.2)
- export data in zip archive, nur shapefiles (siehe 4.7.2)

- 9 .... font size
- Calibri ...... font face

The commands in the small toolbars apply only to the objects of the corresponding section:



- .... delete the selected objects in the section
- .... show the selected objects in the section
- .... hide the selected objects in the section
- − / + ... hide/show the section

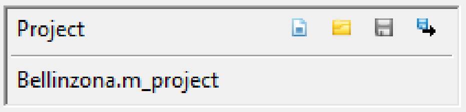
4.5 Data Management

MPT sessions are based on projects. Starting a session, the program opens a new project by default. You can work in the new project or open existing projects and continue working there. Closing the program, the user will be asked to save the data, if not already done. Project and data can be saved at any time.

Projects allow the user to retrieve the data and documents of a new working session in the same way as they were saved in the last session. Documents can be saved individually or with the *save all* command.

4.5.1 Project management

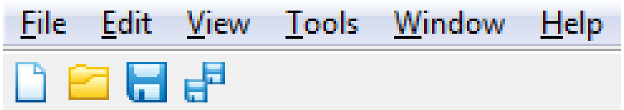
Projects are managed using the small toolbar of the project windows:



- .... create a new empty project
- .... open an existing project
- .... save the current project
- .... save the current project with a new name

4.5.2 Document management

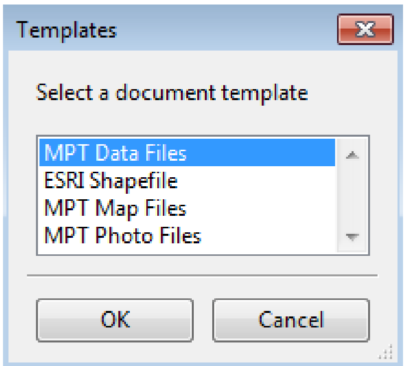
Documents are managed with the commands in the main toolbar or with the corresponding menus. The possible actions are:

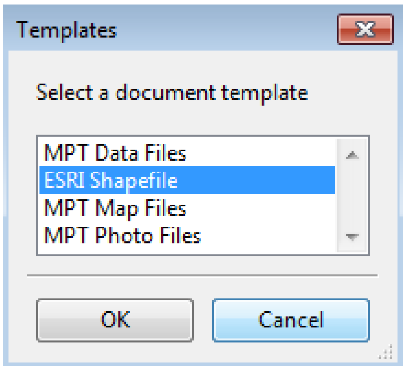


- .... create a new empty document
- .... open an existing document
- .... save the active document
- .... save all: project and documents

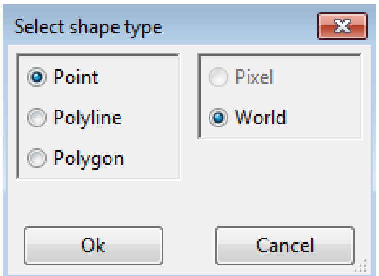
4.5.2.1 *New document*

To create a new, blank document, the user must choose between the available templates:





Choosing ESRI shapefile, also the shapefile type has to be specified:



4.5.2.2 *Open document*

To open documents, you first have to select the desired document type and then open the corresponding file:

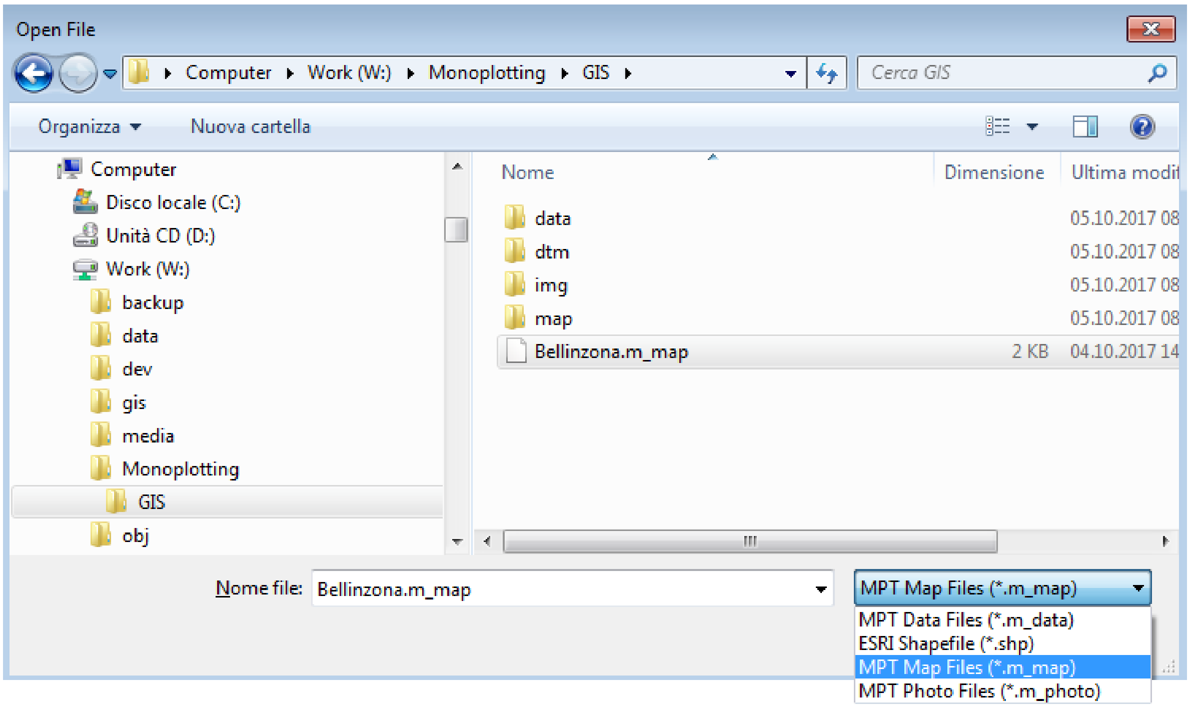


Figure 8 - MPT open document.

The document opens with the same position and settings as it was saved.

4.5.2.3 Save document (as)

The *Save* menu or button is used to save the document. The *Save as ...* option, which is only available in the menu, is used to save the document with a different name

4.5.2.4 Save all

Save all will save both project and any open document; when there are new, unnamed documents, the user is prompted for naming them.

4.6 GIS EDITOR

MPT provides a very simple GIS editor. This allows you to define or change GIS objects (points, polylines and polygons).

On oblique images you can additionally compute the height of the objects (houses, trees).

Within the MPT, each object has an ID and a name, which are assigned automatically during the object definition. The user can change these at any time.

4.6.1 Point definition

The *point* menu button in the data window toolbar, opens the point editor. The point can be defined with a mouse-click in a geo-window or by typing in the coordinates from the keyboard.

In *Quick mode*, a new point is defined on every click. Otherwise, the point definition must be confirmed each time with the *Apply* command.

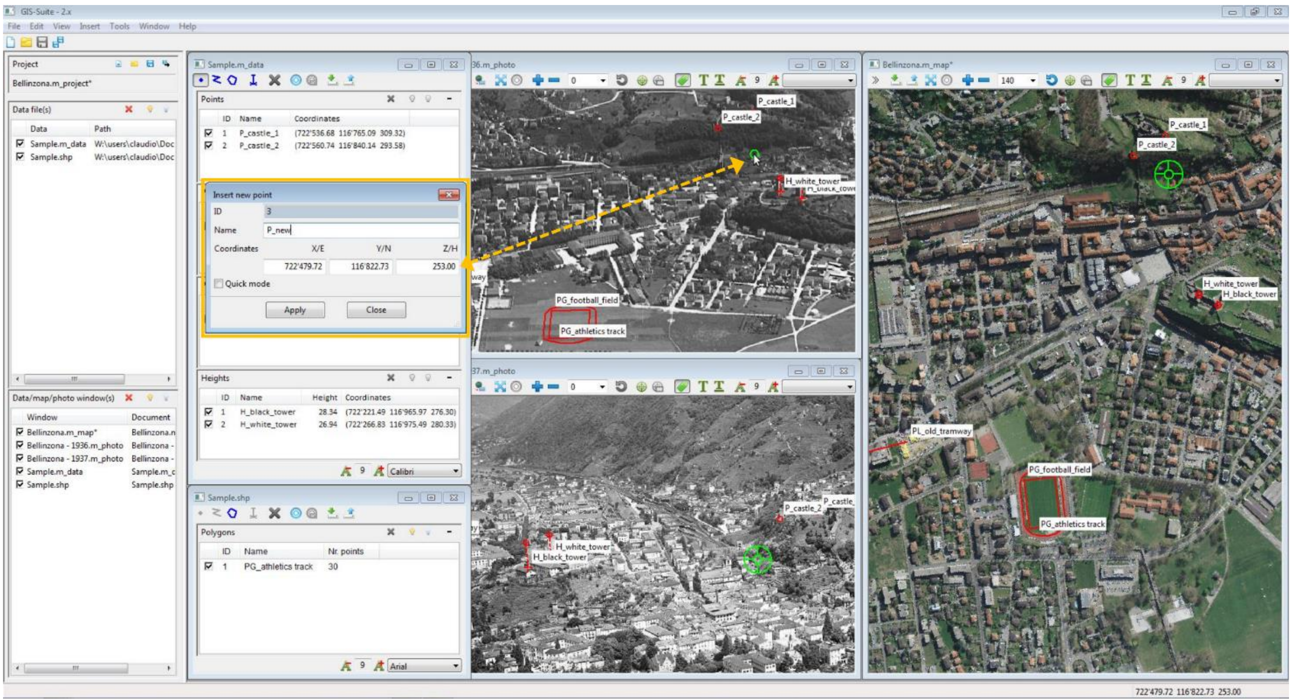
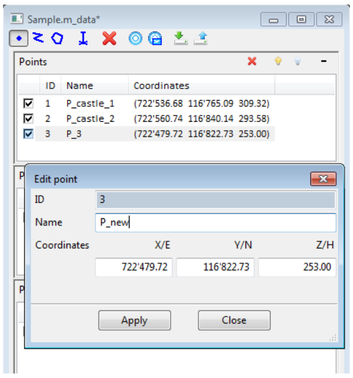


Figure 9 - GIS editor: point definition.

To edit existing points, you have to double-click in the corresponding section of the data window. This opens the point editor and the point can be modified with a mouse click in the corresponding geo-window and dragging the point in the new position or by typing in the new coordinates on the keyboard

Changes must be confirmed clicking the *Apply* button.



4.6.2 Polyline and polygon definition

The *polyline* or *polygon* menu buttons in the data window toolbar, opens the corresponding editor. The procedure for defining these objects is the same. There is only one simple difference between the two objects: polylines are open, while polygons are closed.

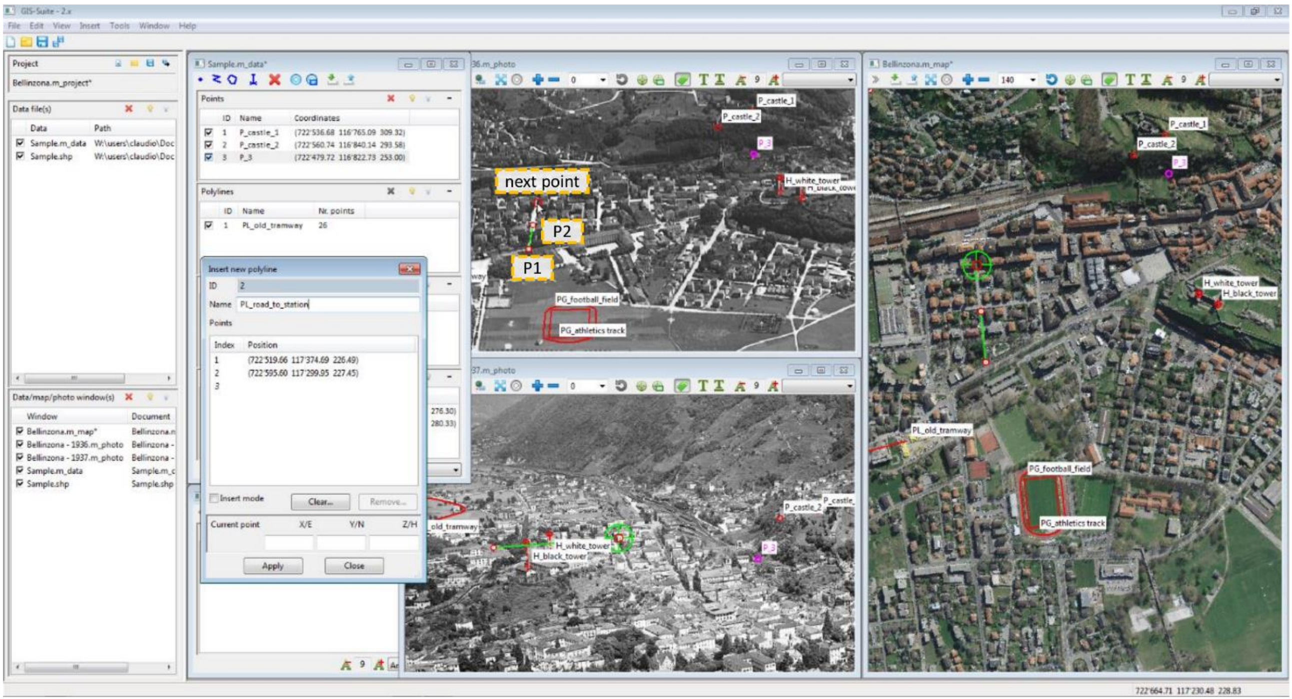
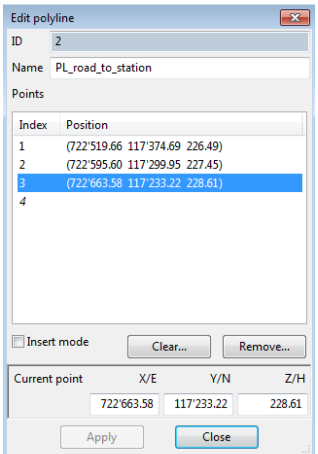


Figure 10 - GIS Editor: polylines and polygons definition.

If no point of the object is selected, each mouse click in a geo window appends a new point to the polyline/polygon. When a point is selected and the *Insert mode* is not active, the mouse click changes the coordinates of the corresponding point; if *Insert mode* is active, a new point is inserted before the selected point.

In order to modify an existing polyline/polygon, you must first open the editor by double-clicking it in the corresponding data window. The objects can then be modified by point selections, by activating/deactivating *Insert mode*, by using the command *Clear...* (delete all points) or *Remove...* (delete only the selected points). To modify the selected point, you can enter the new coordinates from the keyboard or by clicking on a geo window.

Changes must be confirmed clicking the *Apply* button.



4.6.3 Height definition

The *height* menu button in the data window toolbar, opens the height editor. A height object consists of an origin (the bottom point on the terrain) and a number that corresponds to the height of the object. The origin must be defined first, followed by the top of the object to be measured.

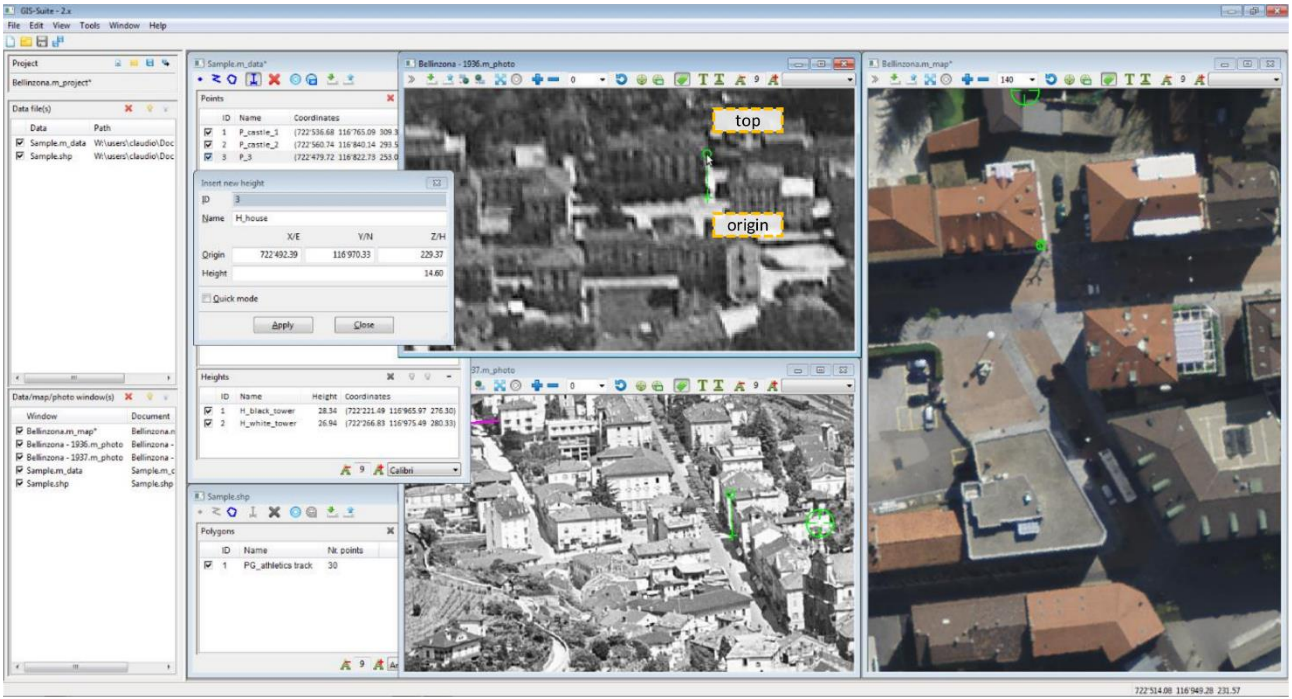
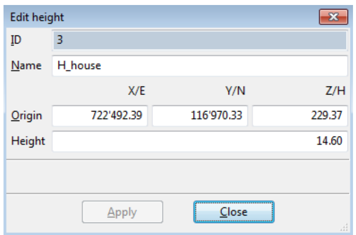


Figure 11 - GIS editor: height definition.

The origin can be defined on any geo document (*m_map* or *m_photo*) where the object to be measured is visible. The top, on the other hand, can only be defined on a oblique images (*m_photo*).



To edit a height just double-clicking it in the corresponding data window, to open the height editor. To change the height, the new data (origin and/or top) can be entered from the keyboard or by clicking with the mouse on the origin or the top of the object and pushing it to the desired position.

Changes must be confirmed clicking the *Apply* button.

4.7 Data exchange

Data exchange can be achieved in CSV or SHP format, which allows the import and export of GIS objects from and to most GIS software (ArcGIS, Q-GIS, ...). Such data import or export can be done in any document window: in image documents, data exchange can take place both as pixels and as world coordinates; in map documents, only as world coordinates.

4.7.1 Pixel coordinates

Software managing data in pixel coordinates uses different data formats. These are briefly presented here before going to the actual data exchange procedure.

Following pixel coordinates formats are used (in brackets the MPT name).

4.7.1.1 GIS pixel coordinates (pix_y_minus)

Origin is top left, positive X-axis goes to the right, negative Y-axis goes down.

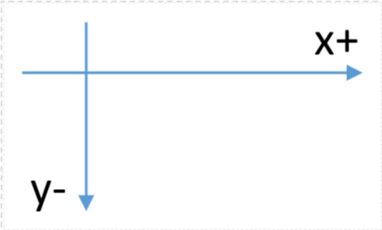


Figure 12 - GIS pixel coordinates (ArcGIS, Q-GIS).

4.7.1.2 Windows coordinates (pix_y_plus)

The origin top left, positive X-axis goes to the right, positive Y-axis goes down.

Figure 13 - Window pixel coordinates (Photoshop, …).

4.7.1.3 Standard coordinates (pix_y)

The origin is lower left, positive X-axis goes to the right, positive Y-axis goes up.

Figure 14 - Standard pixel coordinates.

4.7.2 Data export

The *Export* menu/button (see 4.3.2 and 4.4.2) allows exporting of objects; if one or more objects are selected, in the dialog box you have to specify whether only the selected files or all should be exported.

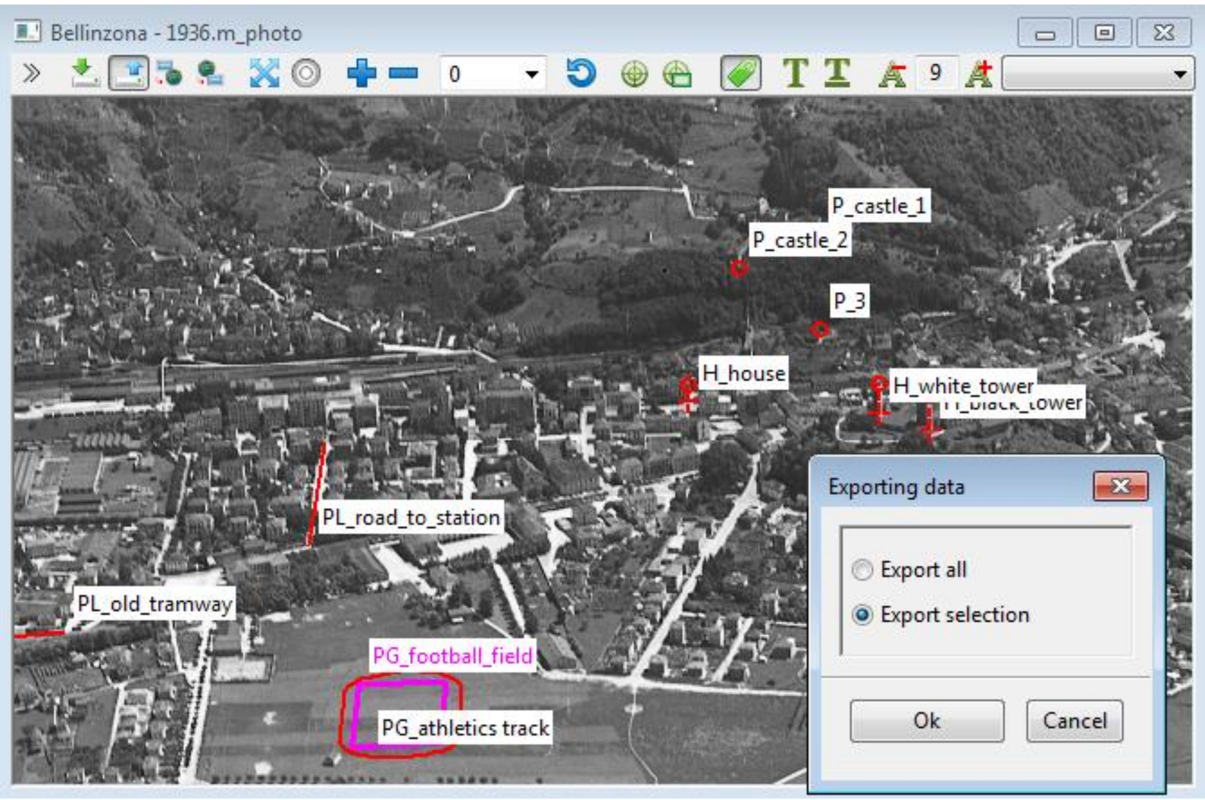


Figure 15 - Dialog to specify the objects to export.

Then the export dialog window opens:

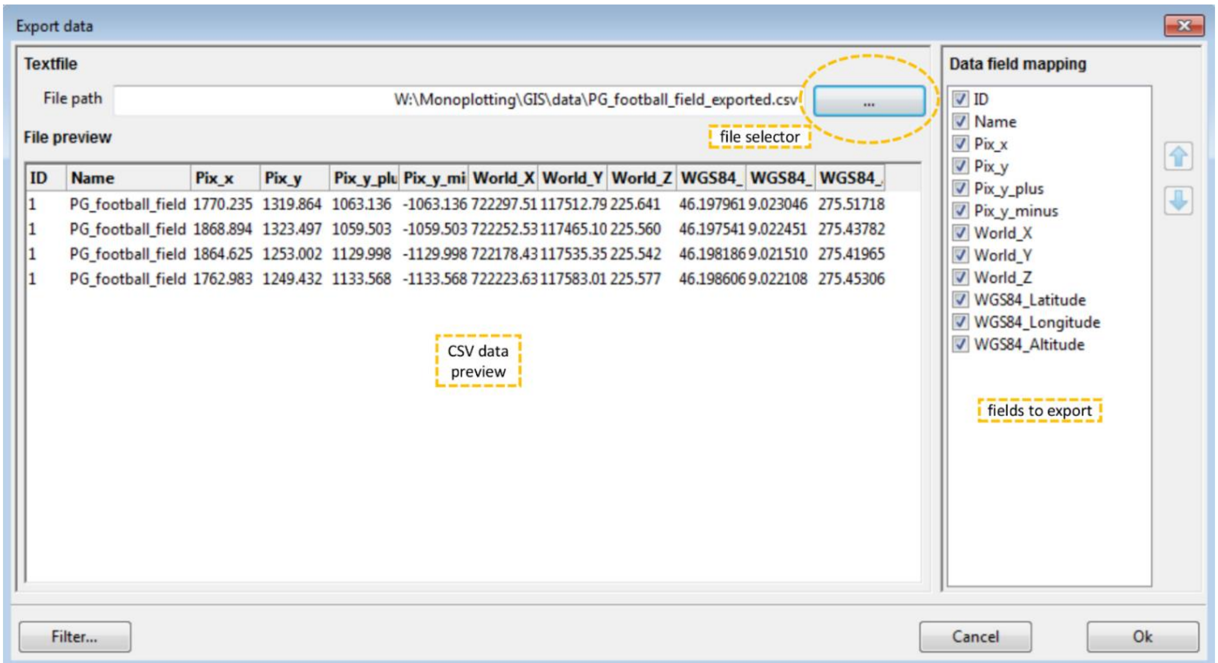


Figure 16 - Export dialog.

With the *File* button you define the target file (Figure 16). In the lower window, a preview of the data to be exported appears, while in the right window, the fields to be exported can be selected. Please note that pixel coordinates are only available for image documents.

Objects have unique IDs. Points from the same polylines or polygons have the same IDs to be recognized as belonging to the same object in the CVS target file.

4.7.2.1 CSV export

Exporting to CSV files, the *Filter...* button opens a dialog box with CSV settings for the corresponding target file (Figure 17). Defining the first line as header (*Use first line as header*) and the separator (*Field separator*) are the most important settings.

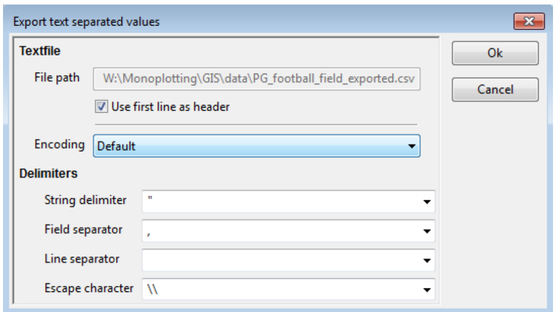


Figure 17 - CSV data export settings.

4.7.2.2 SHP export

Exporting to SHP file, a corresponding shapefile is created with the selected objects and fields. If exporting from an image window, you must also specify whether the target shapefile must be created in pixel or world coordinates.

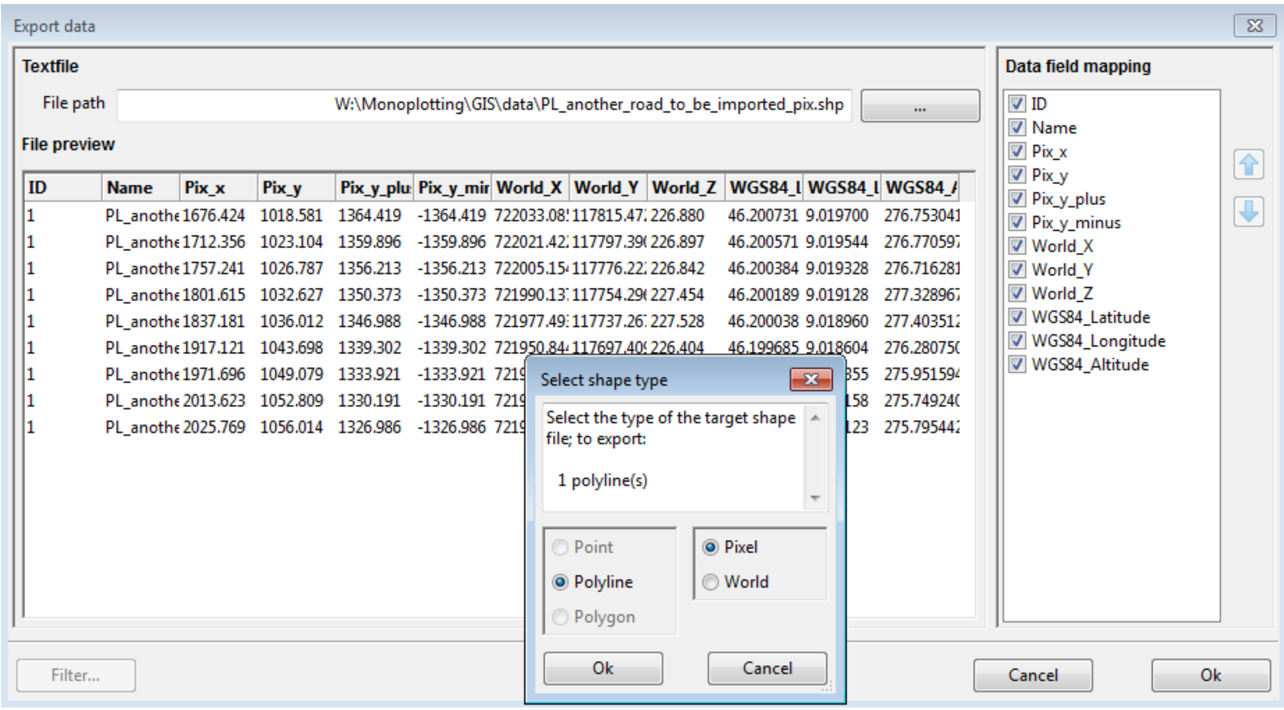


Figure 18 - Export to Shapefile.

4.7.2.3 ZIP export (only shapefiles)

It is possible to export shapefiles in a ZIP archive; this is useful for many applications.

4.7.3 Data import

Data can only be imported if a destination file is open in the MPT. To import data, the target file must be first created or opened.

There are two types of data import that match the available data formats:

- pixel data import, only available in image windows
- world data import, available in all (image and map) windows

World coordinates can be imported in two or three dimensions: when the file to be imported does not contain a z-coordinate, the import process will automatically compute it.

4.7.3.1 CSV import in pixel coordinates

In order to correctly import pixel coordinates from CSV files, you have to specify the corresponding *X* and *Y* coordinate fields in the source file, to get the correct representation of the *y* field (see 4.7.1). In the case of polylines and polygons, the ID must also be specified, so that the points of different objects can be clearly distinguished.

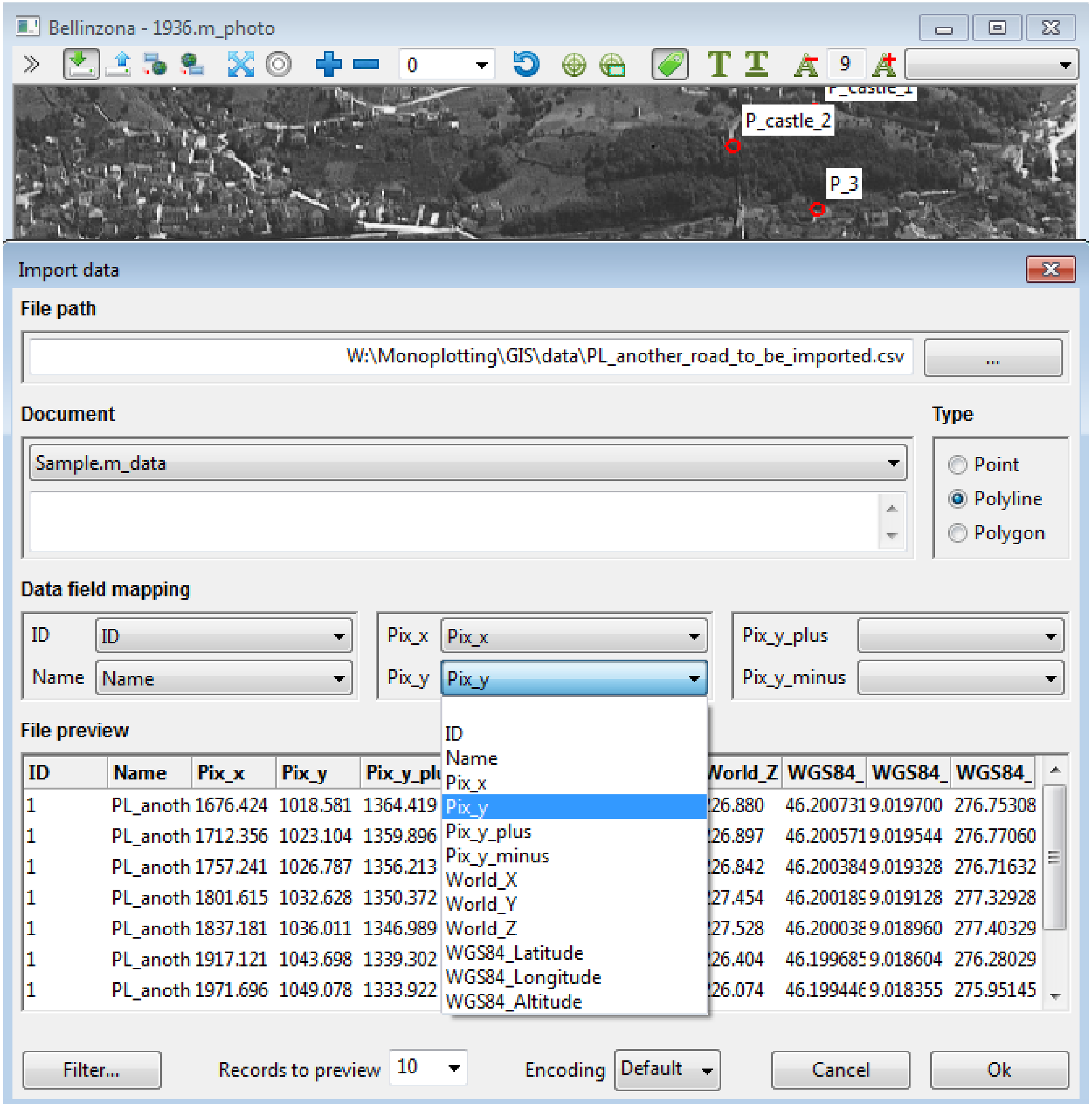


Figure 19 - CSV data import in pixel coordinates.

4.7.3.2 *SHP import in pixel coordinates*

To import a SHP file in pixel coordinates, make sure that the source file is also in pixel coordinates. When so, the *X* and *Y* coordinates are automatically assigned.

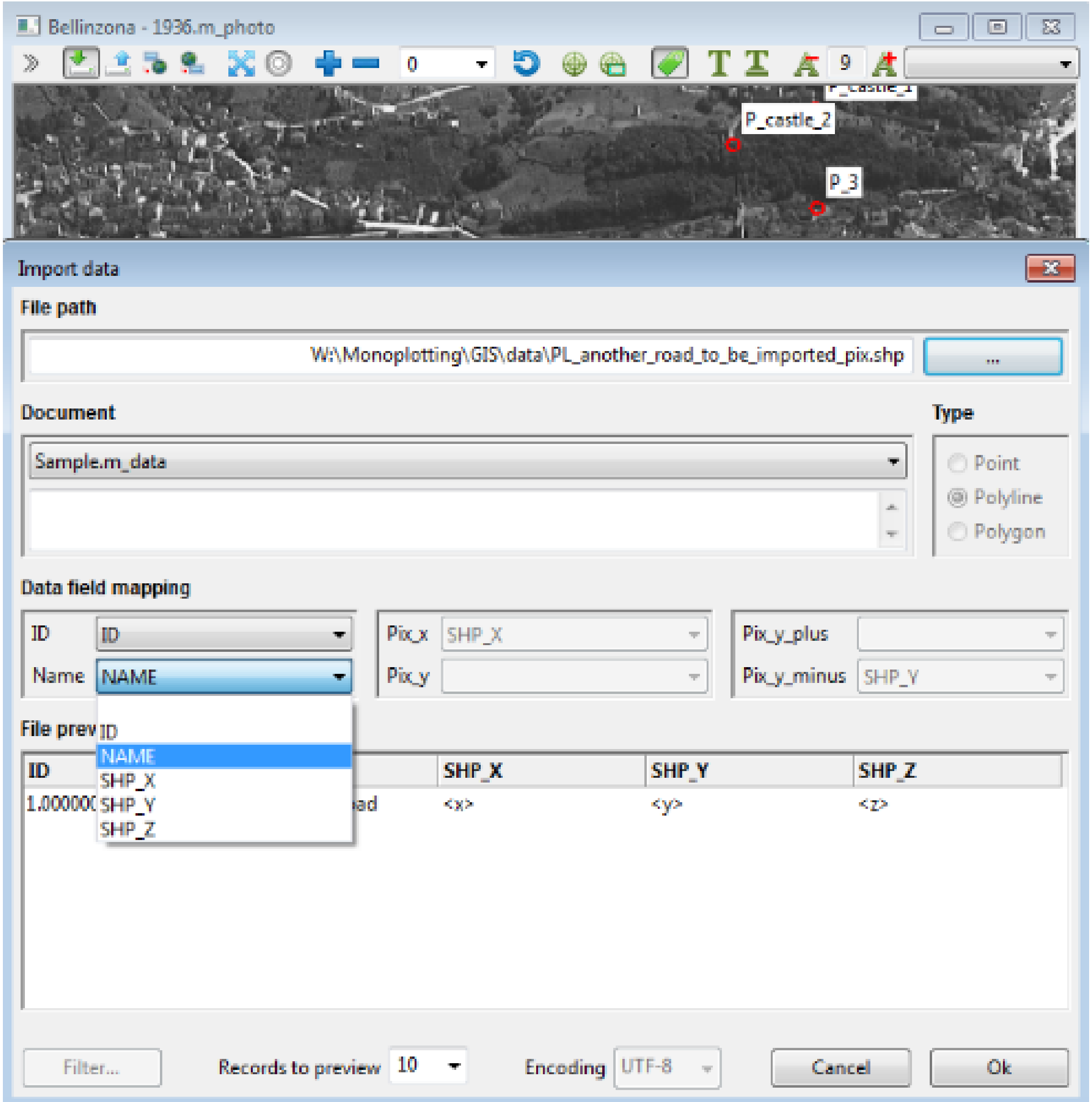


Figure 20 - SHP data import in pixel coordinates.

4.7.3.3 CSV import in world coordinates

To correctly import world coordinates from CSV files, you must specify the corresponding *X* and *Y* coordinate fields in the source file. When the source file contains a correct *Z* coordinates, the corresponding fields can be specified. Otherwise, the *Z* coordinate will be computed by the MPT directly during import.

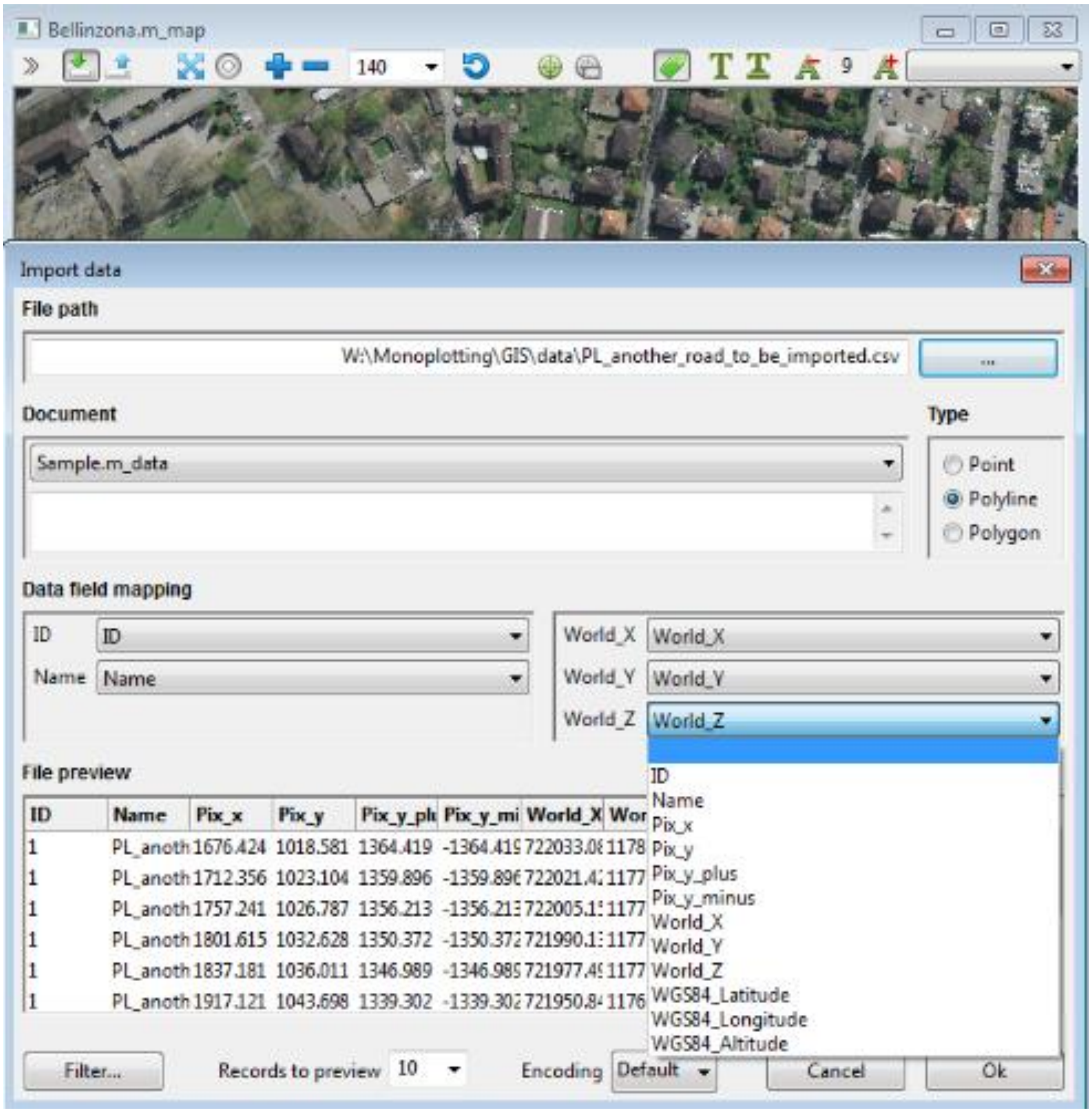


Figure 21 - CSV data import in world coordinates.

4.7.3.4 SHP import in world coordinates

To import a SHP file in world coordinates, you have to make sure that the source file is also in world coordinates. When so, the *X* and *Y* coordinates are automatically assigned. You can assign an existing *Z* coordinate to the corresponding fields or let the MPT calculate the *Z* coordinate automatically during import.

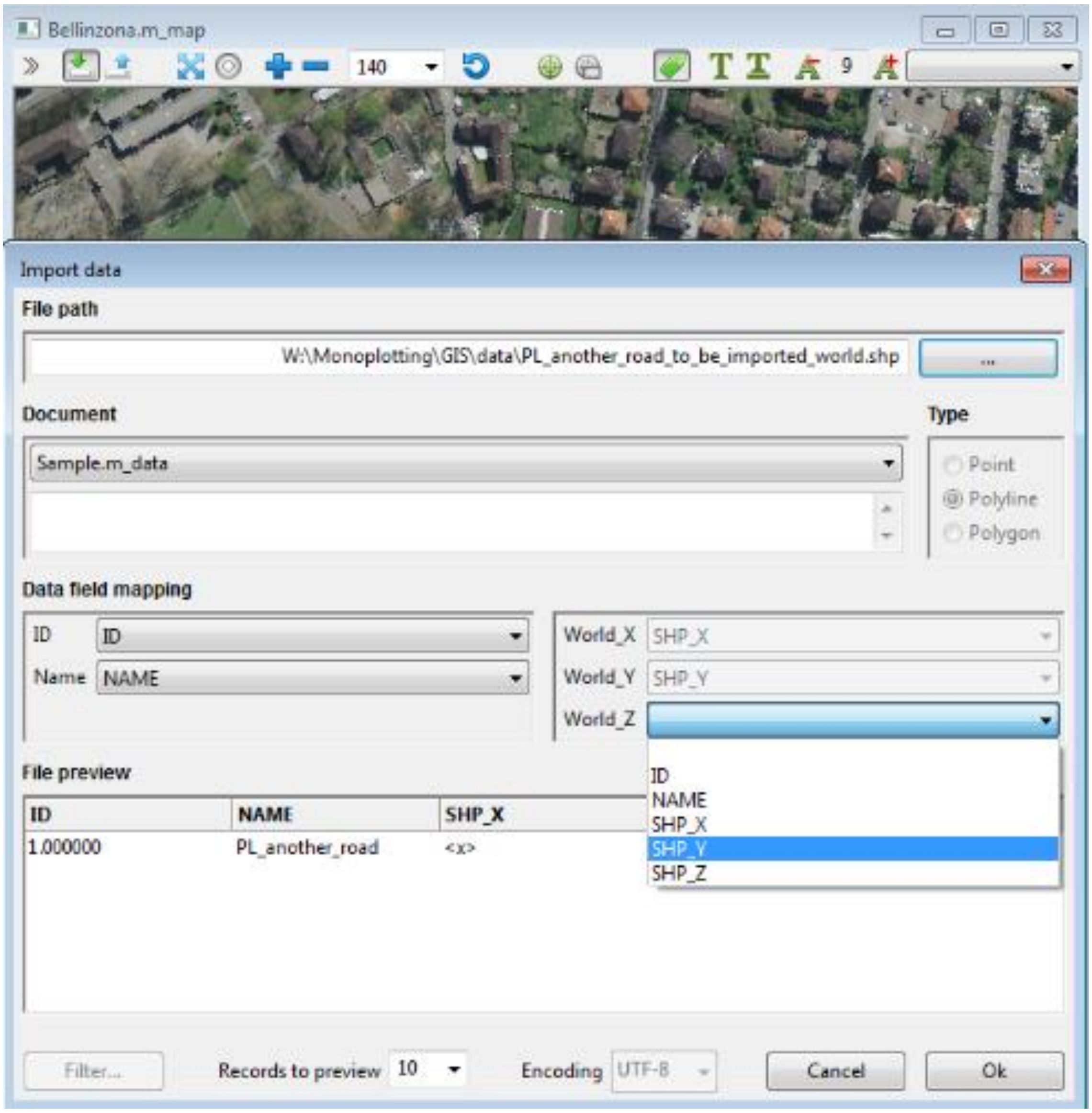


Figure 22 - SHP data import in world coordinates.

4.8 SHAPEFILE: FROM PIXEL COORDINATES TO WORLD COORDINATES

In image windows, pixel coordinates can be converted to world coordinates and vice versa. It is important to specify the correct coordinate system for the files in pixel coordinates (see 4.7.1).

4.8.1 From pixel to world coordinates

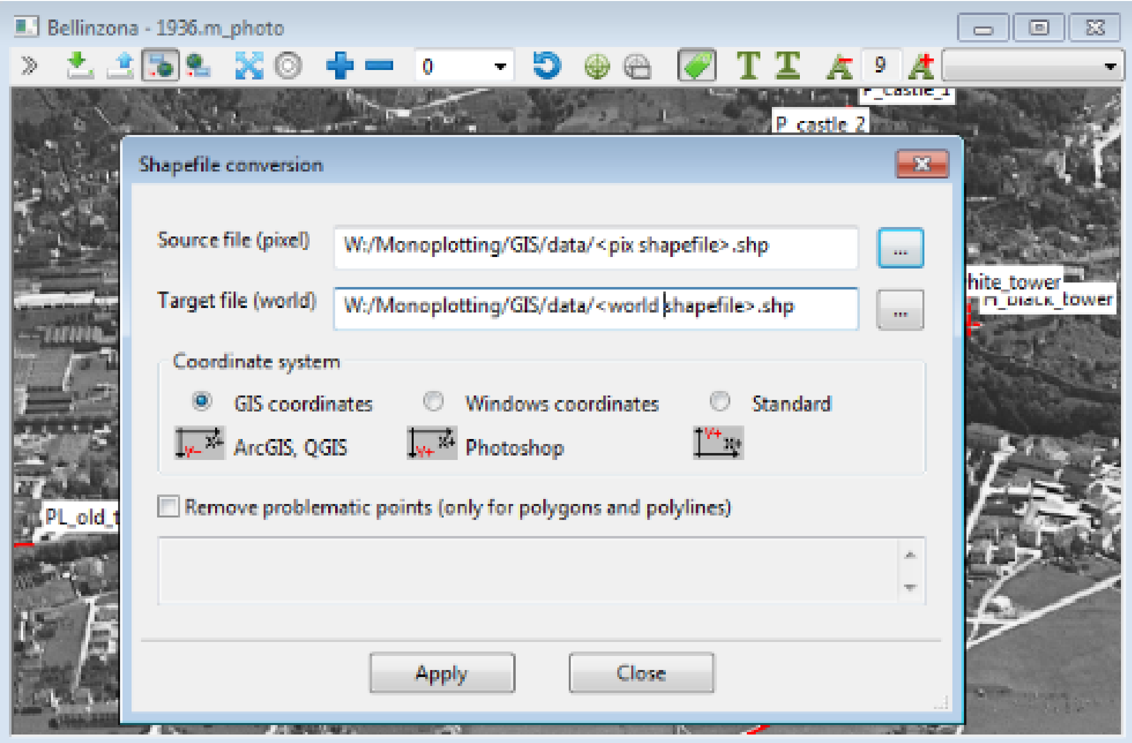


Figure 23 - Shapefile: transforming pixel to world coordinates.

4.8.2 From world to pixel coordinates

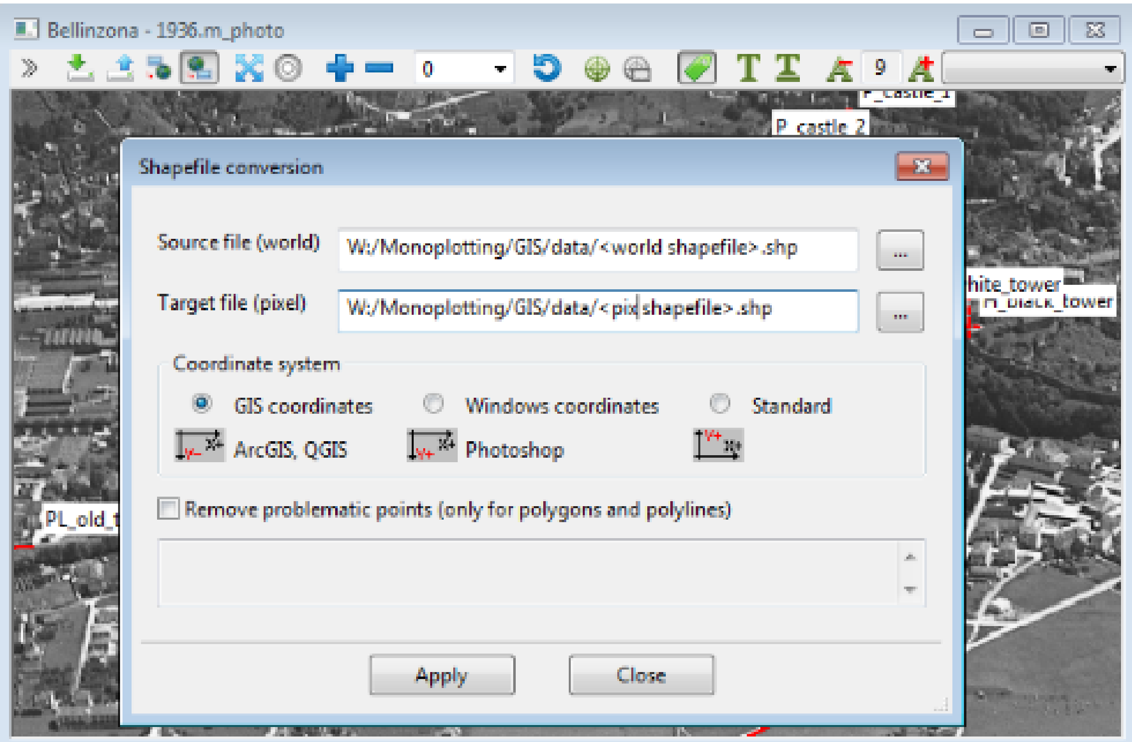


Figure 24 - Shapefile: transforming world to pixel coordinates.

5. SETUP OF GEOREFERENCED DOCUMENTS

This chapter explains the procedures for preparing and configuring geo documents (maps and images) based on GIS standard data. After the setup, the documents are ready to be used in the MPT.

To configure a document, first activate the *control bar* of the map or image window must by clicking on the corresponding menu or menu button (see 4.3.2). The *Info window* in the lower part of the control bar shows the current document status, the cursor (mouse) position, and is mainly used during the software development.

5.1 MAP DEFINITION

A map document consists of one or more GIS standard raster maps (see 2.2) and one or more DEMs (see 2.3). Combining this data, allows obtaining three-dimensional information about the represented area.

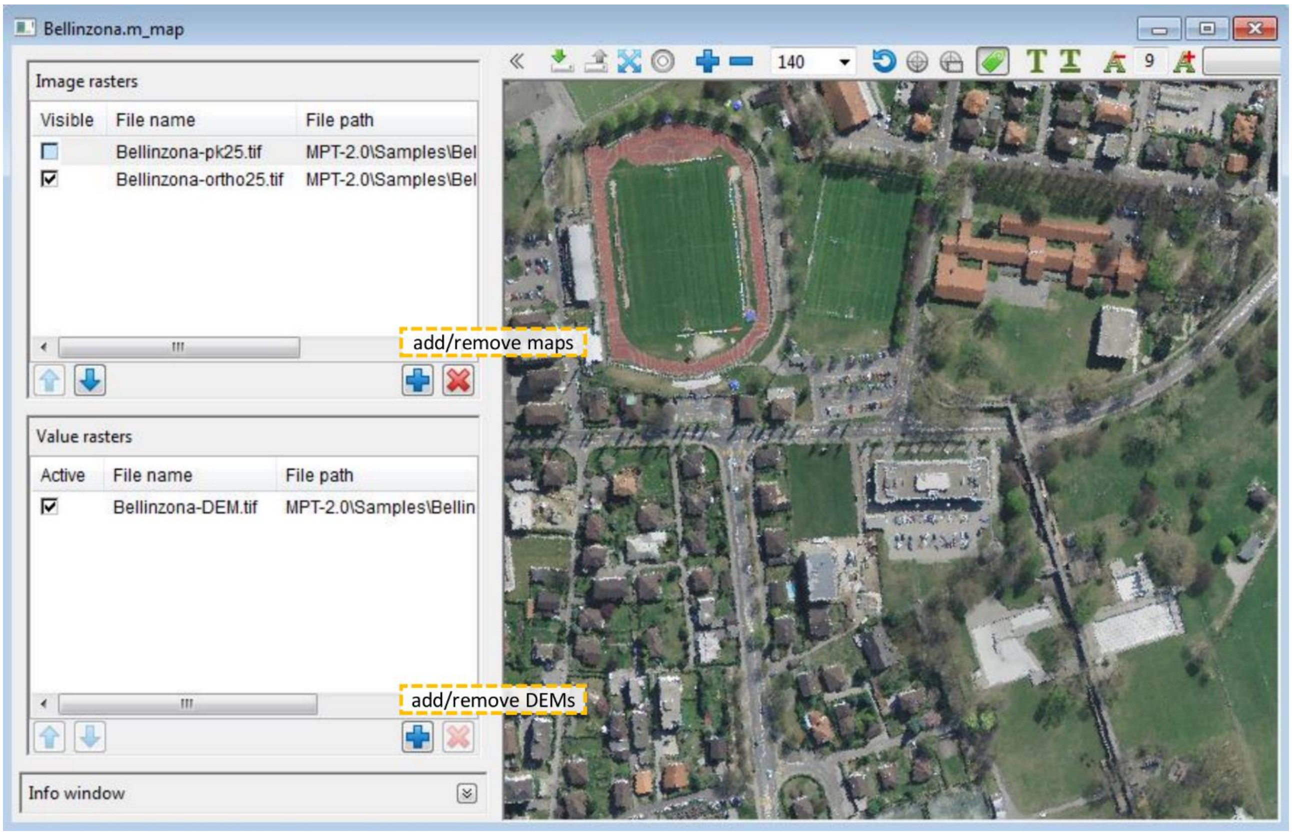


Figure 25 - Map document definition.

5.1.1 Raster map file(s) definition

To insert (or remove) a raster map, press the corresponding button in the *Image raster* section. Raster maps are automatically placed in the correct position and can be shown or hidden by clicking the corresponding checkbox. The position in the list indicates the display priority of the map.

At this point, moving the cursor over the map, the MPT should automatically display the *X* and *Y* coordinates in the small window at the bottom right of the status bar.

5.1.2 DEM file(s) definition

To insert (or remove) a DEM file, press the corresponding button in the *Value raster* section. DEMs are automatically placed in the correct position and can be activated or deactivated by clicking the corresponding checkbox. The position in the list indicates the priority of the DEM when computing altitudes.

Now, moving the cursor over the map, the MPT should automatically display the *X*, *Y* and *Z* coordinates in the small window at the bottom right of the status bar.

5.2 Photo definition

An image document contains one or more oblique images (normally only one), one or more cameras (usually only one), and one or more DEMs (see 2.3). When the camera is calibrated (see chapter 6), combining this information allows you to get three-dimensional information about the displayed area.

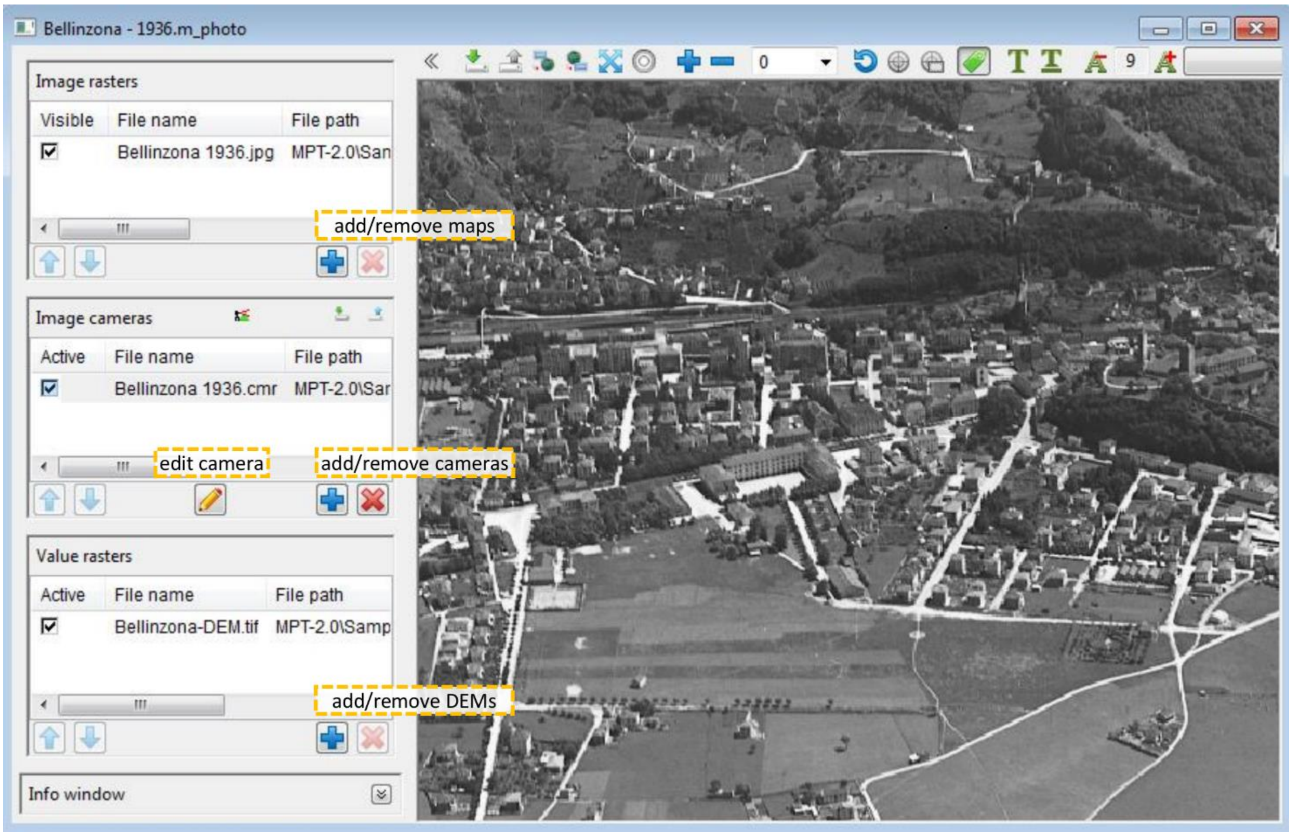


Figure 26 - Photo document definition.

5.2.1 Photo file(s) definition

To insert (or remove) an image, press the corresponding button in the *Image raster* section; the image(s) can be shown or hidden by clicking on the corresponding checkbox. The position in the list indicates the display priority of the image.

5.2.2 DEM file(s) definition

To insert (or remove) a DEM file, press the corresponding button in the *Value raster* section; the DEM(s) can be shown or hidden by clicking on the corresponding checkbox. The position in the list indicates the priority of the DEM when computing altitudes.

5.2.3 Camera(s) definition

To insert (or remove) a camera, press the corresponding button in the *Image cameras* section to open the dialog box:

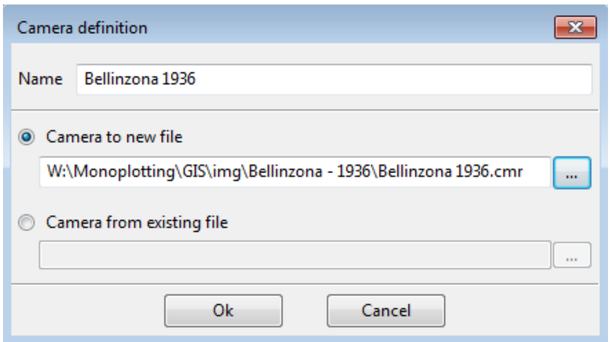


Figure 27 - New camera definition dialog.

Camera parameters, actually a mathematical model of the physical camera, are usually represented in a **.cmr* file with the same name and in the same path as the image itself.

When needed, you can also assign an existing camera to the image. To do this, press the menu button *Camera from existing file* and select the desired camera

After adding the new camera, you can start the calibration procedure (see chapter 6) so that the image document can be used like a three-dimensional map.

The position in the list indicates the priority of the camera.

6. CAMERA CALIBRATION

The camera calibration process tries to reconstruct the mathematical model of the original camera. At least 5 (better some more) control points (see chapter 6.5) and some initialization parameters for the image center, the focal length and the camera position are required. The whole procedure and the necessary data are in the *Camera definition* window.

6.1 Camera definition window

The *Camera definition* window, allowing the camera calibration, is the heart of the MPT and the monoplotting process: in this window you first define the control points and the parameter initial values, and then start the calibration procedure.

Camera definition

Camera name

Camera computed parameters:

origin x
y
z

rotation x
y
z

image center x
y

focal

sense

Camera direction

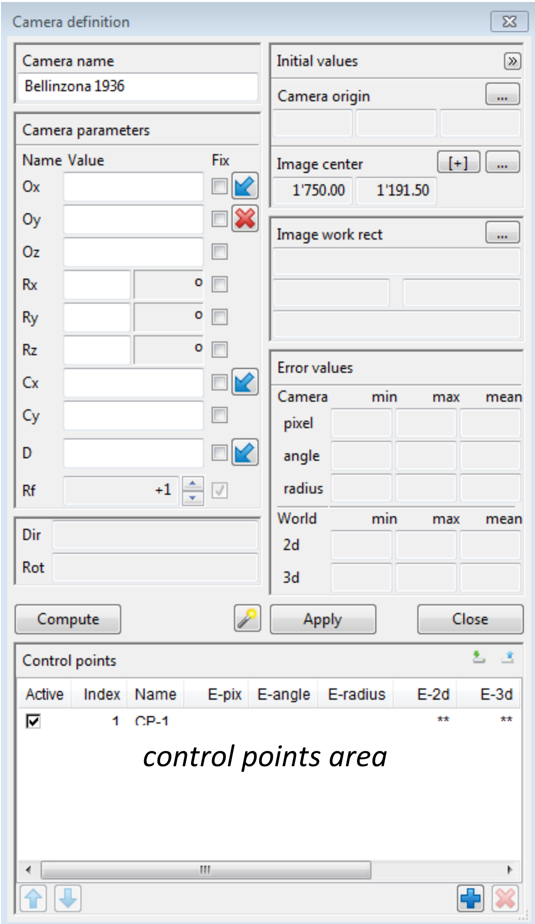
Camera rotation

Buttons:

Compute: calibrate the camera with the given control points and values

Magic compute: to be used when seemingly nothing works…

Apply: apply the changes to the document



Parameter initial values:

camera origin

image center

image work rect

Calibration errors:

pixel errors
angle errors
radius errors

world 2d error
world 3d error

Figure 28 - Camera definition.

Buttons for the parameters definition:

» / «	show/hide the camera manual settings section (see 6.7)
☐ Fix	fix/free, when checked, prevent the parameter to be computed
	copy the initial value(s) to the parameter value
	reset (remove) the camera origin values
…	interactive set the initial value for camera origin and image center
[+]	set the image center (half of width and height) as initial value

Buttons for the control points definition:

 ....import control points (see 6.6)

 ....export control points (see 6.6)

 insert a new control point

 remove the selected control point (s)

6.1.1 Copy of the initialization values

Image center, focal length (focus distance), and camera position default initialization parameters can be copied into the respective fields with the *copy* button to give a first value to the calibration process (see 6.4).

6.1.2 Fix/free parameters

With the corresponding checkbox you can fix the parameter values or leave them free. Free (unchecked) parameters are calculated by the calibration process, while fixed (checked) are considered correct and remain unchanged (see 6.7).

Usually only the image center parameter remains fixed until the end of the calibration procedure. In some cases, this parameter may still be set to free for a final calculation loop to see if the final result improves.

6.1.3 Control points (de)activation

With the corresponding checkboxes each control point can be activated or deactivated. The calibration process considers only activated control points (see 6.7).

6.2 Control points

Control points are points for which both the position on the image (pixel coordinates) and the corresponding position in the real world (world coordinates) are well known. The number, distribution and precision of the control points are critical to the accuracy of the calibration process.

6.3 Camera parameters

The camera parameters are the values of the mathematical model of the camera, that have to be calculated by the MPT calibration process, starting from the initialization values and the control points:

- Ox, Oy, Oz - camera origin: position of the camera (in world coordinates) when taking the photograph;
- Rx, Ry, Rz - camera rotation: Euler's angles (yaw, pitch, and roll, in radians) representing the camera orientation;
- Cx, Cy - image center: center of the photo (in pixel coordinates);
- D - focal length: in fact, a multiple of the original focal length of the original camera, due to the digitization process (i. e. the scanning of the image or the negative);
- Rf - camera direction: the calibration sometimes results in a solution with the opposite direction of the camera, which must be adjusted by setting *Rf* (see chapter 6.7).

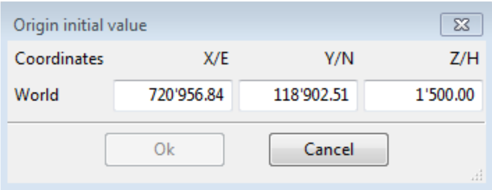
6.4 Initial parameter values

Some initialization parameter values are required to start the calibration process. Necessary initialization parameters are the image center (Cx, Cy) and the focal length (D). In some cases, it is also helpful to specify an approximate value for the camera position (Ox, Oy, Oz).

Initial values can also be defined with the corresponding *copy* button. For the focal length, the *copy* button sets a reasonable default value, which depends on the image size.

6.4.1 Camera position

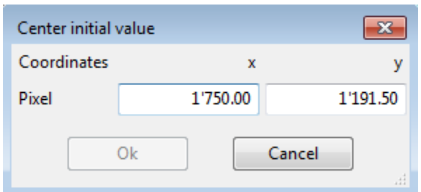
In order to define an approximate initial position of the camera, you have to open the corresponding dialog window with the button ...:



You can enter the coordinate values from the keyboard or by clicking in a geo window.

6.4.2 Image center

The [+] button automatically assigns a start value of the image center with the half of the image height and the half of the image width. The image center can also be defined with the ... button and the corresponding dialog window:



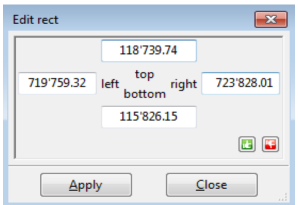
You can enter the coordinate values from the keyboard or by clicking on the image.

6.4.3 Focal length

The initial value for the focal length is automatically calculated internally, giving a reasonable default value, which depends on the image size. This value can be inserted with the *copy* button.

6.4.4 Image work rect

The work area is a rectangle in real coordinates, representing the surface covered by the photo on which you want to operate. It is not a mandatory value, but it helps to improve the performance of the system, and it must be defined in particular when working with a DEM that covers a much larger surface area than the image (i.e. when for a series of images of a vast region for convenience the same DEM is used). In order to define an approximate initial position of the camera, you have to open the corresponding dialog window with the button ...:

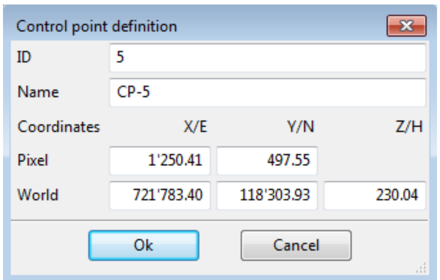


You can enter the coordinate values from the keyboard or with the needed clicks on a map (see 5.1).

6.5 Control points definition

Control points consist of an ID, a name and pixel and world coordinates. To define a control point, its exact position must be known on the image and the map.

The button opens the control point dialog box:



The values can then be entered from the keyboard or, especially for the coordinates, by clicking in a geo window (world coordinates) and in the corresponding image window (pixel coordinates).

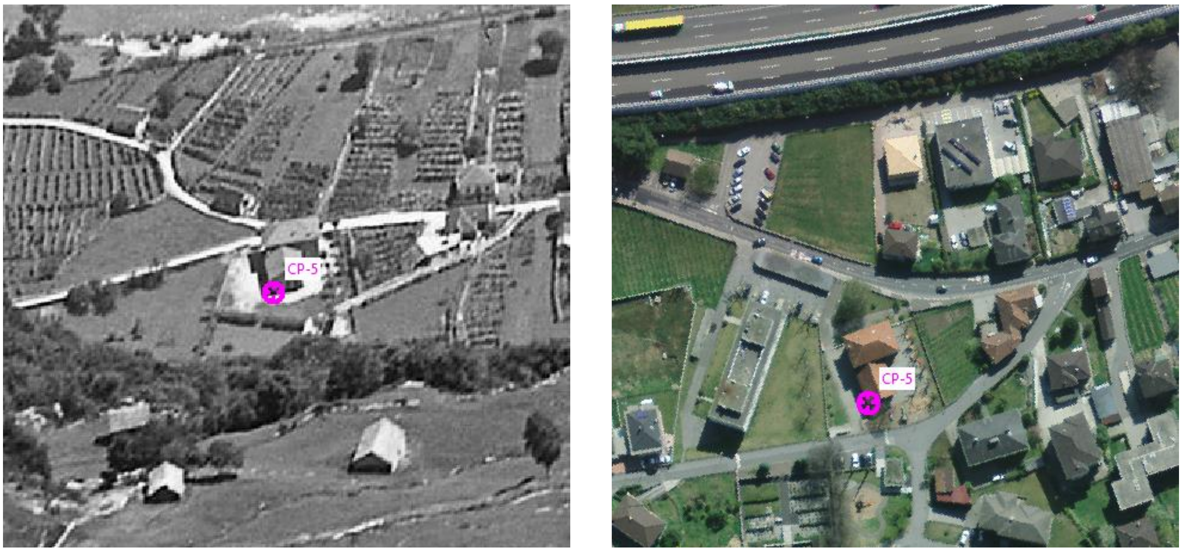


Figure 29 - Control points definition.

The control point coordinates must be defined as accurately as possible. The accuracy of the entire MPT calibration depends on the accuracy of the control points. For example, to define world coordinates, we recommend using orthophotos that are (usually) of better quality and allow better accuracy.

The following aspects and details should be given special attention.

6.5.1 At ground level

The control points must always be selected at the ground level, so that the coordinates of the DEM are exactly reproduced. When available, corners of houses and buildings are ideal candidates.

6.5.2 On regular surfaces

The DEM consists of a series of grid values; values of points that are not on the grid are simply interpolated from the nearest grid points. To minimize errors, as shown in Figure 30, the control points should be possibly chosen on regular surfaces.

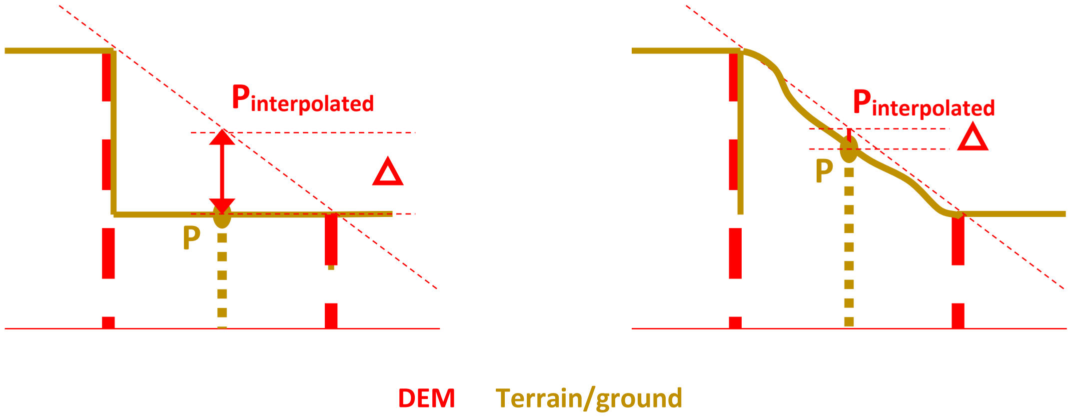


Figure 30 - Control points depending on ground regularity.

6.5.3 The problem of eaves

When a corner of a house is chosen as a control point, it must be noted that the corner of the eaves may be covered from above (in particular when using orthophotos):

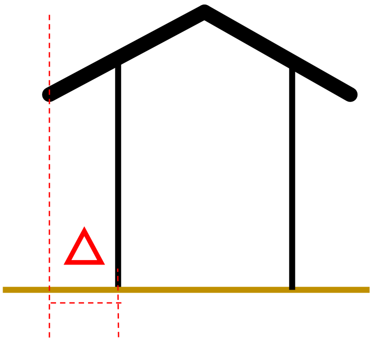


Figure 31 - Eaves effect on control points.

6.6 Control points import/export

Control points import/export takes place in a similar way as import/export of data points (see 4.7.2 and 4.7.3). To import control points, you have to open the dialog box with the corresponding button:

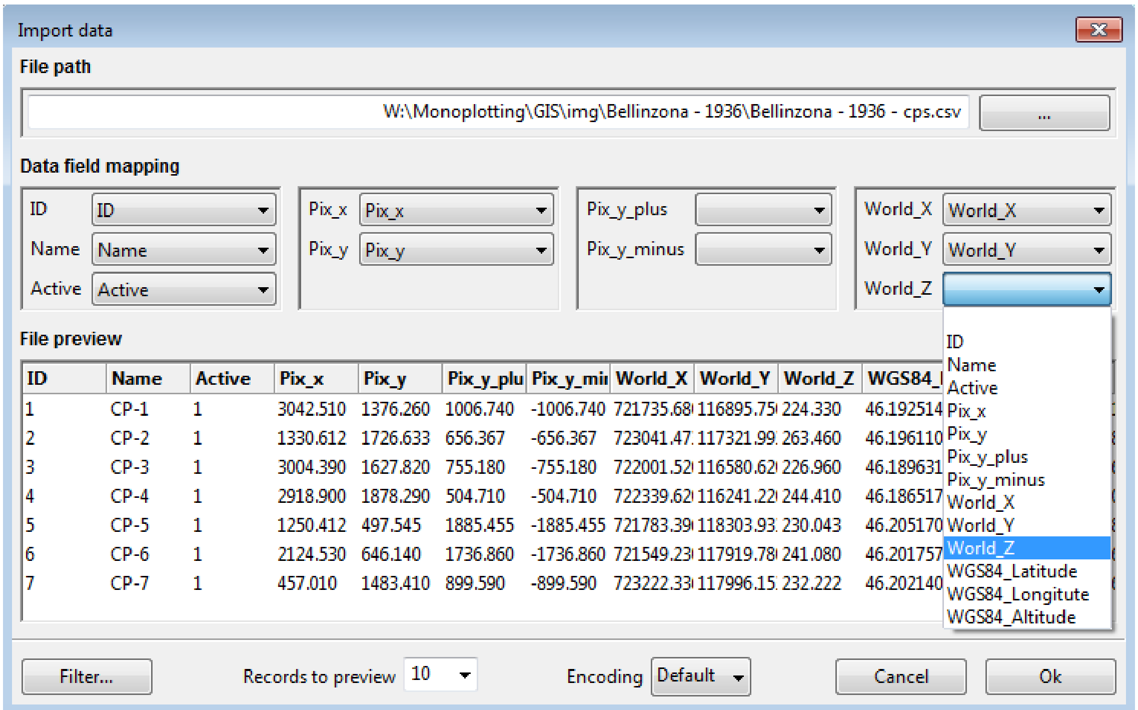


Figure 32 - Control points import dialog.

First select the desired source file, then define the correspondence between the fields (please pay particular attention to the pixel coordinates, see 4.7.1) and press *Ok*. The control points are imported and added to the existing ones.

Exporting of control points occur in a similar way.

6.7 Camera calibration

To calibrate the camera usually you need at least 5 control points. Note, however, that a 10-point calibration is generally better than a 5-point calibration with equivalent accuracy.

Once the initialization values and the control points have been defined and copied, the calibration procedure can start:

1. fix the *Cx*, *Cy*, *D* parameters
2. press the *Compute* button
3. if the result is not satisfactory, define and copy the initial value of the camera position
4. press the *Compute* button
5. when necessary, i. e. if the camera orientation is wrong, correct the *Rf* parameter (see 6.3)
6. check the control points matching and try to improve it as needed, enabling, disabling, or redefining some control points
7. press the *Compute* button
8. free the *D* parameter
9. when needed start again at point 1

The calibration process calculates the camera parameters and generates a series of information to help the user to evaluate the achieved accuracy.

The information about the errors concern (see 6.8):

- pixel error
- angle error
- radius error
- actual 2D error
- actual 3D error

Pixel, angle and radius errors depend only on the camera calibration (i. e. on the control points accuracy). The 2D and 3D errors depend also on the quality of the DEM.

In the camera definition window, these errors are displayed as global values (minimum, maximum and average), as well as individual values (for each control point). This should allow the user to assess the quality of each control point.

In the geo windows you can see a graphic representation of the calibration procedure: the user defined control points by the appear red-yellow, the computed control points in blue-yellow (Figure 34).

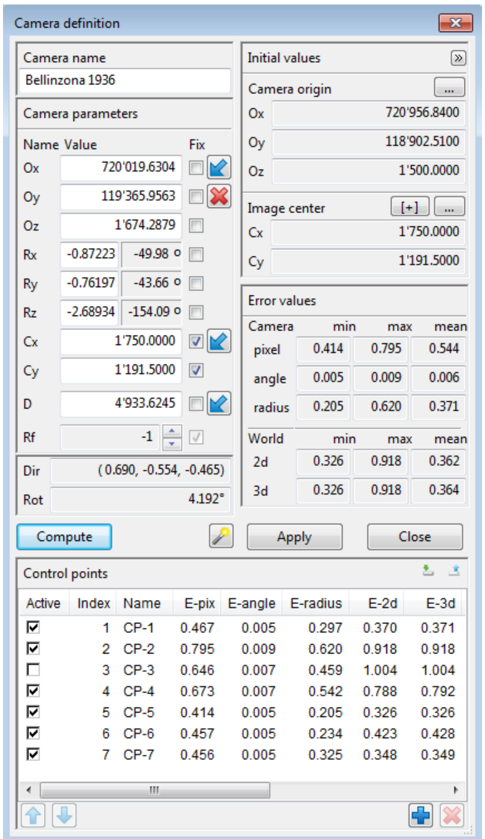


Figure 33 - Camera calibration results.

In the ideal case of a perfect calibration, the red-yellow and the blue-yellow points overlap perfectly.

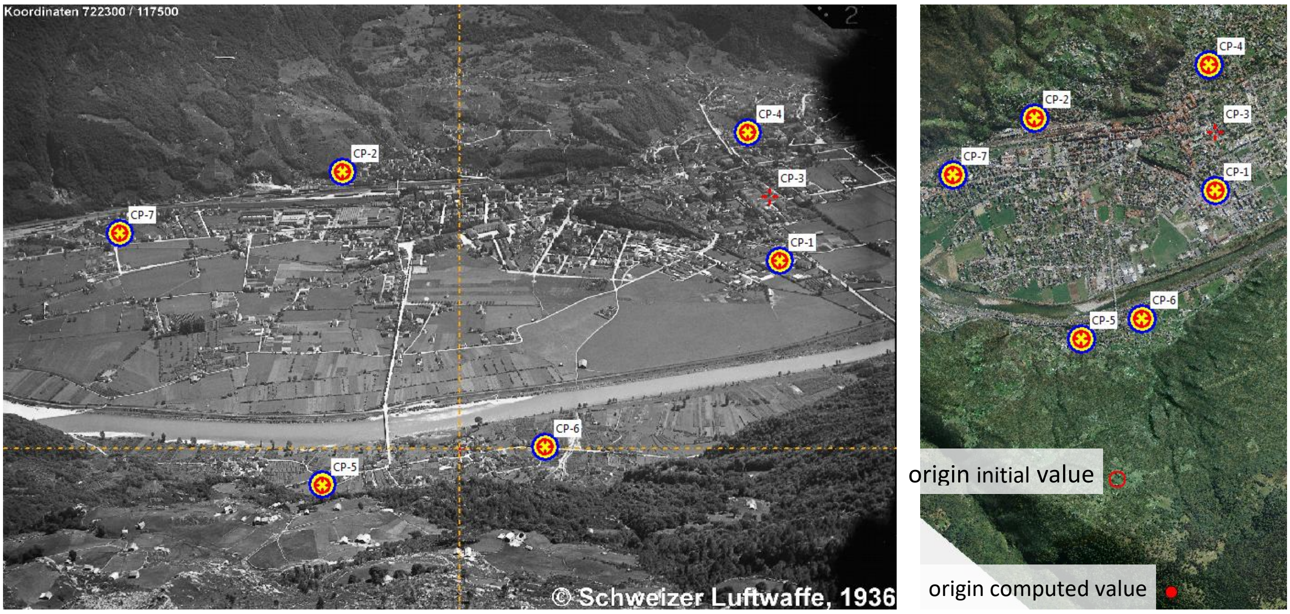


Figure 34 - Graphic representation of the calibration procedure in the geo windows.

6.8 Calibration accuracy evaluation

The calibration process computes the image of each user defined control point (pixel→world and world→pixel). In the ideal case of a perfect calibration, the user defined control points and the corresponding calculated control points would be equivalent, i. e. would have the same pixel and world coordinate values.

Actually, the inaccuracies in the control points definition cause errors that can be quantified with different values: pixel, angle, radius, 2D and 3D errors (Figure 35). A good calibration should reflect a mean angle error value less than 10^{-2}.

However, there are no clear and precise rules for evaluating a calibration, and the error acceptance depends generally on the intended use of the calibrated image. For example, to estimate the limits of an avalanche or a glacier, even an error of 5 meters can be tolerated, while the required accuracy measuring a road width should clearly be less than 1 meter.

.

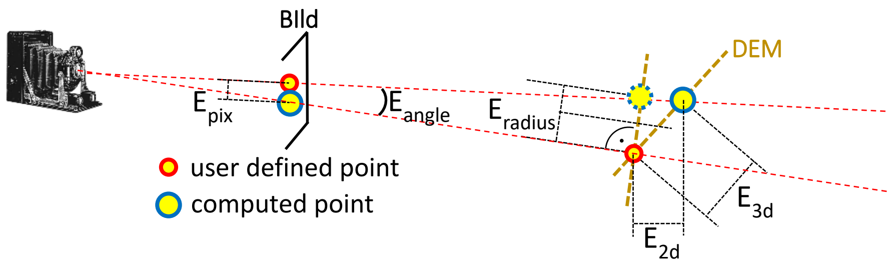


Figure 35 - Camera calibration errors.

6.8.1 Pixel error

The pixel error corresponds to the distance in pixel between the user defined point and the computed point on the image.

6.8.2 Angle error

The angle error is the angle between the rays starting from the camera through the user defined point and the computed point in world coordinates.

6.8.3 Radius error

The radius corresponds to the distance in world coordinates between the user defined point and the projection of the computed point on the plane containing the user defined point and perpendicular to the ray starting from the camera position through the user defined point.

This error depends on the distance of the control point from the camera and increases with increasing distance.

6.8.4 World 2D and 3D error

The 3D error is the actual distance between the user defined point and the computed point in world coordinates. The 2D error is the projection of the 3D error on the horizontal plane.

7. GLOSSARY

camera: mathematical model of the camera

camera calibration: mathematical procedure to reconstruct the parameters of a physical camera, using control points

camera parameters: values needed by the mathematical model of the camera (i.e. camera origin, orientation, image center, focal length)

control bar: left section of map and photo windows allowing the configuration of the corresponding document

control points: points for which the image position (in pixel coordinates) and the corresponding real position (in world coordinates) are well known

data document: document with data, i.e. GIS objects in native (*m_data*) or shape (*shp*) format

data window: window with a data document, i.e. native (*m_data*) or shape (*shp*) data

geo window: windows with georeferenced documents, i.e. map and photo windows

map document: georeferenced document with a standard GIS map and DEM, providing tridimensional information

map window: window with a map document

MPT: WSL Monoplotting Tool

info window: lower section of the control bar, with information about the current status of the document and the mouse position, used specially for development purposes

map window: window with a photo document (*m_map*)

photo document: georeferenced document based on a photograph, a calibrated camera and a DEM, providing tridimensional information

photo window: window with a photo document (*m_photo*)

pixel coordinates: two-dimensional coordinates in pixel, representing a position on an image

statusbar: lower section on the bottom with real time information about menu selection and coordinates corresponding to the current mouse position

world coordinates: three-dimensional coordinates in a standard unit (usually meters), representing a position in the real world in a projected coordinate system

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