Software System Facilitating GIS Data Acquisition by Interpretation of Aerial Photos

W.Schneider, H.Madjidi, R.Mansberger

Institute of Surveying and Remote Sensing
University of Agriculture, Vienna

ABSTRACT

A PC software package developed at the Institute of Surveying and Remote Sensing of the University of Agriculture in Vienna for thematic mapping and GIS data input from aerial photos is described. The software is based on AutoCAD and can be operated independently of a GIS for thematic mapping from aerial photos. Data transfer from and to a GIS is off-line by file transfer. Geometric rectification is achieved according to the monoplotting principle using digital terrain model data. Special functions support edge matching at the boundaries of photos as well as exact and immediate geometric registration of data stored in the GIS, digitized from maps and interpreted from photos. Provisions are made to guarantee an efficient but stringent structure of the digitized data, so that little postprocessing is necessary for transfering the data to a GIS. Plotting of thematic maps is supported.

1. INTRODUCTION: GIS DATA INPUT FROM AERIAL PHOTOS

Data acquisition, both for primary data base input and for periodic information updating, is of crucial importance in any geographic information system (GIS). Aerial photos represent a valuable source of metric and, even more important, of thematic information for large-scale geographic information systems. These systems are used increasingly for various environmental monitoring and planning purposes on a regional or local level such as general land use analysis, agriculture-related planning, forest recources management, etc.

Compared with other data sources (e.g. maps, field work), the advantages of using aerial photos for GIS information input can be seen in the following points:

- reliability and objectivity of information: An aerial photo represents an incontestable document of reality, unlike a thematic map, which is the result of subjective valuation of reality.
- wealth and quality of information: Aerial photos contain abundant information on the type and the properties of the terrain surface and all objects visible from above. This information can be deduced from features such as size, shape (3-dimensional at stereocopic vision), gray tone or colour, texture etc.
- homogeneity: Aerial photos show large areas of the terrain true to nature in a homogeneous form, as it was on the day of photo acquisition, whereas a map often is the result of lengthy field work lasting for years.
- timeliness: Aerial photos can be at the disposal of the photo interpreter a few days after photo acquisition. Maps, on the other hand, usually are updated at intervals of many years only.
- economy: Depending on the area under investigation and the type of information needed, aerial photo interpretation often is the most economical method of data acquisition. Especially for monotoring purposes, aerial photos may provide the only realistic method for periodically repeated data acquisition.
- geometric quality: Aerial photos, if taken with a metric camera, have excellent geometric properties. Virtually all topographic maps and, as a consequence, all base maps for geographic information systems are compiled from aerial photos with photogrammetric techniques.

The position (terrain coordinates) of every point to be identified on the photos can be determined with high accuracy from pairs of photos. In every single aerial photo, however, the terrain is metrically distorted. A direct input from an aerial photo using a digitizing tablet, like for map digitizing, therefore is not possible.

Orthophotos may provide a solution to this problem. Some of the above-mentioned advantages of aerial photos, however, do not apply to orthophotos: Orthophotos as standard products usually are available only in black and white and without stereo partners, and they often lack timeliness. The information content of orthophotos - being second- or third-generation photographic products - is reduced, even if they are in colour (in particular with regard to information contained in subtle colour differences and fine textures and patterns). If, on the other hand, special orthophotos (timely, in colour, with stereo partners) are produced, the costs often are prohibitive.

Alternatively, the techniques of stereo photogrammetry may be employed for direct input of data from aerial photos into geographic information systems. It must be kept in mind, however, that the photo interpretation tasks have to be carried out by experts from various fields of application (vegetation science, forestry, geology etc.) which usually are not trained in photogrammetric stereo plotting. Also, expensive photogrammetric equipment usually is not at their disposal.

In this paper, a PC software package ("DTA" ... Digital Thematic evaluation of Aerial photos) developed at the Institute of Surveying and Remote Sensing of the University of Agriculture in Vienna for thematic mapping and GIS data input from aerial photos is described.

Many of the concepts implemented in this software package have been described before in the literature. A very similar approach, which came to our attention only recently, is documented in Molenaar and Stuiver, 1987.

2. MAIN CHARACTERISTICS OF PC SYSTEM FOR AERIAL PHOTO INTERPRETATION AND GIS DATA INPUT

2.1 System considerations

The system to be described here has been designed to fulfill the following requirements encountered repeatedly in projects at the Institute for Surveying and Remote Sensing:

- The system can be used as a stand-alone instrument for thematic mapping from aerial photos (single photos and blocks of photos).
- The emphasis is on ease of use also for untrained personnel. Geometric accuracy requirements are moderate (e.g. in applications like forestry, vegetation mapping, etc.).
- The system incorporates certain basic analysis functions such as area calculation.
- The system is suited for the analysis of time series of aerial photos (e.g. for monitoring of landscape changes).
- The system is capable of connection with a geographic information system in the sense that exact registration of data from aerial photos and from the GIS is supported.

The basic idea is to enable the recording of photo interpretation results either in the photo coordinate system or in the map (GIS) coordinate system and to switch freely between both with the option of exact registration of objects in the two projections.

The system is not intended to serve as a complete GIS. For implementing elaborate analysis operations, a GIS proper should be employed. On the other hand, the photo input system is expected to perform certain GIS functions (Fig. 1). The main reason for this unsharp demarcation between GIS input and GIS management and analysis modules mainly lies in the requirement of geometric merging of input data (from different photos) and data already in the GIS map coordinate system. Another motive for this system configuration, of course, is the general usefulness of a stand-alone photo interpretation and thematic mapping system.

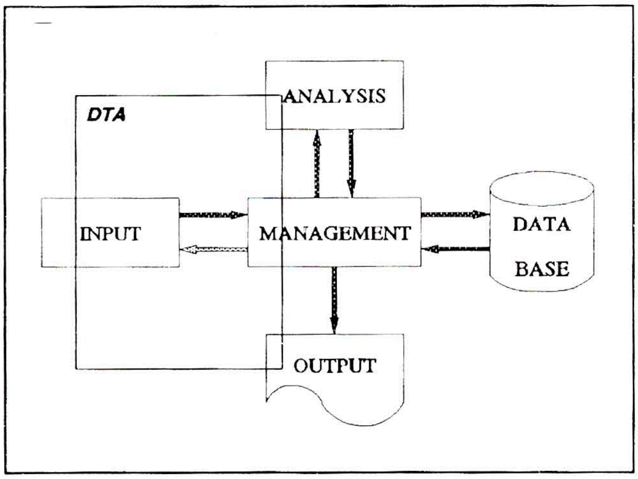

Fig. 1 - The photo interpretation system DTA in the context of a GIS.

Visual photo interpretation is a time consuming task usually performed by experts in the theme of interpretation. It seems reasonable to solve simultaneously the problem of exact geometric registration with little additional manual effort (as it will be described below) and not to leave it to an automatic processing step susceptible to errors. An extra benefit of this method of interpretation is the possibility to realize a "map guided" interpretation, i.e. to have the interpretation supported by information already in the GIS.

2.2 Hardware

The hardware of the photo interpretation system includes

- a PC with a high-resolution colour monitor and (optionally) a second monitor for a separate display of alpha numerical data,
- an (optionally translucent) digitizing tablet or a coordinate measuring device integrated in a stereoscope,
- a stereoscope (optional),
- a plotter (optional) and
- a printer (optional).

One can work with diapositives of aerial photos (to be recommended for colour photos), with paper contact prints or with enlarged paper copies. The photos may be viewed monoscopically or through a stereoscope. When working monoscopically or with a simple folding mirror stereocope, the photos are placed directly on the tablet. Alternatively, a stereoscope equipped with a coordinate measuring device may be employed. For example, for critical stereoscopic interpretation we use a Wild Aviopret zoom stereoscope coupled with a digitizing tablet (Schneider, 1986), which renders the photo coordinates of the point coincident with the floating mark in one of the eyepieces.

2.3 Software

The software is using AutoCAD for the graphic part, in particular for performing the digitizing operations. The reasons for this choice are the wide spreading of this CAD package, the ease to modify and to enhance it with software of one's own, and the knowledge and experience available at our institute.

The software module structure is illustrated in Fig. 2. Besides the AutoCAD package, there are modules written in Turbo Pascal (TP) as well as in AUTOLISP (AL). The main program module (TP) calls a number of other TP modules (e.g. for handling and editing of different data files like digital terrain model files, a control point files etc.) and the AutoCAD program for performing the graphic functions. From within AutoCAD, certain TP programs and AL programs can be called in the same manner like AutoCAD commands. Some of these AL programs in turn call other TP programs in order to optimize the time behaviour of the system. Several types of files are designated for storing data on: the cameras used for photo acquisition (interior orientation), exterior orientation of the aerial photos, control points, digital terrain models, cartographic data etc., as well as for data exchange between the processing modules.

The software system provides the following functions:
- input of camera data (interior orientation, i.e. principal distance and image coordinates of fiducial marks, optionally also lens distortion parameters and/or reseau grid coordinates)
- input of terrain coordinates of control points, or alternatively input of exterior orientation parameters (e.g. from aerotriangulation)
- input of digital terrain model data
- tablet calibration by digitizing fiducial marks (establishing the transformation from internal tablet coordinates to image coordinates)
- computation of the exterior orientation of photos by spatial resection using control points
- defining the interpretation categories, the layer structure and signature banks for the thematic information
- digitizing geometric/thematic information, which may consist of points, lines, areas and associated attributes. This information may be taken from a map, an orthophoto or a (distorted) original aerial photo, with the option to "snap" points and lines (digitized before from the same or another map or photo or stored in the GIS).
- transformation of the geometric information from the perspective projection of a photo to the orthogonal projection of the map (GIS) and vice versa using digital terrain model data ("monoplotting")
- transformation of thematic information (e.g. merging of categories to a new category)
- area calculation
- plotting of thematic maps.

Most functions, especially those needed during digitizing, can be called using a tablet menue to ensure an effective and convenient digitizing procedure. The AutoCAD functions to be used during digitizing are embedded in special AutoLISP procedures which guarantee that a prescribed data structure is adhered to (see chapter 4). The experienced user can, however, use any standard AutoCAD command at any time at his own risk.

Data exchange with geographic information systems (Intergraph, ARC/INFO) is realized with DXF files which can be read and written by the GIS.

3. GEOMETRIC CONSIDERATIONS

The geometric problems can be subdivided into those of rectification and of registration. While rectification means the transformation from the photo coordinate system to the

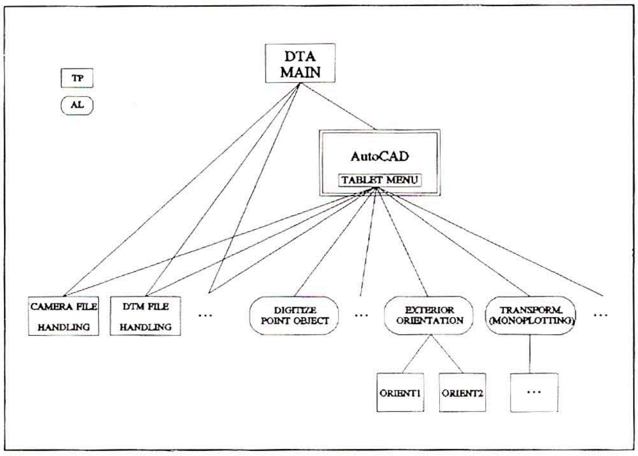

Fig. 2 - Software module structure.

map (GIS) coordinate system, registration refers to the exact coincidence of objects in different layers or from different sources.

Rectification is provided by the method of "monoplotting" [Makarovic, 1973 and 1982; Waldhusl et al., 1986]. The basic idea of this method is illustrated in Fig. 3. For every point in the photo coordinate system, the projection ray through this point can be found, if the interior orientation (position of the perspective centre relative to the photo) and the exterior orientation (attitude of the photo in space at the time of photo acquisition) are known. The intersection of this projection ray with the terrain surface, given in the form of a digital terrain model, provides the terrain coordinates of the point under consideration.

In our system, off-line monoplotting is realized: The photocoordinates are stored in original form during the digitizing operation. The transformation to terrain (map, GIS) coordinates is performed in a following separate processing step.

Correlated objects in different layers of a GIS must coincide exactly in order to avoid "spurious polygons" or "slivers" in any analysis step combining information from different layers. Inaccuracies in digitizing as well as errors introduced in the rectifying transformation will cause misregistrations. The method chosen in our system to avoid these problems is a manual procedure: Whenever a point or a line is digitized which should coincide with objects digitized before or being stored in the GIS already, these old features are used as a standard (template, master) layer, and the new features are digitized using "snap" functions to the old ones. When digitizing from the photo, therefore, the first step is to transform the template features to the photo geometry using a "distortion" function

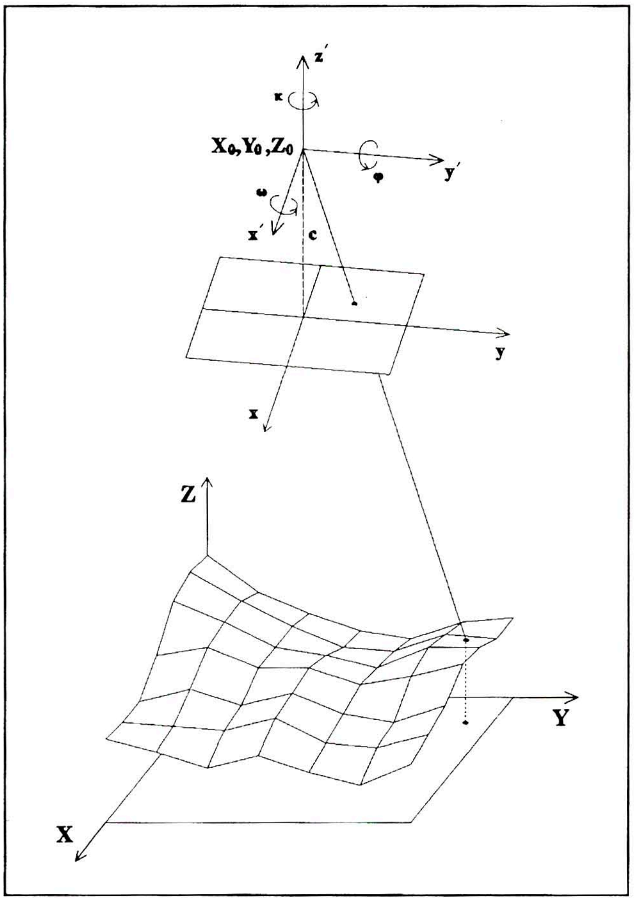

Fig. 3 - Principle of monoplotting.

that represents the inverse of the rectifying function. After finishing the digitizing process for one photo, the newly digitized objects are transformed to the map coordinate system, where they now coincide with the map template features. Special provisions are made to cope with errors caused by computational effects (e.g. finite number of iteration steps in computing GIS coordinates).

A similar procedure is used for edge matching of data in the overlapping region of neighbouring photos of a block (see chapter 5), as well as for digitizing time series data from aerial photos of different acquisition dates.

The geometric accuracy of the data thus obtained depends on a number of factors such as photo scale, scale of enlargements used on the digitizing table, resolution and accuracy of the digitizing table, raster width and accuracy of the digital terrain model, position of the features under consideration on the photos, etc. As a general rule of thumb one can say that the accuracy of the monoplotting method will not be inferior to that of an orthophoto produced from the same aerial image using the same digital terrain model.

4. THEMATIC AND CARTOGRAPHIC CONSIDERATIONS

A GIS data base is a highly structured collection of information. It is essential for new data put into the GIS that they conform to this structure in order to permit automatic analysis. In the photo interpretation system described here, provisions are therefore made that the digitized data come up to certain structural requirements.

Digitized objects must either be points or lines or areas (bounded by polygons). The allowable categories of point objects, line objects and area objects have to be defined in an initializing procedure. For cartographic plotter output, a signature (point signature, line signature, hatching pattern) and a colour have to be defined for every category. An elaborate layer structure (Fig. 4) is established to hold the data of the different categories, both in the photo coordinate and in the GIS coordinate system. A special type of layers are the "template" layers, which are generated for use as templates by transforming data from the GIS geometry to the photo geometry without erasing them in the GIS layers. These layers need not be transformed back to the GIS geometry.

For area objects, an arc-node-structure is built up. Every boundary line must start and end at a node. New nodes on existing arcs can be generated at any time by dividing one arc into two. All boundary lines usually are stored in one layer. The thematic attribute of every area is stored in one special layer. Hatching of the areas is performed in the rectified data set.

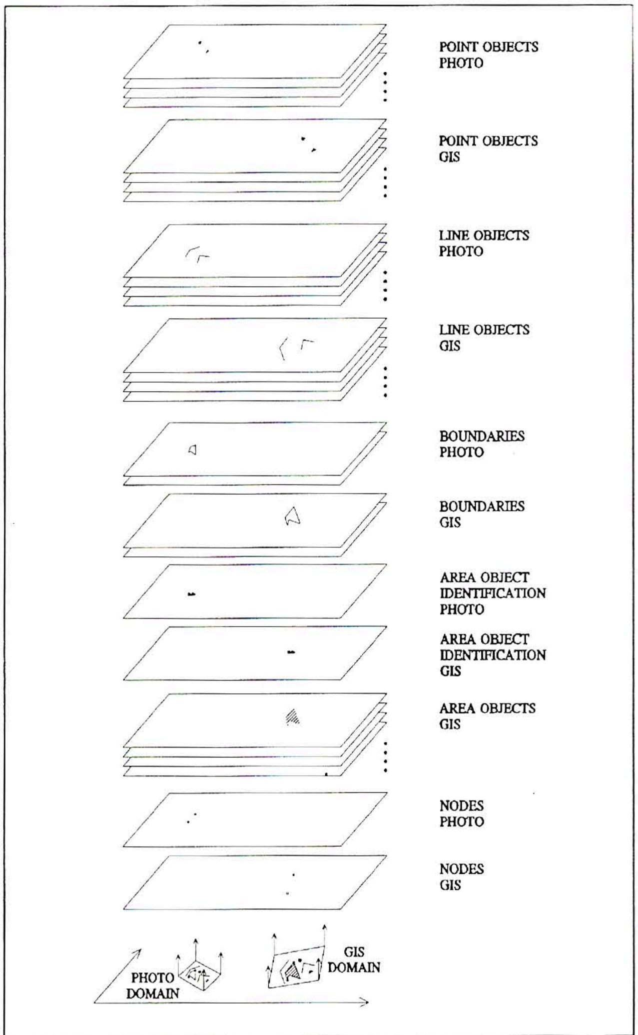

Fig. 4 - Layer structure.

5. EXAMPLE OF PHOTO EVALUATION PROCEDURE AND APPLICATION

The procedure of the air photo evaluation method for digitizing interpretation results from a block of photos is as follows:

- initialize system (input of camera data, control point data, digital terrain model data)

- define categories to be interpreted and signatures characterizing them

- place 1st photo on tablet and calibrate it

- interpret and digitize 1st photo

- rectify data from 1st photo to GIS geometry

- distort data from overlapping region of 1st and 2nd photo to geometry of 2nd photo

- place 2nd photo on tablet and calibrate it

- interpret and digitize 2nd photo, in the overlapping region snap to objects digitized from 1st photo

- rectify data from 2nd photo to GIS geometry

- distort data from overlapping region of 2nd and 3rd photo to geometry of 3rd photo

- etc. for further photos

- hatch areas in rectified data set

- plot thematic map and/or convert data to GIS format.

The method for analyzing a time series of aerial photos is very similar to this procedure. A base map or the interpretation result from the photo of one particular acquisition date is distorted to the geometries of the other acquisition dates to be used as templates.

It may be advantageous to plot the interpretation results in a rough form on transparent overlays on the photos, concentrating on thematic problems, and to digitize these records in a second step, concentrating on geometry.

A typical application, in which the photo interpretation system is used with advantage, is the acquisition of GIS data from colour infrared aerial photos as a basis for protection forest tending and high-altitude afforestation: As a consequence of unfavourable age phase structures and environmental stress, mountain forests sometimes are no longer capable of fulfilling their protection functions. Reliable data on the forest structure are required as a basis for tending and afforestation measures. Aerial photos providing the necessary stereoscopic detail on the forest texture and the necessary synoptic view of the structure of stands are an ideal source of information for the protection forest inventory. The geometric accuracy requirements being moderate, the monoplotting principle is well suited for solving the rectification problem. The standard digital elevation data available for the complete territory of Austria are sufficient for this task. These digital elevation data at the same time yield valuable forest stand information (slope, aspect) to be used for further analysis of the protection forest data in the GIS. The forest experts interpreting the aerial photos can at the same time perform the metric evaluation without special training in photogrammetry. Data from a forest map digitized before and/or stored in a GIS can support the photo interpretation.

Another application is the mapping of alpine vegetation from colour infrared oblique aerial photos acquired from an airplane with a hand-held camera. Here, again, the photo interpretation system is suited in the best way from the point of view of moderate geometric accuracy requirements, ease of operation demand and limited project size.

CONCLUSION AND OUTLOOK

The software package for thematic mapping and GIS data input from aerial photos as described here is a useful tool for many applications. The PC software system is well suited for smaller projects (typically for blocks of up to 20 - 30 aerial photos). In addition to the benefits of exact registration of information from aerial photos, from maps and from GIS, the system offers the possibility of a map-guided photo interpretation.

Further improvements of the system are planned, including an extension of the monoplotting module for digital elevation models containing break lines, a module for affine transformation for the registration of photo and GIS data in flat terrain without the use of a digital elevation model, etc.

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