LOW-COST FEATURE EXTRACTION FROM AERIAL PHOTOGRAPHS FOR DATABASE REVISION

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ABSTRACT:

With the advent of geographic information systems, photogrammetric methods have become once more an important means for acquiring spacial data. This paper describes a comparative study of digital monoplotting, using standard PC equipment, and stereoplotting using a low-cost analytical plotter, both in the context of GIS. The functionality of the methods for different application fields is evaluated.

KEY WORDS: Monoplotting, Database revision, stereoplotting, Analytical plotter, Accuracy, Interpretability.

INTRODUCTION

Digital spatial data handling systems are widely used. Map making, map updating and the collection and production of geoinformation is no longer the domain of specialists of a certain discipline but of all professionals who need spatial data for their particular applications.

Adequate data collection remains critical. Up-to-date spatial data acquired from recent imagery can provide appropriate geoinformation. Several types of sensors and platforms are used for this purpose. Satellite imagery and near vertical aerial photographs are used mainly for making and updating maps. Satellite data are usually gathered in digital form and thus can be directly processed digitally. Standard aerial survey cameras record images on photographic film; digital cameras are not yet widely used in airborne surveys.

Database revision using aerial photographs implies several operations, including interpretation, detection of changes, digitization and transformation to a reference coordinate system before the data can be integrated into an existing database. The process of interpretation can be performed prior to or simultaneously with digitization. Feature extraction can be realized by either stereoplotting or digital monoplotting; both methods yield digital output and can be used with any terrain type.

Revision processes are required by users such as natural resource scientists, urban planners, etc, who are not professional map producers. The low utilization rates of photogrammetric systems make low-cost solutions appealing, but even for professional map makers low-cost systems may be of interest since revision requires interpretation, and thus rather long idle times for equipment. Being a low-cost system, digital monoplotting has become very popular, especially in "thematic disciplines". On the other hand, analytical plotters have become cheaper and easier to use, and may offer an attractive alternative to monoplotting, also for non-photogrammetrists.

In this paper, we will discuss the advantages and disadvantages with respect to accuracy, interpretability and time-efficiency of digital monoplotting in a PC environment, compared with low-cost analytical stereoplotting for updating and/or upgrading an existing database.

DATABASE REVISION BY PHOTOGRAMMETRIC MEANS

Aerial photographs, are one of the important sources of up-to-date geoinformation for digital map and database updating and/or upgrading. Photogrammetric techniques are used to extract, process and integrate in to existing databases the information from photos.

Stereoplotting method

Stereoplotting is manual digitization of features in a well-oriented stereomodel formed by two overlapping photographs. It is commonly used to extract accurate spatial geoinformation in 3-D. The method requires dedicated equipment, preferably analytical plotters, and experienced operators.

Digital photogrammetric workstations, also referred to as "soft copy systems", offer the same possibilities as analytical plotters, but without dedicated hardware except for the stereoviewing provisions. Although providing image enhancement tools and superimposition, image interpretation and feature extraction still have to rely largely on "manual" operations.

The operators should be able to interpret, perform the necessary orientations, i.e.,image-to-model and model-to-map (or ground) transformation and digitization of the required information, and also edit and condition the collected information for integration in the database.

A variety of plotters have been produced in the past. Nowadays, photogrammetric manufacturers are producing only analytical plotters, but, because of their durability, analogue stereoplotters with microcomputer support are still much in use. Analytical plotters increase accuracy and production rates. They are ergonomically designed and equipped with highly interactive software that makes operation more convenient, thus decreasing the time needed for operator familiarization. Presently introduced low-cost analytical stereoplotters supported by microcomputers further reduce equipment costs.

Changes can be mapped inexpensively using a transparent overlay of the photo indicating the areas of change (prepared before digitizing) which is then positioned with the photo in the instrument. More sophisticated but rather expensive superimposition techniques can also be used. The digital data from the database to be revised are mapped to the image space, and one or two synthetic images (mono or stereo superimposition) are injected in the optical stream of the instrument and viewed with the stereomodel. This technique also provides on-line quality control of the data, but is not yet implemented on the low-cost range of analytical plotters.

Digital Monoplotting Method

Digital monoplotting is a feature extraction method that used two-dimensional digitization of single photographs supported by relief information in the form of digital terrain models (DTM). Monoplotting was developed as a simple, inexpensive alternative method for feature extraction, good enough for certain applications [7,8,11]. The required computations include two stages.

- External orientation of a single photograph by space resection: the 6 orientation parameters are evaluated using well-distributed ground control points - Image-to-ground transformation: the intersection of the ray, from the image point and the camera station, with the DTM surface is iteratively evaluated.

Digital monoplotting requires operators who can interpret and simply digitize photographs, similar to the method used for manual digitization of existing maps. There are three viewing possibilities: with the naked eye (using either the original or enlarged photographs), with a magnifying glass or a stereoscope.

For change detection, the existing digital data which are to be revised are converted to photo coordinates (by applying the inverse transformation). The transformed digital data are then displayed on the graphics screen and visually compared with up-to-date photographs; the changes are indicated during digitizing. It is also possible to plot the transformed digital data on a transparent sheet, and then superimpose it on the photograph for manual change detection.

PERFORMANCE EVALUATION

To evaluate photogrammetric systems, a number of items can be considered, such as versatility, flexibility, cost, performance, reliability, human factors, support requirements, etc [9]. In our case, digital monoplotting and stereoplotting systems were experimentally evaluated with respect to their accuracy, interpretability and time-efficiency. The tests were carried out by selecting an area of interest in which there was a variety of features portrayed. The data were collected and processed by the photogrammetric systems and the results were evaluated against a source of higher quality information, referred to in the sequence as "reference data".

Geoinformation is related to both time and position. Data are collected during a certain period of time, and the observed phenomena change with time. Aerial photography provides a snapshot of the status of the phenomena. Positions can be measured after determining the geometry of the photographs with respect to the ground.

Both the boundaries of some features appearing on the photographs and/or their attribute information can be difficult to extract. Feature extraction involves two types of interpretation: delineation of the feature and determination of its associated attributes, which implies subjectivity. Apart from the nature of geoinformation, the equipment, methods, scale and quality of the photographs are also major factors that influence the accuracy of spatial data extracted from aerial photographs.

Accuracy is defined as the closeness of results of computations or estimations to the true values, or values accepted as true, and is classified into attribute accuracy and positional accuracy [5].

Method of determining attribute accuracy

Attributes are defined here only in relation to object type and dimension, such as main road, track and path, river, vineyard, etc. Attribute accuracy is experimentally quantified by the rate of success of feature classification. After being digitized, an existing topographic map is used for true attribute values, and the rate of success per system is determined by comparing features extracted from the photographs by digital monoplotting or stereoplotting with those of the map.

Objects such as towers, windmills, etc, appearing on the map are difficult or sometimes impossible to interpret in medium-scale photographs. Point features were therefore omitted in the evaluation.

The correctness of classification of objects was evaluated by comparing the number of objects on the map with those extracted from the photographs. For this purpose, vector-based GIS software (PC Arc/Info) was used, calculating the total length of lines per object class and the total area of polygons per object class.

The rate of success, expressed in percentage, was computed by dividing the total number of objects per class extracted from the photographs by the number of objects digitized from the map.

Positional accuracy evaluation

To quantify the positional accuracy of digitized features, two coverages were overlaid. One was the expected higher quality data, in our case the existing digital map, and the other was the result from either digital monoplotting or stereoplotting of the same area and features. In the evaluation, linear features were considered, such as man-made (well-defined) features (e.g, roads), natural features (e.g, rivers), and polygon boundaries (e.g, land use boundaries).

Determination of positional accuracy

The two coverages, which contain the same linear features, were overlaid. If there are no gross errors, the linear features should more or less coincide. Small deviations and sliver or spurious polygons may occur because of different sources and methods of digitization, and random digitizing errors.

One way to evaluate accuracy is using the epsilon band concept. The epsilon band is intended to describe a mean probable location for a line; it is an area defined by two parallels to the most probable location of the line. The true position of the line will occur at some displacement from the measured position. Geometrically, the line dilates to a sausage-shaped zone, contouring a probability density function of the line's true location [4,3]. The width, epsilon, of the band is a measure of the uncertainty of the line's location; half of this width is called the epsilon distance. Implementation of this concept requires GIS vector-based software with spatial analysis capabilities. An epsilon band is formed around the reference line and its width is changed until the superimposed lines are enveloped by the band or only a specified percentage of the points remain outside. An accuracy measure is thus obtained.

Another way to evaluate positional accuracy, and which was used in this work in conjunction with the epsilon band concept, is the following. The line coverage from the test data was re-formatted to point coverage (by programming outside the PC Arc/Info environment). The line coverage from the base data was superimposed on the point coverage. The distance from each point to the base line was measured. Accuracy was expressed as a standard deviation, and an epsilon distance was also calculated.

THE EXPERIMENTS

Materials

Having topographic database revision in mind, we selected the following materials for the experiments.

- . Wide-angle photographs (diapositives and paper prints) from the Gould area (southern France) at scale 1:30,000, taken in 1989
- . Wide-angle photographs (paper prints) of the same area at scale 1:30,000, taken in 1976
- . IGN (France), topographic map at scale 1:25,000 of the same area, photogrammetricaly produced from photographs taken in 1980 and revised in 1986
- . Digital map, produced on a Zeiss C120 analytical stereoplotter from the photographs taken in 1976, and stored in DGN Microstation format

Analytical plotter

There are several analytical plotters on the market today. Some have very sophisticated designs and high performance, but are very expensive in terms of both investment and maintenance. There are also low-cost analytical plotters with somewhat simple designs and using the popular budget-priced PCs. Their precision is lower than the sophisticated ones, but may be the best choice for some specific applications. A survey of low-cost analytical plotters can be found in [6].

The Topcon PA-2000 analytical plotter was used in the experiments. It was designed at ITC (The Netherlands) and is licensed to Topcon. The instrument has one photo carrier for the two photographs. The photo carrier is movable in X and Y directions and rotatable around a fixed axis. One rotary and two linear encoders connected to the photo carrier are use to determine positional and angular coordinates relative to a fixed coordinate system.

The PA-2000 incorporates a unique concept for the inner orientation of the photographs. The film or paper print has to be perforated by a punch tool that matches the corresponding studs on the instrument's photo carrier. The orientation procedure consists of only relative and absolute orientation. The inner orientation is obtained by preparing the photographs as described above, and measuring the central points.

The magnification of the optics is 4x (6.5x with an optional eyepiece). The resolution of the measurement system is 5 μm, while its measuring accuracy is 20 μm. The instrument at ITC supports Microstation PC as a 3D or 2D digitizing software.

The system software is designed to run on PCs with the following minimum recommended configuration
- IBM-AT compatible 80286 processor and 80287 coprocessor
- colour monitor VGA, 16 colours
- RS-232 communication port
- tablet with 4-button cursor (Calcomp drawing board 2300 series)
- GPIB-interface PCII/IIA or RS232

Data collection

The data needed for the experiments were divided in two groups. The first group contained the reference data, and the second group contained the test data sets.

The reference data for attribute accuracy evaluation were derived from the IGN topographic map (scale 1:25,000). An area shown in figure 1 of 8.8 x 11.0 cm at the map scale was selected and features of interest were digitized using ILWIS software developed at ITC [10].

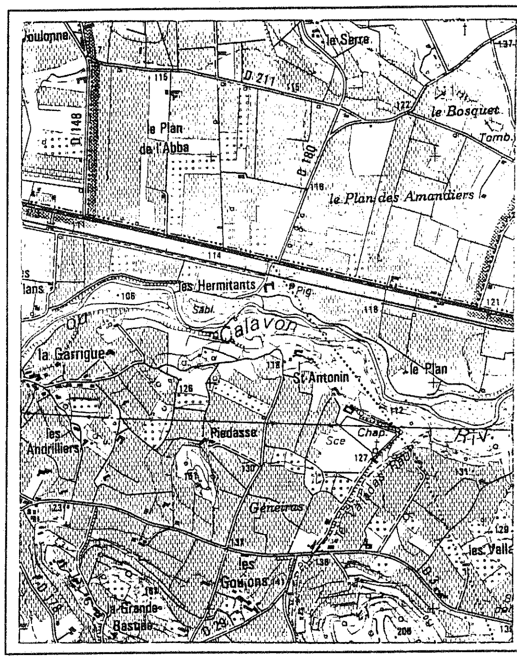


Figure 1: A portion of IGN topographic map, used as a true attribute value.

The available digital map was used for positional accuracy evaluation.

The test data were collected from the 1989 photographs by both digital monoplotting and stereoplotting systems after the necessary orientation data were created. The available control point field (seven points) was densified by aerial triangulation. A small block consisting of three models was measured on the Zeiss C120 analytical plotter, and adjusted by the PATM program. Thus 30 extra control points were established.

The digital monoplotting system also requires a digital terrain model (DTM) for the transformation of feature data, sampled on the image plane, into the terrain coordinate system. DTM data from two models covering the test area were collected on the Kern DSR1 analytical plotter, on which progressive sampling software (COPS [13]) is installed. DTM data with 50 m grid spacing were generated by the SCOP program and then transferred to ILWIS.

Because point features such as towers, monuments, windmills, etc, could not be identified from the photographs, and isolated houses and small villages had been subjected to cartographic generalization on the reference data set, point features were omitted from the attribute accuracy evaluation. Only line and polygon features were used.

Only roads were used for the positional accuracy evaluation of well-defined features.

Data processing and analysis

All data were converted to PC Arc/Info coverages. Three types of coverage were created: roads for positional accuracy evaluation, and lines and polygons for attribute accuracy evaluation.

Attribute accuracy evaluation of linear objects

After building line topology, the lengths of linear attributes contained on the coverages, i.e, roads, railway and rivers, were calculated. The rate of success was evaluated, and the results are presented in table 1. Because of the short time interval between the collection of the reference and test data (3 years), and the types of object considered, we can reasonably assume that no attribute changes occurred.

Feature name	I.G.N. Map	Mono	PA-2000	Rate of Success %	
	Distance m.	Distance m.	Distance m.	Mono	PA-2000
Main road	2258.43	2262.40	2261.46	100.17	100.13
Narrow road	8188.03	9972.27	8289.14	121.79	101.24
Track & path	21125.36	7589.87	18497.87	35.93	87.56
Railway	2255.35	2257.23	2262.78	100.08	100.33
River	2807.5	2649.07	2691.5	94.36	95.87
Stream	6479.55	1992.40	2517.86	30.75	38.86
Total	43114.22	26723.24	36520.60	61.98	84.47

Table 1: Rate of success of line objects

Attribute accuracy evaluation of polygon objects

Each land use polygon coverage from both monoplotting and stereoplotting was overlaid with the corresponding reference land use coverage produced from the IGN map. The polygon areas from the overlaid coverage were calculated per area attribute. The rate of success was then calculated; the results are given in table 2.

It should be pointed out that for the identification and digitization of lines and polygons in the digital monoplotting system, no magnification was used, while magnification of 4x was used on the PA-2000

Feature name	I.G.N. Map	Mono	PA-2000	Rate of Success %	
	Area m.^{2}	Area m.^{2}	Area m.^{2}	Mono	PA-2000
Flood area	256109.8	45054.24	91373.34	17.59	35.68
Vineyard	3885623	3612250	3608500	92.96	92.87
Orchard	573008.8	225816.6	259665.1	39.41	45.32
Open area	864855.4	45574.76	218962.8	5.27	25.32
Forest	470403	338552	352494.3	71.97	74.93
Total	6,050,000	4,267,248	4,530,995	70.54	74.90

Table 2: Rate of success of polygon objects

Analyzing the results in tables 1 and 2, the following can be stated. Interpretation using the PA-2000 is better than digital monoplotting because of stereo viewing and magnification. The rate of success with linear features from the PA-2000 was 23% higher than monoplotting and close to the IGN map (85% success). These very good results where obtained, because generally, linear features are easier to interpret under high magnification and in stereo.

In table 1, it can be observed that the rate of success with "narrow roads" using the monoplotting method exceeds 100%, while the "tracks & paths" have a success rate of only 36%. This indicates that misclassification occurred between "narrow roads" and "tracks". The rate of success of polygons with PA-2000 was only 4% higher than monoplotting. When compared with the IGN map, the PA-200 success rate for polygons is only 75%. This result is believed to improve if the definition of polygon objects is sharpened.

In interpreting the figures in table 2, we must remember that the totals of feature classes are influenced by both attribute misclassification and attribute change. Some features were obviously subject to change, which blurred the attribute accuracy of polygon objects. As can be expected when using a test site in southern France, the vineyards showed the highest rate of success.

Positional accuracy evaluation

Positional accuracy was evaluated using only road features. The line coverage of the digital map data was chosen as reference data, since they represent the higher-order survey. The digitized IGN topographic map was not used for positional accuracy evaluation because of possible paper distortions.

The reference coverage in vector format was compared with the test coverages collected by monoplotting and the PA-2000. Before comparing, the test coverages were reformatted from line to point coverages. The absolute distances from the base coverage to test coverages were calculated.

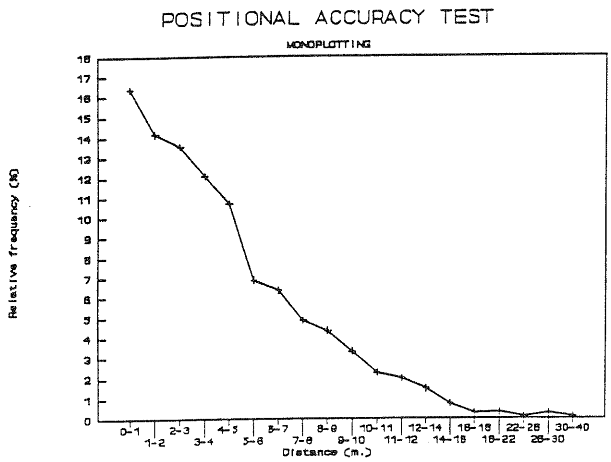
The results of the calculations are given in figure 2, where the relative frequencies of the absolute distances are shown. The statistical parameters are given in table 3.

Statistical results (m.)	Monoplotting	PA-2000
Maximum distance	39.23	17.72
Minimum distance	0	0
Average distance	4.35	1.06
Standard deviation	3.80	1.09
Variance	14.41	1.18
Total digitized points	2,310	3.051

Table 3: Statistical parameters for positional accuracy evaluation.

The positional accuracy of both methods was analyzed using the normal distribution as the statistical model. The results of accuracy estimation with various confidence levels are shown in table 4. The values of the parameter Z in this table were drawn from the normal distribution.

Using the 90% confidence level as an example, the following interpretation holds for the corresponding accuracy values. "The positional error at any point is expected to be 9.21 m or less for data collected by digital monoplotting, or 2.46 m or less for data collected by the PA-2000, in 90% of the cases" [1,2].



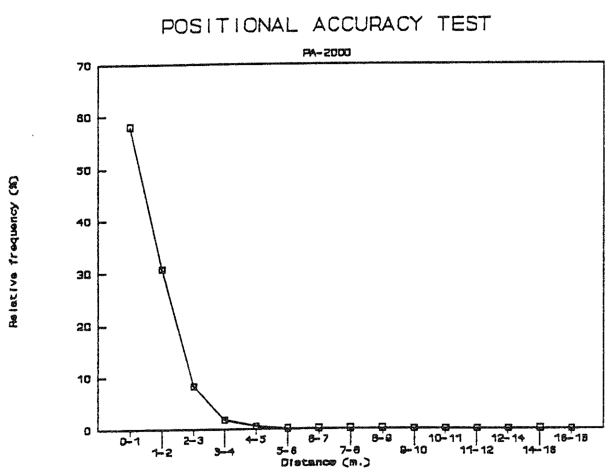


Figure 2: Relative frequency line graphs of data of digital monoplotting and PA-200.

Confidence level (%)	Monoplotting		PA-2000	
	z*SD+Mean	Accuracy (m.)	z*SD+Mean	Accuracy (m.)
68	0.468*3.8+4.35	6.13	0.468*1.09+1.06	1.57
80	0.84*3.8+4.35	7.54	0.84*1.09+1.06	1.98
85	1.044*3.8+4.35	8.32	1.044*1.09+1.06	2.20
90	1.28*3.8+4.35	9.21	1.28*1.09+1.06	2.46
95	1.645*3.8+4.35	10.60	1.645*1.09+1.06	2.85
98	2.055*3.8+4.35	12.16	2.055*1.09+1.06	3.30

Table 4: Positional accuracy estimation using normal distribution as statistical model.

The accuracies with the same confidence levels were calculated from the sample data and are shown in table 5.

Confidence level (%)	Monoplotting Accuracy (m.)	PA-2000 Accuracy (m.)
68	5.10	1.24
80	6.96	1.62
85	8.02	1.79
90	9.21	2.08
95	11.05	2.52
98	13.60	3.46

Table 5: Positional accuracy, calculated from sample data.

Positional accuracy requirements

Positional accuracy requirements vary according to application. For example, according to United states national map accuracy standards for horizontal accuracy of maps on publication scales of 1:20,000 or smaller, no more than 10 percent of the points tested can be in error by more than 1/50 inch (0.5 mm). These accuracy limits apply in all cases to positions of well-defined points [12]. A line is captured by digitizing both end points; thus the accuracy of lines is a function of the positional accuracy of the points involved. The accuracy specifications of lines can be converted to epsilon distances [3].

In order to cover a wide spectrum of accuracy requirements, epsilon distances (1/2 of the epsilon band) ranging from 0.1 mm to 0.25 mm on the map were translated to meters on the ground for several map scales (see table 6).

Scale	Positional accuracy requirements for spatial data			
	0.1 mm	0.15 mm	0.2 mm	0.25 mm
1:20000	2 m.	3 m.	4 m.	5 m.
1:25000	2.5 m.	3.75 m.	5 m.	6.25 m.
1:30000	3 m.	4.5 m.	6 m.	7.5 m.
1:50000	5 m	7.5 m.	10 m.	12.5 m.

Table 6: Positional accuracy requirements of spatial database in several scales.

The estimated positional accuracies of digital monoplotting and stereoplotting at the 90% confidence level (see table 4), were compared with the positional accuracy requirements of the above table; the results are summarized in table 7. They indicate the expected suitable scales for which the digital data produced by digital monoplotting and stereoplotting can be used.

Scale	Positional accuracy of Monoplotting (±9.21 m. with 90% confidence level)				Positional accuracy of PA-2000 (±2.46 m. with 90% confidence level)			
	±.1mm	±.15mm	±.2mm	±.25mm	±.1mm	±.15mm	±.2mm	±.25mm
1:20000	-	-	-	-	-	+	+	+
1:25000	-	-	-	-	+	+	+	+
1:30000	-	-	-	-	+	+	+	+
1:50000	-	-	+	+	+	+	+	+

Remarks + positional accuracy under standards
- positional accuracy out of standards

Table 7: Expected suitable scale of digital data produced by monoplotting and PA-200.

The data collected by monoplotting from photographs at scale 1:30,000 are suitable of updating a database at scale 1:50,000 with 0.4 mm accuracy at 90% confidence level, while data collected by stereoplotting are suitable for producing and/or updating a database at scale 1:20,000 with 0.3 mm at the same confidence level.

For proper appreciation of the results, the following facts should be emphasized.

. The data used for the positional accuracy evaluation were derived from line coverage collected in dynamic mode and converted to point coverage.
. The data were collected by an operator with limited experience.
. The results were derived from only one experiment on 1:30,000 scale photographs.
. No magnification was used for the data collected by monoplotting, while the CalComp drawing board was used for digitizing.
. DTM of only one grid spacing was considered

Time-efficiency

The experiment used for attribute accuracy evaluation was also used to evaluate time efficiency. The time needed for the orientation of each system was registered, and the time required for interpretation and digitizing of line features was expressed in meters/second.

The times needed for orientations were as follows: 5 minutes for the IGN map prior to digitizing; 30 minutes for the monoplotting system, including the orientation of the photograph and determination of the exterior orientation parameters; 3 hours for the orientation of the analytical plotter, including inner, relative and absolute orientation for two models as well as edge matching. Unfortunately, the recorded digitizing rates were not conclusive and further experiments are needed.

CONCLUSIONS

The obtained results indicate that interpretation by analytical stereoplotter is better than digital monoplotting, because of its stereo viewing and magnification. This was demonstrated by the rate of success with linear features in the attribute accuracy evaluation.

The results of the positional accuracy test show that by relaxing the specification, data collected by monoplotting from scale 1:30,000 photographs are suitable for updating a 1:30,000 scale database with 0.5 mm accuracy at 80% confidence level. It should noted, however, that the digital monoplotting system cannot be used if the terrain relief has changed and the DTM is not updated.

The use of analytical plotters is recommended when high precision is required and/or when extensive database revision projects are planned. Digital monoplotting can be particularly valuable for revision or primary data acquisition processes in certain application fields, such as forestry, geomorphology, etc., where results of photo-interpretation of natural resource data must be transformed to a reference coordinate system.

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