INSTRUMENTATION FOR A CADASTRAL LAND INFORMATION SYSTEM

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ABSTRACT

The requirements for photogrammetric instrumentation, to be used for data acquisition in a computerized cadastral land information system, are discussed. A prototype system has been installed in Colombia as part of an experimental project, carried out jointly by the National Research Council of Canada and the Instituto Geografico "Agustin Codazzi" of Colombia. The system configuration is described and test results obtained with the stereo-orthophoto components are presented.

INTRODUCTION

The selection of photogrammetric data acquisition equipment for a computerized land information system depends on a variety of factors. The accuracy required for the information is a primary consideration and is affected to a great extent by the value and the use of the land. Different accuracy specifications are usually set for urban and for rural areas, which may result in a requirement for different types of photogrammetric equipment. Related to this is the question, particularly for rural areas, whether the parcel-boundaries to be digitized, are targeted prior to the aerial photography or whether their identification in the images is based on natural features such as road and vegetation patterns. In the latter case there may not be a justification to use high precision - usually meaning sophisticated and expensive - equipment.

A consideration which also may influence the selection of equipment is a possible decentralization of data acquisition procedures. The collection of field information is often organized at a regional level and there may be certain advantages of performing the actual digitizing of this information at the regional cadastral offices as well. In this case it may be considered to have the digitizing and the field work carried out on a rotational basis by the same persons. These may not be highly trained photogrammetric operators so that relatively simple photogrammetric digitizing equipment would be advantageous.

Other factors which have to be taken into account in selecting the equipment are the possibility for verifying the completeness, checking and, if necessary, editing of the data bank information. Last but not least the cost is an important factor, particularly when considering that, once the information has been collected and digitized, the equipment will be mainly used for updating the land information, which may not require its use on a full-time basis and therefore may not justify the purchase of sophisticated and expensive instrumentation.

THE PILOT PROJECT "CADASTRE LATIN-AMERICA"

The pilot project "Cadastre Latin-America" is the result of the interest of Latin-American countries, and Colombia in particular, to develop an integrated multipurpose land information system and to upgrade the existing cadastral systems which are of limited capability and which were originally established mainly for taxation purposes (Gonzalez-Fletcher, 1980). The project is conducted jointly by the Instituto Geografico "Agustin Codazzi" (IGAC) of Colombia and the National Research Council of Canada (NRCC). It is financially supported by the Colombian and Canadian Governments. About two thirds of the project budget is supplied by the Colombian National Department of Planning and the Colombian Ministry of Finance and Public Credit and one third by the Canadian International Development Agency.

The pilot study is carried out for a 2000 km^2 test area containing approximately 20 000 parcels, with topographical features, land-use patterns, and soil types which are representative for the agricultural areas of Colombia. The area also includes typical built-up areas such as villages and towns of various sizes. The general objective of the project is the establishment of a prototype cadastral land information system based on the implementation of modern concepts, methods and technology, which will allow for testing and analysis of procedures for acquisition, processing and exploitation of information (Jaksic, 1981).

The project consists of two different phases. The first one was completed during the summer of 1983 and consisted, among others, of the installation of hardware, selection of the test area, aerial photography, aerial triangulation, and development of prototype software for data collection and information management.

The second phase, which is presently in progress, is concerned with the overall analysis of the system, introduction of possible refinements and corrections of software, and definition of detailed specifications for country-wide implementation of a cadastral land information system.

SYSTEM COMPONENTS

The Colombian land information data base is organized as a geocoded system, containing cadastral geometrical information on properties, soil types and land use patterns as well as cadastral attribute data such as name and address of a parcel, its owner, its cadastral value, dates of changes in ownership, types of buildings, etc. The digital information is used to define the parcel boundaries in the data base, to calculate areas, elevations, and slopes and to produce cadastral base maps and graphical records for individual parcels. The digital and attribute information are stored in different files and the cadastral parcel identification number is used as a key to retrieve the two types of information for a particular parcel (Jaksic and van Wijk, 1983).

The photogrammetric system components, installed at IGAC during the first phase of the project, will allow for the evaluation of various photogrammetric on-line techniques. The data acquisition for the rural areas is based on the stereo-orthophoto technique which offers simple instrumentation for digitizing planimetric and elevation data. In the field interpretation stereo-orthophotos offer the advantage over regular aerial photos that they represent the terrain in orthogonal projection. The orthophoto scale is uniform and straight boundary lines appear therefore straight in the orthophoto image. This allows for the use of simple tape measurements to define in the orthophoto those boundary points which cannot be readily interpreted. The use of stereo-orthophotos, offers the possibility to observe a true three-dimensional terrain model by using a simple field stereoscope. The field interpretation data, such as parcel boundaries, cadastral reference numbers, and land use patterns are marked on orthophoto mosaics, arranged according to the cadastral map sheet system. After completion of the field identification these mosaics offer a preliminary, up-to-date, graphical cadastral record, even before the digitizing of the information is initiated.

Many areas in Colombia are characterized by rugged terrain conditions and steep slopes often offer a challenge for the use of orthophotos. The practical limits for the use of the stereo-orthophoto technique, with respect to accuracy and image quality, are assessed as part of the pilot project.

The accuracy of coordinates and elevations, provided by the stereo-orthophoto technique, will have to be considered in order to decide to what extent the stereo-orthophoto technique can be used to provide cadastral information for built-up areas such as villages and smaller towns. It is expected that for the larger towns and cities a higher accuracy, provided by a more sophisticated photogrammetric system, will be needed.

Equipment for data acquisition, data processing and display of information, which was installed at IGAC as part of the pilot project, and which will be able to handle the amount of cadastral information, typical for one cadastral region in Colombia, comprises the following:

Analytical Plotter

The analytical plotter (US-2) is intended primarily to provide by aerial triangulation the control coordinates for the production of stereo-orthophotos and digital elevation models. The dedicated computer (PDP 11/34) of the instrument will, during the second phase of the pilot project, be connected to the data bank computer to allow on-line acquisition of digital data for areas that require higher accuracy boundary information. The data acquisition will be carried out under control of the data collection software, developed as part of the pilot project.

Orthophoto Production Equipment

A Gestalt Photo Mapper II system is used for the production of orthophotos, stereomates and digital elevation models. The system has been equipped with two printing units for simultaneous recording of the orthophoto and stereomate images. The height data needed for the generation of the stereo-orthophotos is recorded as a regular grid of elevation data which is used for the plotting of contourlines on a computer-controlled plotting table.

Stereocompilers

Four Stereocompilers are available to collect the digital information from stereo-orthophotos (fig. 1).

The Stereocompiler offers the possibility of plotting a manuscript on a transparent overlay on the orthophoto, during the digitizing process (van Wijk, 1982). The operator observes the plotted information superimposed over the stereoscopic model, which provides him with an up-to-date record of the digitized data and reduces the chance of errors due to double digitizing and omissions.

The Stereocompilers are on-line with the data bank computer and each one is equipped with an alphanumeric terminal which provides a communication link between the operator and the computer and allows the data acquisition to be performed under computer control.

Digitizing Table

A Gentian Hi-state digitizing table with a 90 cm x 120 cm digitizing area is used for digitizing soil type boundaries from field interpretated orthophotos

Figure 1
Stereocompilers at IGAC.

and may, in the future, be used for planimetric updates and revisions. The table is connected to the data bank computer so that all the digitizing operations can be performed under computer control.

Data Bank Computer

A PDP 11/44 minicomputer with a RSX-11M operating system is used for the data bank system of the pilot project test area. The central processing unit has a memory capacity of 1 Mbyte, is equipped with two 10 Mbyte disks and a dual drive magnetic tape unit. Peripherals also include a VT 100 terminal, a DECwriter, a Tektronix interactive graphical terminal for editing and a small XY plotter for graphical presentation of parcel information.

The computer has a sixteen channel multiplexer. Two channels are used for each of the four Stereocompiler digitizing stations (one for the computer alpha-numeric terminal and one for the digitizing system), two for the XY digitizing table, and one for each of the four above mentioned peripherals. The remaining channels are available to include the analytical plotter in the on-line data acquisition system.

Plotting Table

A Data Tech plotting table controlled by a Nova 3 minicomputer is used for the plotting of contourlines from the GPM generated digital elevation models and cadastral information obtained from the data bank system.

DATA ACQUISITION

Photographs taken at various scales, selected according to the density of information to be collected and the required accuracy are used for the data acquisition. Photo scales vary between 1:50 000 and 1:6 000. The smaller scales (up to 1:10 000) are used for the rural areas. For these areas the scales of line and orthophoto maps, produced as part of the pilot project, range from 1:25 000 to 1:2 000. Urban areas are photographed at scales 1:20 000 to 1:6 000, depending on the size of the town. Map products for these areas may be at scales of 1:5 000 to 1:1 000 (IGAC, 1980).

The photogrammetric data acquisition process consists of different stages, which are briefly described as follows:

Aerial Triangulation

The control points needed for producing the stereo-orthophotos and the digital elevation models, and for digitizing and plotting operations are determined on the analytical plotter using on-line aerial triangulation software developed at NRCC. The subsequent block adjustment is also based on NRCC software. It is foreseen that, in the near future, the orientation parameters, derived from analytical aerial triangulation will be used directly for the relative and absolute orientation process on the Gestalt Photo Mapper.

Production of Stereo-Orthophotos and Digital Elevation Models

The stereo-orthophotos and digital elevation models are produced by automatic image correlation on the Gestalt Photo Mapper. The orthophoto and the stereomate are recorded simultaneously on the two printing stages. X-parallaxes, introduced in the stereomate, permit three-dimensional interpretation and the derivation of terrain heights from the stereo-orthophotos. Providing that the orthophoto and the stereomate are produced from the two different photographs of the stereo overlap, also small details such as buildings and trees can be interpreted and measured three-dimensionally.

The X-parallaxes in the stereomate are usually generated according to the base-to-height ratio of the stereo-overlap. For areas of high relief, which are common in Colombia, a smaller X-parallax to height ratio could be used to reduce image quality problems occasionally encountered in the stereomate for areas with large elevation differences.

The orthophotos are enlarged to the required map scale (2 to 5 times magnification) and combined into orthophoto mosaics according to the cadastral map sheet system. This allows for a convenient use of the orthophotos in the cadastral regional offices and offers the possibility of a systematic sheet by sheet revision process.

Field Identification

Enlarged orthophotos and stereomates are used for identification of the cadastral information in the field. Cadastral survey teams mark the parcel and field boundaries on the orthophotos based on information observed in the field, obtained from the cadastral records, and provided by the property owners. In addition, information on cultivation types, buildings, road classifications, drainage patterns, etc. is indicated. Attribute information on parcel name or address, ownership, owner identification, cadastral value, date of change in ownership, etc. is collected for each parcel on special forms.

Soil types are identified by specialized soil survey teams, involving field inspection as well as laboratory analysis. The soil boundaries are marked on the orthophotos for subsequent digitizing. The stereo interpretation of the terrain surface, offered by the stereo-orthophotos, has been recognized to contribute to the accuracy of the interpreted soil type boundaries.

The interpreted information is transferred to orthophoto mosaics, copies of which are kept in the cadastral regional office as an up-to-date cadastral record. Other copies serve as a guide for the digitizing operation.

Digitizing

The data acquisition is based on individual parcels and is carried out according to the information on the field interpretated orthophotos. All data, pertaining to a certain parcel, such as its boundaries, cultivation outlines and buildings, are digitized before proceeding with the following parcel. Strings of coordinates form segments which are parts of boundary lines located between points common with adjacent parcels or land use units. Segments, in turn, make up closed polygons. For parcels extending beyond the window which delineates the area to be digitized in a stereo model, polygons are closed with a "virtual" segment along the window.

The digitizing is carried out under computer control, so that the measured model coordinates can be transformed into the ground control coordinate system in real-time and are used as such during the entire data acquisition process. This on-line procedure offers the possibility of using the same strings of coordinate values to define segments shared by adjacent parcels. The operator defines a segment as "old" when it was digitized as part of a previous polygon and identifies it by pointing at its end points and one intermediate one. The original segment then becomes part of the new polygon. The segment file in the computer memory consists consequently of a unique set of segments which can be used repeatedly to form different polygons. A special code is used before the digitizing of a segment is started to indicate whether the segment is new, old, virtual or internal, the last expression being used for segments common to two different cultivation types within a parcel. At the end of each segment a code is used to indicate whether the last segment point is a new one or whether it has already been digitized as part of a different parcel or field. These features, combined with the condition that all data make up closed polygons, ensure that each boundary point is defined in the data bank by a single set of coordinates, even when such a point belongs to different parcels or cultivation fields.

As mentioned before, the Stereocompiler offers the possibility of producing a graphical overlay of the digitized information on the orthophoto simultaneously with the digitizing process. The operator observes this graphical record superimposed over the stereo model and it provides him with an up-to-date record of the digitized information. A previously digitized segment will, for example, be recognized and can consequently be identified as "old". Windows are marked as a preparatory step on the overlays to assure that the required overlap is obtained for the data digitized in adjacent models. Cadastral information, such as parcel identification numbers and identified boundaries, can also be indicated on the overlays and can thus be observed superimposed over the stereoscope model. The operator consequently has all information, needed for the digitizing operation, displayed in the instrument's field of view.

The graphical record observed by the operator during the digitizing process also reduces the chances of errors, omissions and double digitizing. Since also certain checking routines, such as a polygon closure condition, are incorporated in the data acquisition software, the digitized data are generally of good quality and at the present no need is foreseen to provide each data collection station with an editing facility. The editing, instead, is carried out as an off-line operation, performed only after the different models have been joined. A Tektronix interactive terminal is used for that purpose. A disadvantage of the off-line editing is that, in the case of serious omissions or errors, the stereo-orthophotos may have to be set up again in the Stereocompilers to complete, or correct the data. The orientation process on the Stereocompiler, however, is simple, consisting merely of aligning the orthophoto and the stereomate on the image carriers and remeasuring the ground control image coordinates, which normally can be done in about five minutes.

INITIAL TEST RESULTS

The tests, which have been performed so far, are intended to demonstrate the overall accuracy of the stereo-orthophoto technique including the effect of the X-parallax to height ratio used in the stereomate production, the accuracy of the process at IGAC to produce the stereo-orthophoto enlargements, the instrumental accuracy of the Stereocompilers and the interpretation accuracy of the boundary information.

Photographs of the NRCC Sudbury test area, containing a dense net of signalized control points, and photographs of two different Colombian areas were used. The accuracy analysis of the Colombian stereo-overlaps was based on approximately 75 points which were artificially marked in one of the transparencies used for the stereo-orthophoto production. The terrain coordinates of these points were determined from stereo-comparator measurements and the available ground control points.

The Sudbury stereomodel was used to test the accuracy of the various technical operations at IGAC including the production and enlargement of the stereo-orthophotos and the instrumental accuracy of the Stereocompilers. In order to obtain the necessary comparative data, the contact size stereo-orthophotos were measured on a Zeiss PSK Stereocomparator while 2.5x enlarged stereo-orthophoto transparencies were measured on the NRCC Stereocompiler, which is of a similar design as the Stereocompilers at IGAC. The values of the photogrammetric base (at image scale) and the calibrated principal distance, indicated on the GPM orthophoto negatives, were used to convert the X-parallaxes measured in the stereo-orthophotos, into heights. In each model half of the number of ground control points were used to compute the orientation parameters for deriving the terrestrial coordinates and heights from the measured image coordinates. The other half served as check points. No significant differences were found in the residuals for both groups of points and the indicated rms errors represent the combined result for check and control points. The calculation of the terrestrial coordinates from the stereo-orthophoto model coordinates was based, in all tests, on a linear conformal XYZ transformation. It was found that identical rms errors were obtained for the stereocomparator measurements of the contact size stereo-orthophoto transparencies and the enlarged copies, measured on the Stereocompiler. In both cases, the rms errors, expressed at the scale 1:16 000 of the original images and obtained for position ($m_p = \sqrt{m_x^2 + m_y^2}$) and elevation ($m_z$) for the 92 targeted control points in the overlap, were the following:

$$m_p = 66\ \mu m$$
$$m_z = 52\ \mu m$$

The above values are in agreement with earlier results from the GPM System (van Wijk, 1979). The fact that identical results were obtained for the stereocomparator and the Stereocompiler measurements indicates that the enlargement process, used at IGAC to produce the Stereocompiler transparencies, and the instrumental accuracy of the Stereocompiler do not appear to affect the accuracy which is obtained by the system.

Stereo-orthophotos produced from the two Colombian stereo-overlaps were used to determine the stereo-orthophoto accuracy for terrain conditions, typically encountered in the project. The results obtained from these models may be affected by vegetation, which for the Sudbury test area is virtually non-existant. Also the elevation differences relative to the flying height for one of the models is more representative for Colombian terrain conditions.

The influence of using X-parallax to height ratios, different from the base to height ratio, in the production of stereo-orthophotos, was evaluated for the Colombian test models and a Sudbury model, different than the one used in the previous test. Using a smaller ratio will result in smaller X-parallaxes in the stereo-orthophotos, improving the image quality of the stereomate, but affecting the accuracy, as demonstrated by the results. The rms errors, obtained for contact transparencies of all test models, as measured on the PSK stereocomparator are indicated in Table I.

test model	relative elevation difference	p_x/h	image scale	rms error at image scale		number of
				m_p	m_z	points
Sudbury	2.3%H	0.6455 (= base/height)	1:16 000	68 μm	49 μm	95
"	2.3%H	0.4317	1:16 000	72 μm	57 μm	108
"	2.3%H	0.2891	1:16 000	85 μm	64 μm	96
Colombian	8.4%H	0.6254 (= base/height)	1:20 000	81 μm	76 μm	56
"	8.4%H	0.2811	1:20 000	98 μm	112 μm	60
"	2.2%H	0.5995 (= base/height)	1:53 000	44 μm	44 μm	72
"	2.2%H	0.2957	1:53 000	45 μm	83 μm	65

Table I
rms errors for stereo-orthophotos produced
with different X-parallax to height ratios

The results indicate the accuracy limits of the stereo-orthophoto technique. They have to be compared with the effect of other error sources, such as inaccuracies in identification and measurement of parcel and land use boundaries, which may affect the final accuracy. This was evaluated for a test with approximately 85 typical boundary points which could be identified in the photographs by natural features. The test was performed on stereo-orthophoto transparencies, enlarged by a factor 2.5 with respect to the original 1:20 000 scale photographs. Two operators identified and digitized the boundary points each two times. No significant difference in the results was established for the two operators and their combined result indicate standard errors of 100 μm in position and 57 μm in elevation, expressed at the original image scale 1:20 000, and corresponding with standard errors of 2.0 m and 1.1 m, respectively, in the terrain. The planimetric error in identifying and digitizing non-targeted boundaries exceeds the stereo-orthophoto system errors in Table I and appears therefore to be the limiting factor in the acquisition of the digital data bank information. As expected the standard error in the vertical identification of the boundary points was lower than the standard error in planimetric identification, and is exceeded by the rms vertical errors in Table I, derived for the tests with reduced X-parallax to height ratios. The advantages of improved image quality by the use of smaller X-parallax to height ratios in the generation of stereo-orthophotos must therefore be carefully weighted with respect to the resulting drop in vertical accuracy which may have a significant effect on the final accuracy.

CONCLUDING REMARKS

The experience obtained so far in the pilot project has demonstrated the suitability and versatility of the stereo-orthophoto technique for the acquisition of cadastral information. It has been demonstrated that, for the type of information, to be collected for the rural areas, the accuracy of the stereo-orthophoto system, presently in operation at IGAC, is adequate. The dominant source of errors in the system was found to be in the identification of parcel boundaries in the photographic images. Additional tests are necessary to determine to which extent the stereo-orthophoto technique can be used to digitize the information for built-up areas and at which stage more accurate systems, such as the analytical plotter, will have to be used.

The configuration of the present prototype system at IGAC is capable of processing and storing the amount of data required for a typical cadastral region in Colombia. Although aerial triangulation and the production of stereo-orthophotos and digital terrain models would remain to be carried out centrally at the head office in Bogota, the data acquisition at a regional level, particularly when based on the stereo-orthophoto technique, appears to be a logical and desirable solution.

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