131

COMBINED FILM AND SOFTCOPY PHOTO-INTERPRETATION SYSTEM

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ABSTRACT

There is overwhelming evidence for the fact that image analysis is rapidly moving into the digital domain. Computer workstations serve to analyze pixel arrays, thereby providing the user with automation opportunities otherwise not available. Sensing of visible light imagery has made great strides into the digital arena as well. However, for the time being high resolution metric cameras and film will remain very important means of imaging the earth's surface, the environment and objects in industrial settings for non-real time applications. The problem therefore exists to provide capabilities of using film imagery but to submit this to digital analysis. We are discussing a solution to this need in the form of a system for on-line digitization of film and interactive analysis of the digitized pixel arrays. The result is a combination of state-of-the-art film imaging with state-of-the-art softcopy image analysis.

Key Words: Photogrammetry, reconnaissance imaging, photography, softcopy imagery, computer-based photo-interpretation.

1. INTROCUCTION

Recent decennia have seen various attempts at automating the photo-interpretation process. Two major stumbling blocks prevented great successes from being achieved:

a) image sensing was essentially an analog process resulting in imagery either on film or on analog video tape;

b) analysis technology was excessively expensive when compared to the stereoscopic or single image analysis using a stereoscope and light table or a photogrammetric stereo instrument.

The achievements in automating various steps of the image analysis process were modest enough to not justify a major acceptance of then existing digital analysis technology.

The scenario is rapidly changing at the current time. Tools for the analysis of large pixel arrays are not excessively expensive anymore. Powerful 32-bit personal computers in combination with board level frame grabbing and image refresh memories have led to an ability to configure fairly inexpensive softcopy analysis tools. The need for special purpose hardware is quickly evaporating.

On the imaging and sensing side of the photo-interpretation and photogrammetry process, we are seeing a sharp increase of the availability of digital or electro-optical sensing. However, the majority of these capabilities is a result of a need to transmit images rapidly, in real-time, from the sensor platform to the user. Examples are satellite imaging or military reconnaissance. In those cases where very high resolution, large fields of view and strict geometric accuracy are required, electro-optical sensing can not compete with classical aerial photography. We therefore see a need for devices that accept film based imagery of very high resolution and present this imagery to a softcopy analysis workstation in a form meaningful for automation and the advantages of a computerized photo-interpretation and stereo-photogrammetric analysis.

The current approach to solving this requirement is to systematically scan film imagery, resulting in a large pixel array that, for a high resolution aerial photograph, may well produce 20,000 x 20,000 to 40,000 x 40,000 pixels for one photograph. If in color, this constitutes a data set of 4.8GB per photograph. Such data sets are subsequently submitted to an analysis workstation in a manner that typically overwhelms the capabilities of a low cost approach. Two compromises have therefore been accepted:

a) one sacrifices resolution of the photographic original to not create a large pixel array;

b) one does not take advantage of low-cost image analysis technology but instead creates high-cost special purpose hardware to process the very large data sets obtained in the high-end film scanning process.

We are reporting a development which promises to successfully combine the advantages of low-cost image processing with those of high resolution film imaging into an operational system for film-based, yet softcopy photo-interpretation and stereo-photogrammetry. Applications are expected to range from reconnaissance image analysis via natural resources photo-interpretation to the creation and updating of geographic information systems and map data bases.

Our approach is based on combining an image processing system, geographic information system and a digital camera looking at film into a flexible, versatile system. An initial civilian implementation of the technology is to create, update and generally support a master land data base for municipal utility billing; this is based on land surfaces and types of areas in each parcel within a municipality. Experiences thus far have shown that in one shift 100 land parcels can be processed per day at an accuracy that is equal or superior to that obtained by manual measurements in the field.

2. ISSUES OF FILM SCANNING

A very large selection of film and document scanning systems is being sold at the present time. Applications range from lithographic scanning via desk-top publishing and slide scanning for the graphic arts to cartographic scanning of map separates and finally, scanning of remote sensing source documents in the form of imagery on film. Each of these categories may have its own set of performance criteria and throughput requirements.

In the mapping and photo-interpretation fields the scanning problem differs from other fields since a requirement exists to reproduce in the digital domain the full information content of an aerial photograph at a format of 23 x 23 sqcm. This implies that the pixel size be in the range of 5 to 17 micrometers in the film plane (20 to 70 line-pairs per millimeter, each line-pair being resolved by $2.\sqrt{2}$ pixels). It further implies a geometric accuracy of up to ± 2 micrometers. These numbers result from routine photogrammetric performance of current aerial photographic data. Clearly not all applications require the same level of accuracy. However, the reproduction of the full information content of aerial film does imply that those high-end numbers be met.

Current film scanning is typically based on technologies as listed in Table 1. Note that systems for systematic off-line scanning vastly dominate over the occasional occurrence of on-line scanning systems such as those by GSI, Helava and Rollei (Table 2).

Table 3 presents a list of current film scanning vendors with major parameters for those systems that might occasionally or routinely be used for the scanning of aerial photography. It is easy to conclude that tools for film scanning are not a frequent offering on the commercial market. It is further evident that the implemented technology in these systems is dated. It is typical that a single aperture (dot) is mechanically guided across the film format so that a pixel array is tiled from a great number of individual point observations. This is the solution implemented by major vendors, e.g. Optronics, Perkin-Elmer and Joyce-Loebl.

Innovation in film scanning is needed for cost reduction at high performance to support the low cost approaches to digital image analysis and to make digital analysis superior to the common manual interpretation of photographs under a magnifying glass or stereoscope. We will report on our technical contribution in Chapter 4.

TABLE 1: Major approaches to film and document scanning (see Leberl et al., 1988)

A. Off-Line Scanners

- Drum Scanners
- Flat Bed Scanners
- Moving Spots
- Moving Linear Arrays

B. On-Line Systems

- Moving the Film
- Moving the Camera
- Reseau-Based Systems

TABLE 2: Photogrammetric on-line scanning systems (from Brown, 1988; Helava and Seymour, 1988; Luhmann and Wester-Ebbinghaus, 1986)

NAME	COMPANY	COMMENT
DCCS	HELAVA ASSOCIATES, INC.	STEREO POINT MEASUREMENT PRECISION STEREO COMPARATOR
AUTOSET	GEODETIC SERVICES, INC.	AUTOMATED POINTING TO INDUSTRIAL POINT TARGETS; PRE-CISION MONO-COMPARATOR
ROLLEI-METRIC	ROLLEI GesmbH	FUNCTIONALLY SIMILAR TO AUTOSET, BUT BASED ON RESEAU-APPROACH

3. COMPONENTS OF AN INTEGRATED FILM-BASED PHOTO ANALYSIS WORKSTATION

We are introducing a computer workstation concept that combines a digital image processor and film reading equipment into a novel tool for high resolution, high accuracy image analysis. Figures 1 and 2 outline both the hardware and software configuration concepts, Figure 3 presents the workstation. As one can extract from Figures 1 and 3 that the hardware consists of a group of sub-components as follows:

a) the computer with common peripherals;

TABLE 3: Comparison Between Some Current Film Readers/Scanners (Preliminary)

	RESO-LUTION	SPEED 4000X5000 PIXELS	FORMAT	COST U.S. $	ACCUR-ACY	RESO-LUTION SETTING
EIKONIX	4,000 PIXELS	A FEW MINUTES	MANUAL ZOOM	30,000	1 PIXEL	FIXED
JOYCE-LOEBL	25,50 100 etc μm	A FEW MINUTES	30 cm x 40 cm	66,000	1 PIXEL	STEP
DATA COPY	4,400 x 3,400	A FEW MINUTES	VARI-ABLE	36,000	1 PIXEL	FIXED
OPTRON-ICS	12.5, 25,50, 100μm	2 HOURS	23cm x 23cm	100,000	10μm	STEP
PERKIN-ELMER	5,10, 20,50 100μm	MANY HOURS	23cm x 23cm	150,000	3μm	STEP

b) the image analysis sub-system consisting of board level imaging products or a packaged image analysis system;

c) the film stage and image scanning component consisting of a light table and digital array camera;

d) the user interface hardware consisting of a video display terminal, a mouse and digitizing tablet, voice recognition and color image display monitor with graphics overlay;

e) other input and output peripherals such as a color hardcopy printer.

This hardware configuration is sufficient to provide a single-image interpretation approach, whereby the imagery itself may be on an uncut roll of film or individual photographs. If the hardware is to be configured for a stereoscopic system two additions are required:

f) a stereoscopic softcopy display;

g) either a second light table and image conversion unit or software to support the sequential grabbing of homologous image segments from two photographs on one film stage using one camera.

The software is very elaborate. Figure 2 describes the great range of software function groups that will be implemented in a widely usable softcopy analysis workstation.

Note that the central elements are clearly the following:

a) the system software and user interface which jointly form the backbone of the system driving all the hardware and passing data from one software component to the other autonomously or under user control;

b) photogrammetric software for processing of coordinates to register images to the real world, images to one another and maintain numerous coordinate systems (geographic, UTM, screen, table and photograph);

c) generic image processing to manipulate the geometry and radiometry of the pixels that have been converted from film to softcopy format;

d) pattern recognition software to automate analysis tasks or to support by computer the interactive work of an operator;

e) application software that is specific to a particular problem domain, for example the extraction of impervious surfaces from aerial photography per land parcel to support the creation of a data base for utility billing, or the extraction of vehicles from long range oblique military reconnaissance imagery;

f) geographic information systems software to manipulate data about the land in symbolic form, for example digitized maps or information extracted from imagery.

Note that the various software components do not stand all by themselves, they instead interact with one another. This may lead, for example, to the support of change

FIGURE 1: ARGUS hardware components

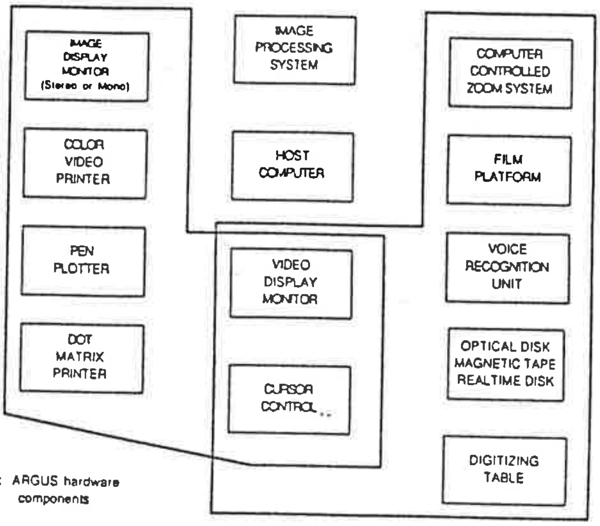


Figure 1: ARGUS hardware components

FIGURE 2: ARGUS Software Function Blocks

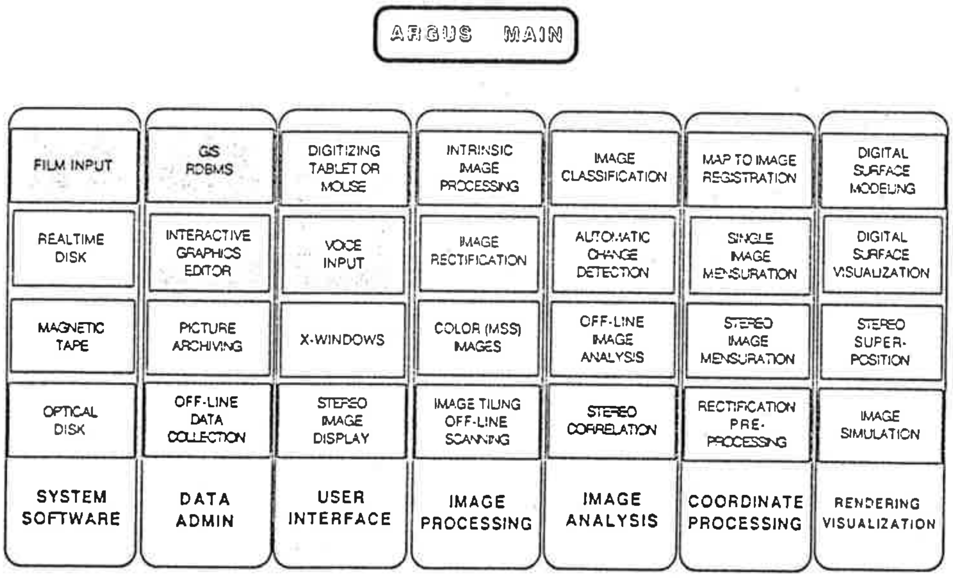


FIGURE 3: Film-based softcopy image analysis workstation ARGUS

detection by automatically comparing what is stored in the GIS with the contents of an aerial photograph. The major software function groups can of course be decomposed into sub-groups; however, a detailed description of those sub-groups is beyond the scope of this paper.

4. ON-LINE FILM SCANNING

It has become a frequent approach in stereo-photogrammetric systems to equip the optical train of an analytical plotter with a half-silvered mirror through which an image is cast onto a CCD array camera. In this manner the photogrammetric mensuration stage becomes an on-line film scanning system that converts windows of imagery instantaneously into pixel arrays ready for automated analysis.

Table 2 has enumerated three commercial systems that utilize that kind of approach in a manner that is proprietary to the vendors. Simultaneously, of course, there are numerous photogrammetric research institutions that employ various customized approaches. One can classify all of these as on-line film scanning since there is no systematic creation of a large pixel array and also no need for such an array. The analysis is always by window and no more than that window is needed in digital form. The classical application of this approach is twofold:

a) the image windows are used in a stereo instrument to support automated stereo correlation;

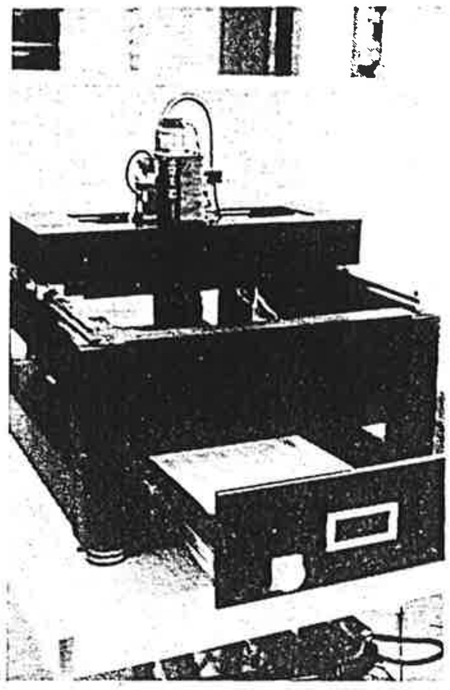
b) specific well-known objects are automatically located in the image windows and used in a manner similar to an astronomical star comparator for the identification and marking of well-known, often also symmetrically arranged targets in the imagery.

The latter approach is evident in the systems by GSI and Rollei.

We are proposing a new on-line scanning concept that differs from the current ones by the ability to very precisely grab windows individually and then combine them into a larger array. This is achieved without a need for high optical-mechanical accuracy. It supports the use of a computer driven zoom system so that, at the discretion of the user, the magnification and therefore the window size can be changed under software control. We achieve this by placing an invisible reseau grid into the film plane. Figure 4 presents a photograph of a prototype of Vexcel's CPRIME on-line film scanning system.

At the current time the CPRIME on-line film scanner supports a format of 10" x 20" and a magnification range from 1 to 10; the smallest pixels can be 12.5 micrometers in diameter, the largest 125 micrometers. Preliminary tests have demonstrated that the approach is accurate to well within a fraction of a pixel.

FIGURE 4: CPRIME film scanner



The typical utilization of the type of scanning arrangement is in the form that we denote as "mensuration frame grabbing". With this concept we describe the fact that the analysis system can grab an image window of arbitrary magnification and size, and at an arbitrarily specified location at any time and bring it on the screen. Thereby, we maintain extreme accuracy among the pixels grabbed in individual windows. The reference among the image windows is maintained by the utilization of the invisible reseau. The on-line scanning can also be operated as an off-line scanner by systematic tiling of image windows into a large seamless pixel array. Another approach to image digitization is the creation of an image pyramid built from an un-tiled array of individual image windows. Typically a need for a large seamless image pixel array exists only if work is to be done in a systematic manner for large images without human interference. As soon as interactive work needs to be done a user will always only view the data set through a window. Therefore, the need to tile the individual windows into a seamless data array may not really be all that great. We have seen in some military management workstations that the underlying data arrays are simply organized as overlapping windows to support rapid access and anticipatory pre-loading of windows to support fast, interactive work. This may be advantageous over the utilization of a seamless pixel array where the extraction of individual windows of a specific pre-determined or selected size may be slowed down by the search processes that one needs to go through.

5. SOFTCOPY IMAGE ANALYSIS

Photo-interpretation and photogrammetry have long argued the doubtful advantage of analyzing imagery in the form of softcopy when the original source material is not electro-optical. These doubts are gradually disappearing with the advent of techniques to maintain the quality of the original data in the softcopy environment and with the increase of computing power to actually implement automation functions in competitive ways and at competitive accuracies. In photogrammetry the major utilization that has been made of automation of softcopy image segments has been with image correlation for automated parallax detection. More recently utilization has been widened to include the transfer of points and features from one image to another to support the automation of a process called in photogrammetry "Aero-Triangulation".

In our work on the film-based softcopy workstation we have implemented a number of automation tasks on single images to support the extraction of linear features and areas om aerial photography. In particular, we ..ave been concerned with the problem of developing a data base of municipal land parcels containing roof lines of buildings, outlines of driveways, decks, swimming pools and the like. We have implemented various algorithms to attempt to extract roof lines autonomously or interactively with accelerated throughput compared to an un-aided approach. Figure 5 illustrates the concept of detecting edges along roof lines. One technique is based on a histogram in a window taken of the roof and the surrounding non-roof area, it links the edges to extended straight lines, intersects the lines so that corners are built, and completes the roof polygon by squaring the resulting line work.

With an unaccelerated workstation computer the process of automatically detecting the outlines of roofs are not faster than the manual approach. In order to offer a speed advantage, algorithms have to be developed that are running in parallel on various parcels or run autonomously without an tending operator.

We have found that the manual process of outlining features in the image may not be as accurate as automated processes if operations are done under the pressure of time. Therefore, we have implemented support functions that permit the operator to interactively digitize features without concern for accuracy. However, the computer will post-process the line work generated by the operator and place it where an algorithm will optimally find that line work in the pixel array.

The promise of softcopy analysis of data that were originally on film depends entirely on ones ability to offer a significant throughput and accuracy advantage over manual methods and classical instruments. Without those throughput advantages there may only be logistics advantages in combining film data with digital geographic information in a convenient manner (the so-called "image back-drop" approach).

The true promise of this kind of technology is in the autonomous updating of existing data bases. Data stored in a GIS and registered to a film image can be compared with that film image through pattern recognition that is being guided by the GIS data and analyzes the pixel arrays to detect where the film does not corroborate what the GIS data base contains; or, vice versa, where the image contains data of a type that is suspected to be of relevance to the GIS but that the GIS does not contain.

6. WORKSTATION PERFORMANCE

In Chapter 3 we have described the overall system components and in Chapter 4 our implementation of an on-line film scanning concept to support the softcopy analysis of film-based data. We have configured a system that we have thoroughly tested and that is now in operation at the City and County of Denver to create a master data base for the Public Works Department and the City Assessor to, first of all, bill for the storm drain utility and secondly to support the Office of the Assessor. In Denver, a total of 540 assessor maps had to be digitized and converted to a seamless GIS data base consisting of 165,000 parcels. Our workstation is currently being utilized by City employees to amplify that assessor data base by adding on, in each parcel, those surfaces that are impervious to rain water. This is being done with an accuracy equal or better that 3% of the true area that is impervious.

At the current time 120 parcels are being processed per day. This is in contrast to the manual technique that was based on City Inspectors going into the field and assessing the impervious areas manually. What is being done in a few minutes per parcel used to be done in a process of perhaps one to two hours per parcel in the field.

The advantage of the current system is, of course, that all information is available in a spatial organization that lends itself very well to graphical visualization both on the display monitor and as a hardcopy plot. The measurements taken in the field and the classical methods used by the assessor were not supporting a map data base. Instead the information per land parcel was simply kept as a set of entries into a table without a shape description, let alone a rigorous city wide coordinate basis.

The true advantages of the approach become evident when data collected earlier need to be revisited at a later time. These revisits might be caused by disputes between the City and land owners or might be just part of a routine updating process of an existing data base using new photography.

The utilization in a municipal environment for creating and updating a master data base does not necessarily require stereoscopic coverage and stereoscopic analysis. Classically, municipal data bases do not even contain a Z coordinate. However, our concept would also support a stereoscopic approach. Depending on the throughput requirements and the degree of interactivity of the system one can add a second film scanning device that will be supported by the software to grab two image segments for stereoscopic viewing and analysis. If the cost for a second system is to be avoided then an option is to grab the two film segments by using one camera and one film carrier but two sequential mensuration frame grabbing operations. If thorough analysis of an image window is required, then the time of that analysis will be long enough so that other image pairs can be grabbed in anticipation while the analysis takes place of the initial pair.

7. CONCLUSION AND OUTLOOK

It is to be expected that electro-optical imagery will not be able to supplant current film cameras in those applications that require highest resolution and geometric accuracy. The film camera that is being used in the mapping field is supporting an accuracy of 2 micrometers and offers a field of view of 20,000 x 20,000 pixels to 40,000 x 40,000 pixels imaged instantaneously.

The current electro-optical sensing technology typically supports high radiometric resolution but cannot support the same geometric accuracy that a film camera currently supports. The motions of the airplane lead to a kinematic imaging process that destroys geometric relationships between features imaged in different along-track locations of an electro-optical image.

Even if an electro-optical equivalent to an aerial mapping camera were to be available today it would still be unlikely that the price would be such that the vast established base of cameras and infrastructure would simply be abandoned. Unless there is a clear cost and performance advantage in those parameters that are important to the mapping disciplines, the electro-optical sensors will not be accepted.

Clearly they are accepted in those circumstances where geometric resolution is not a high requirement but where real time links between the sensor and the analyst are of relevance or where the sensor cannot be brought back to the analyzing institution such as is the case in satellite imaging.

We have described the approach that we have been using in configuring a workstation that analyzes digital pixel arrays while the source data are on film. Major innovations are the manner in which the film is being brought into the computer and the manner in which the user interacts with the data incorporating a geographic information system, pattern recognition, photogrammetry and image processing.

The approach to on-line film scanning can also be supported by the use of an optical disk or similar storage device that contains image windows that are created off-line. The advantage of that approach would be that to the workstation user it would not really matter whether an optical disk or an aerial photograph with on-line scanner is available. The issue is merely one of work preparation, throughput and organization.

A systematic use of our type of approach by many operators in close proximity may be organized better by the use of disk systems that hold the mensuration frames grabbed on a single film scanning device thereby having one device supporting multiple analysis workstations. However, if a single user is to work on film images and no need exists for multiplexing several workstations, then there is no need for large pixel storage peripherals. The additional advantage of an on-line operation is the flexibility of grabbing frames at a large range of magnifications and in arbitrary locations, whereby great metric accuracy will be maintained.

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