PRECISION SCANNING OF AERIAL PHOTOGRAPHY

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ABSTRACT

The successful introduction of digital photogrammetric systems or so-called softcopy photogrammetric workstations is contingent upon an ability to convert current aerial photography into digital pixel arrays in a manner that preserves the geometry and thematic contents of the metric photography. Therefore, scanning of photogrammetric material becomes a crucial issue.

This paper discusses a innovative scanning device that is available to scan transmissive photogrammetric material at resolutions between 8.5 and 165 µm and with accuracies in the range of 0.1 pixel. Scanning speeds are at 2 minutes per photograph for 120 µm per pixel to 40 minutes per photograph at 25 µm per pixel producing an 81 MB file per photograph.

INTRODUCTION

The analog to digital conversion of film originals is a technology driven by the demands of the graphic arts market. As a result, there exist high-end scanning devices for color separation, typically for centralized service bureau operation that provides for high performance at high cost. On the other end of the spectrum, that same market provides for a requirement of desk-top or desk-side scanning for photo retouching or design of graphic materials. For that application, a much lower performance at much lower cost is acceptable.

The vast requirement for document scanning presents a second driver for the development of scanning technology. In that case, however, the requirement is for scanning of opaque material at low radiometric resolution and comparatively low geometric resolution as well. The application is to scanning of line work on drafting material, or of printed text.

None of the existing drivers satisfy the requirements that the photogrammetric applications have: high geometric accuracy at reasonable radiometry and cost. We, therefore, describe in this paper an innovative scanning system that has been shown for the first time in 1990 but has in the meantime matured to a fully functional and deliverable solution to address the photogrammetric scanning problem.

The design emphasizes geometric accuracy in combination with low cost. As a result, the scanner is the enabling technology that permits one to put together a production facility for photogrammetric mapping that is less expensive per workstation and promises higher productivity per person than conventional analog or analytical approaches to photogrammetric mapping.

SCANNING TECHNOLOGY

There exist three major ways of converting film originals into pixel arrays (Leberl et al., 1988). These are built around:

a. The use of photo multiplier tubes collecting one pixel at a time and obtaining a seamless array of pixels by moving the light sensitive module over the document in a meandering fashion. This is implemented with rotating drum technology.

b. The use of linear detector arrays will convert a whole row of image gray values into pixels at the same time and a seamless square array of pixels will be created by moving the linear detector array in a dynamic mode over the film original. This may be done by a single sweep over the document or, if the ultimate pixel array is wider than the width of the individual linear detector array, then a meandering motion over the document will need to be applied. This technology uses both drums and flat beds.

c. The use of square array CCD's is typically denoted as "step-and-stare." The original is decomposed into windows or tiles which are individually converted into pixel arrays. A large seamless array is then created by "tiling" individual tiles or windows into a seamless result. The implementation is always on a flat bed.

These various approaches have advantages and disadvantages with respect to one another which are typically discussion in terms of "conventional wisdom" with little scientific basis. The statement is often made that highest-quality scanning is only available if a photo multiplier tube is used because "only such tubes have the light sensitivity sufficient for highest quality radiometry" for analog to digital conversion. The conventional wisdom furthermore states that "faster scanning is available with the use of linear detector arrays" because only a single sweeping motion over the document is needed to convert an analog original into a pixel array. And finally conventional wisdom states that the "step-and-stare approach will be unable to avoid visibility at the seams where individual tiles abutt."

THE VX-SCANNER WITH INVISIBLE RESEAU TECHNOLOGY

This paper is not the correct place for a scientific analysis of erroneous statements of conventional wisdom. Instead we *demonstrate* by implementation of our VX-scanner the use of a specific scanning technology resulting in the best price-performance ratio available today for photogrammetric scanning. This was described for the first time at an ISPRS-conference (Leberl, 1990). Photogrammetry requires a scanning technology that is first and foremost *geometrically accurate*. Moving drums and kinematic scanning with the help of linear detector arrays can only be made to work accurately if precision mechanical motion is implemented which typically leads to significant costs to achieve significant accuracy.

We have employed a calibration grid or reseau which would be unacceptable to use in a conventional manner in which photogrammetry has been using reseaus for geometric stabilization of film deformation in metric photography. This unacceptability would be the result of having a digital image with many reseau crosses covering up the relevant image content. To avoid this interference between the reseau and useful image content, one needs to make the reseau *invisible*. As a result, we are describing a scanning system based on *invisible reseau technology*.

The implementation of scanning is described in Figure 1. A square array CCD moves into a position at which a square window of imagery is to be digitized and images a reseau. From that image the precise geometry of the camera can be reconstructed. One now removes the reseau (makes it invisible) and images the object itself. Using the precise camera geometry, the object window is now placed into its proper location in a large array. By careful calibration of

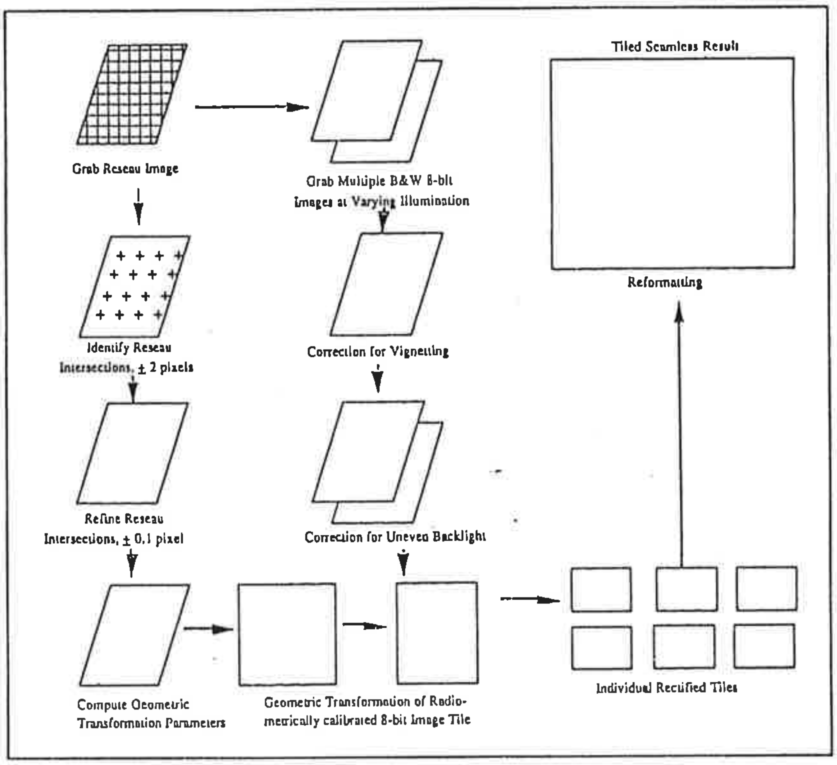

Figure 1. Principle of operation of the VX-scanner using an invisible reseau.

geometry and radiometry, one can assemble individual windows or tiles into a large seamless array of the size that is essentially unlimited.

How does this approach get implemented to produce high radiometric accuracy? Very simply stated radiometric *accuracy* is a result of carefully calibrating all effects on the radiometry that may result from lens vignetting, irregularities in the CCD, illumination differences, ambient light and temperature effects. Radiometric *resolution* is a result of taking advantage of the "step mode" of the approach: one can image an individual tile as often as one likes and under as many circumstances as one wishes to reduce any effect of noise and to increase both range and resolution of the radiometric recording.

How can one accomplish great speed? First and foremost, speed is a result of ones ability to read out the data from the digital sensor and to subsequently process the data on the controller prior to delivery of the digital pixel array to its final use. The speed can be made appropriate to the cost and currently available technology. Essentially there is no speed limit other than the mechanical motion of the camera. However, there is a strong tradeoff between cost and speed which is dictated by the use of specific computing hardware and by the use of certain sensors. In our current work, we have opted for a priority of cost over speed and have created a scanning system that produces a 100 MB image file in about three-quarters of an hour. One can easily increase this if one were willing to let cost grow.

A DISCUSSION OF PERFORMANCE

Our step-and-stare approach of scanning, which is based on the use of an invisible reseau, allows one to create a scanning device that is very rich in functionality. In effect the same device can serve as

a. A computer-driven *light table* to roam and zoom over an image and selectively inspect various areas at various resolutions by indirectly viewing a computer screen in live video mode.

b. It also is and can be a *monocomparator* if an individual tile is being grabbed and a cursor is being used to measure specific pixels. Because of the use of the invisible reseau, any pixel coordinate will be correctly transformed into the reseau coordinate system. This permits one to measure fiducial marks, define an image coordinate system and even perform a resection in space or relative orientation prior to scanning.

c. Most importantly the device can be used as a *scanner* scanning at any arbitrary resolution between the two extremes that are defined by the hardware. In the implemented mode, this range is limited by 8.5 µm on the high end and 165 µm on the low end.

These basic principles combine now with specific software to offer additional capabilities such as scanning individual sub-areas of a larger area into a coordinate system defined in the comparator mode by measuring fiducial marks. It furthermore permits one to scan into rotated coordinate systems. It allows one to define regions of interest in an image and sequentially scan one or more of those in an unattended mode. It permits one to produce a scan directly in an epipolar coordinate system rather than in the system of the reseau lines or in a photo coordinate system. It scans color by sequentially exposing an individual tile through a red, green and blue filter. And it allows one a choice of transformations between density on the original film and the digital number recorded in the computer.

We have been able to demonstrate that careful calibration produces a radiometry with a root mean square error of less than $\pm$ 1 digital number. As we stated earlier, the throughput is based on 40,000 pixels per second, considering the *total process*. This results in the following:

Pixel Size	Throughput	File Size per 9"x9" Photograph	Photos per Year 1 Shift-1 System
25 µm	40 min.	81 MB	3,000
50 µm	10 min.	21 MB	10,000
120 µm	2 min.	4 MB	35,000

The system is implemented in such a manner that multiple images can be scanned in one scanning operation. This means that small format photography, such as 36 mm slides, can be mounted simultaneously and can be individually scanned in an uninterrupted mode into individual files after proper setup of the scan. Aerial photography is scanned in pairs where two images are loaded and then scanned in an uninterrupted mode. As a result a single shift use of the equipment will permit one to scan: 56 photographs in one week, 245 photographs in one month, and 3,000 photographs in one year at a resolution of 25 µm.

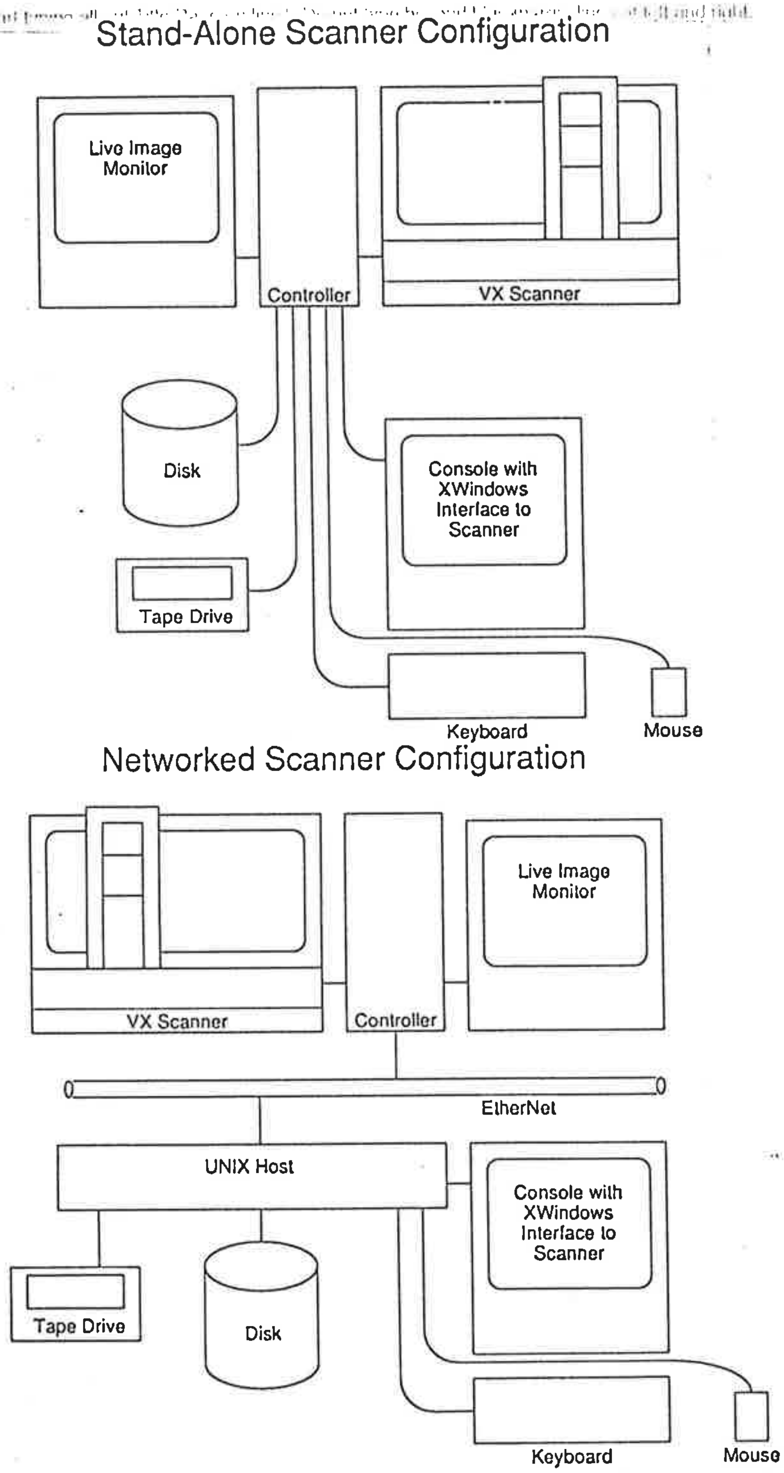

Figure 2. Examples of integrating the VX-scanner into a local area network, or setting it up as a stand-alone device.

SYSTEMS INTEGRATION

The conventional use of film scanners is as stand-alone devices that are operated independently of an existing computer network. The solution described here can be operated in this manner as a stand-alone device with a large disk and/or magnetic tape drive. However, the more economical use of a scanner is as an integrated part of a local area network on which several photogrammetric and GIS workstations operate. The advantage of this approach is that the user interface for the scanner can be shared with any of the user interfaces of any one of the other workstations and that the resources for storage that are available on the existing local area network can be shared with the scanner. Therefore, the control of operations and management of the scanner operation is simplified and can be monitored from one of the existing workstations which is being used for other purposes. Therefore, the use of human labor is minimized in the scanning operation itself. Figure 2 shows two examples of typical configurations of the current scanner.

CONCLUSION AND OUTLOOK

We have described in this paper a scanner system that is based on the innovative technology of an invisible reseau which permits one to accomplish very high accuracy to within a tenth of a pixel while maintaining great flexibility in functionality such as roaming, zooming, continuous selection of geometric resolution and high radiometric resolution and accuracy due to the ability of repeat imaging in the step-and-stare mode. The approach produces the best cost benefit ratio for photogrammetric applications, which in contrast to conventional film scanning values geometric accuracy very highly.

The technology is available for the scanning of transmissive film material. However, it is as well applicable to opaque material. We expect that the further technical assessment and verification of this innovative scanner system will verify its appeal to photogrammetric applications.

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