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Programmetric Tools for panoramic sector scan imagery in the VIDARS analysis station

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Abstract

Computer-assisted photo-interpretation is a recent development supported by the advent of numerous interpretation stations. A unique universal station is VIDARS--manufactured by the Richards Corporation of McLean, Virginia--since it has recently been equipped with a new software system that incorporates complex photogrammetric mensuration capabilities. Photo-interpreters typically find it difficult to perform mensuration tasks; therefore the implementation of the photogrammetric functions must not burden the user with a need to understand photogrammetric theories. This paper illustrates a difficult application of VIDARS to sector-scan panoramic film (Long Range Aerial Panoramic--LORAP) imagery and will show how well the user can perform target positioning tasks within his interpretation work.

Introduction

Typical photo-interpretation (PI) techniques have in the past limited themselves to the measurement of object and target dimensions, but have excluded the determination of object position. This was left to photogrammetry and its elaborate manipulation of image measurements, ground control, least squares adjustments, linearization of non-linear equations and interactive computing techniques.

However, recent computer-assistance for PI stations not only has made the traditional work more efficient, but has made it possible to enlarge the range of tools for the photo-interpreting non-photogrammetrist. The Video Imaging, Display and Recording System (VIDARS), manufactured by the Richards Corporation in McLean, Virginia, offers the usual methods of measuring object dimensions, but also a set of analysis functions previously unavailable in this form to the PI.

Interpretation systems for all-digital images exist in specific settings for more than 10 years. This should not, however, mislead one to believe that computerized techniques for the PI-analysis of film images have a much longer history. In fact, this has not become accepted practice even today. However, today a number of hybrid systems exist, both for reconnaissance as well as for geo-science applications (see References 1-4, 6, 8-12). Such systems exploit the fact that film-based imagery of extremely high resolution will continue to co-exist with all-digital imagery and image processing techniques.

It may be relevant to point out at this time that in both the all-digital as well as film-based hybrid analysis settings, positioning methods from reconnaissance images are conceptually independent of the medium, they do not only apply to film images. They can be equally well employed with digital sensing systems.

This paper describes the application of the recently configured VIDARS-equipment to position extraction from panoramic sector scan imagery. To this end the VIDARS-configuration and overall software capabilities are described; the geometry of sector scan imagery is illustrated and the strategies of determining positions from that type of imagery are outlined.

Actual predictions of positioning accuracy are based on sample computations with fictitious data. Therefore the conclusions are based on so-called "error propagation" through the photogrammetric equations. It will be shown how an image identification error of the

+/- 1mm will limit the accuracy of the results: the aircraft positions along-track (XO), across-tract (YO) and in height (ZO) can be reconstructed with the help of ground control points to an accuracy of +/-120m in XO, +/-110m in YO and +/-77m in ZO. New targets can be positioned with accuracies ranging from +/-155m to +/-600m, depending on the scan angles, density of known ground control points and of image identification accuracies. A smaller image identification error, of for example +/-0.1mm, will lead to proportionally smaller errors of aircraft and target positions.

VIDARS--A computer assisted work station for the analysis of film images

The Video Imaging, Display and Recording System (VIDARS) was introduced in 1983 (Reference 6). Recently it has been reconfigured around a Digital Equipment Corporation computer, currently a PDP Micro 11/73 and a new software system has been created with the following typical functions:

- quick scan of a roll of images and rapid entry of target information into a target data base;
- quick revisits of previously analyzed rolls of images;
- support of classical PI mensuration techniques to determine object dimension in plan and height;
- extraction of target positions from a single image;
- extraction of target dimension even if the target extends over several images;
- manipulation of known ground information;
- manipulation of aircraft position and attitude data;
- target data processing and reporting;
- application to:
    - metric frame photography;
    - non-metric frame photography;
    - oblique photography;
    - multi-lens photography;
    - panoramic (vertical, oblique, sector-scan);
    - radar; and
    - scanner images;
- helpful graphics support functions.

Figure 1 presents the overall VIDARS configuration with its light-table, video camera, video monitor, computer terminal, etc. Details show the auxiliary device for rapid film positioning (FIPS).

A strength of the system is its totally new software. The major function blocks are shown in Figure 2 (a) presenting menus as they appear to the user on the computer terminal. The most interesting function block deals with measurements on the images; the relevant menu is in Figure 2 (b).

It would go beyond the scope of this paper to describe the VIDARS hard- and software in any detail. However, it may be relevant to point out that the guiding principle in the software creation was to avoid overloading the PI-user with decisions; no photogrammetric training is needed to operate the software and to take advantage of sophisticated photogrammetric capabilities.

Sector scan panoramic geometry

One example for the capabilities of VIDARS is its use with sector scan panoramic images. These are typically not created for the purpose of precise positioning. Neither the camera manufacturer nor the image acquisition procedures nor the analyst consider positioning a major concern with such imagery. Instead, this type of imagery serves in Long Range Aerial Panoramic (LORAP) high resolution interpretation of targets.

However, positioning is feasible. While still an exotic capability to the PI it may be of use when offered in a manner that provides photogrammetric solutions in a "black-box" format.

LORAP sector-scan panoramic scanning at long range produces images of peculiar geo-

Figure 1: (a) Photograph of the VIDARS equipment.
(b) Detail showing the film roll and video camera.
(c) Detail showing the film indexing and positioning system.

Figure 2: (a) Main menu of the VIDARS software.
(b) Menu of the image set-up function block.

metry. Figures 3 through 5 will illustrate this geometry to highlight some of the parameters with which VIDARS-positioning is being concerned.

Figure 3 (a) is merely a UTM map projection of a regular pattern of meridians and parallels at a geographic latitude of 40 N. The projection deformation is not well visible to the casual user of such maps.

However, the same grid pattern is extremely deformed on a panoramic sector scan image (Figure 3 (b)). Along a scan from 30 below the horizon upwards towards the horizon the grid lines merge.

From a flight altitude of 15,000 meters above ground and with a focal length of 72", the image scale ranges from 1:17,000 at 30 below the horizon to 1:65,000 at 0. Figure 3 (c) illustrates the imaging arrangement. The spherical Earth is imaged at a distance of 26km from the aircraft nadir to 437km at the far range. Slant distances are 30km at 30° scan angle, and 438 at 0.

We are interested also in forward oblique sector scan imagery. Figure 4 presents the image geometry of the same grid of meridians and parallels when the forward angle is 30°.

Generally a PI does not concern himself with the perturbations of the flight while images are being taken; this is usually considered the realm of photogrammetry. However, new equipment brings photogrammetric capabilities to the fingertips of the PI. Flight perturbations may therefore become of PI interest in the future.

Figure 5 attempts to illustrate the effects of aircraft attitude perturbations on panoramic sector scan images. Figure 5 (a) is an unperturbed section of the grid that was also shown in Figure 3 (b). Figures 5 (b) and (c) present the effects of uncorrected yaw and tip angles of 5°.

If such angles were unnoticed and uncompensated in the computations then they alone would lead to position errors as follows: 5° tip: 0.16km at 30° scan angle, and 22km at 3° below the horizon.

The scope of this paper prohibits one from going into any details of the imaging geometry. It should be noted, however, that various cameras lead to various mathematical models and measuring strategies. Questions may arise regarding roll stabilization, roll rate compensation, fiducial marks, image forward motion compensation, etc.

Some of these questions have been addressed in reconnaissance photogrammetry; when utmost precision is required then the mathematical and statistical model is important. An interesting example of such modeling is the series of reports on panoramic imaging from Milano, Italy (References 5 and 7). The current context is not seeking the ultimate accuracy; instead it is seeking robust solutions for the non-photogrammetric user.

Positioning accuracy

Definition of positioning

A user may only be interested in the horizontal position of a target scan on a single sector scan panoramic image. However, "positioning" relates to the camera and platform as well. In particular, the computation of target position may involve the prior computations of the camera position and attitude angles.

It is understood here that we deal with individual sector scan panoramic images on an uncut film roll. No stereoscopic measurements are taken.

"Positioning" seeks to determine absolute horizontal ground coordinates in a user--selected coordinate system. Height coordinates are not the purpose of the exercise. It is assumed that the absolute height of the target area is known.

Clearly, if all 3 target coordinates must be computed then more than one image must be available. However, long range sector scan pan imagery does not lend itself to promising solutions for all 3 coordinates. Therefore, the single image approach to the absolute horizontal coordinates is considered here.

Experimental data

In order to test the VIDARS positioning capability we performed a series of numerical experiments. We chose a flight height of 15,000m above ground, and a sector scan geometry with:

72" focal length;

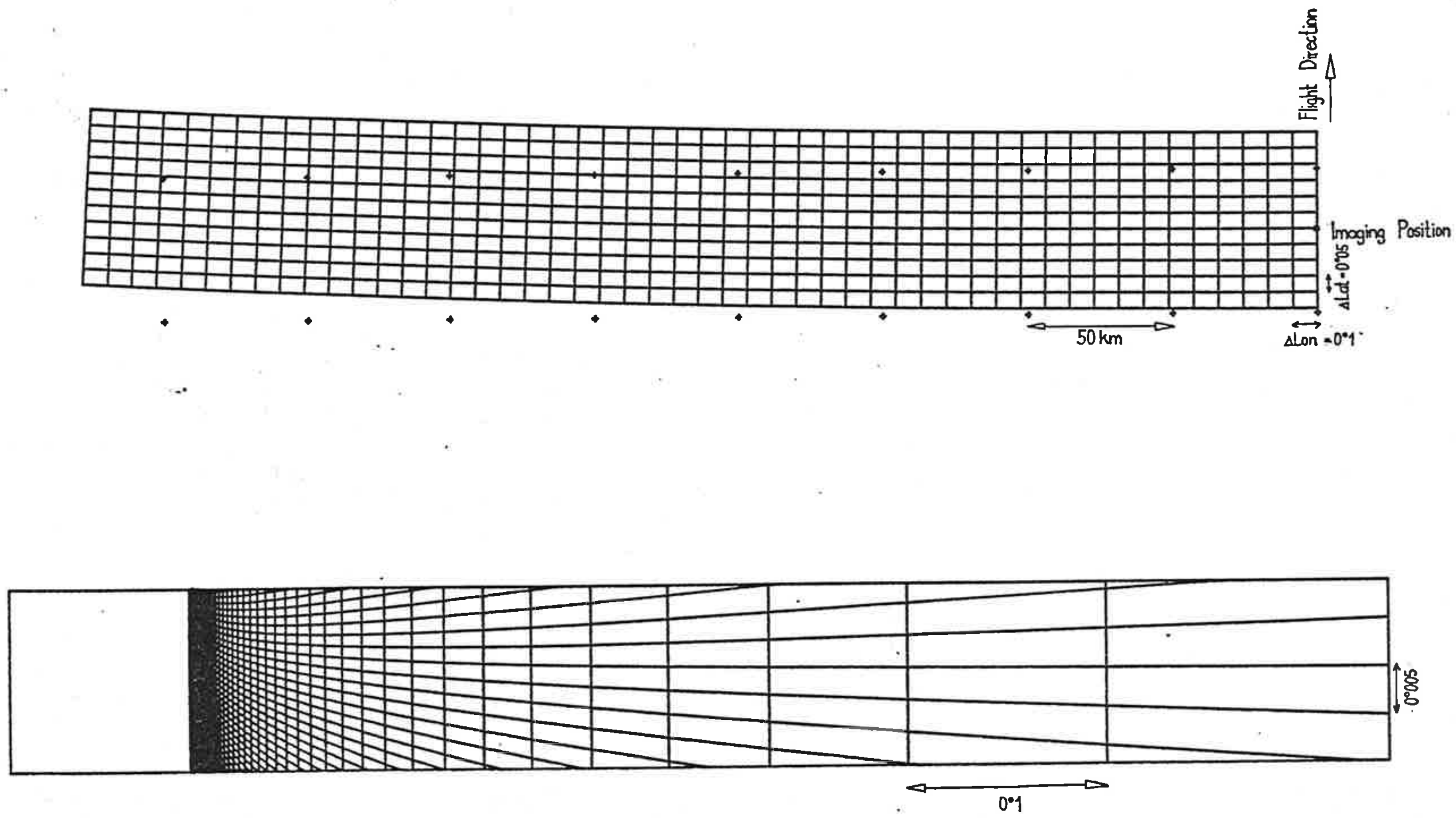

Figure 3: (a) UTM projection of a regular arrangement of meridians and parallels on a spherical Earth.
(b) Sector-scan panoramic geometry of the grid of meridians and parallels, using a scan angle of 0° to 30° from a flight altitude of 15,000m above the ground and 72" focal length.

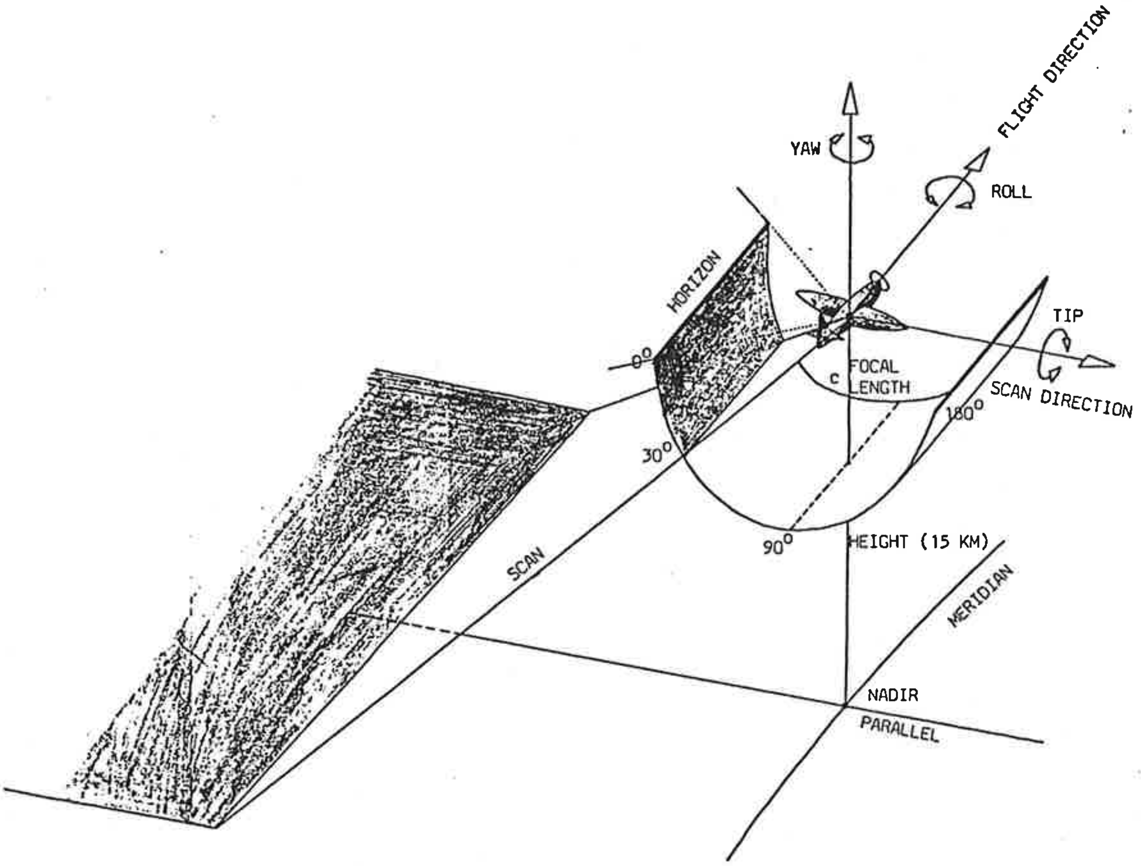

Figure 3: (c) Imaging arrangement for the example (5).

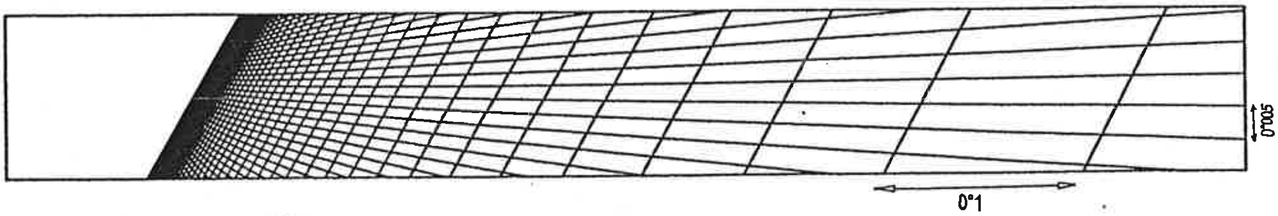

Figure 4: Forward oblique (30) sector scan panoramic geometry, flight height is 15,000m above ground, 72" focal length, scan angles 0° to 30°.

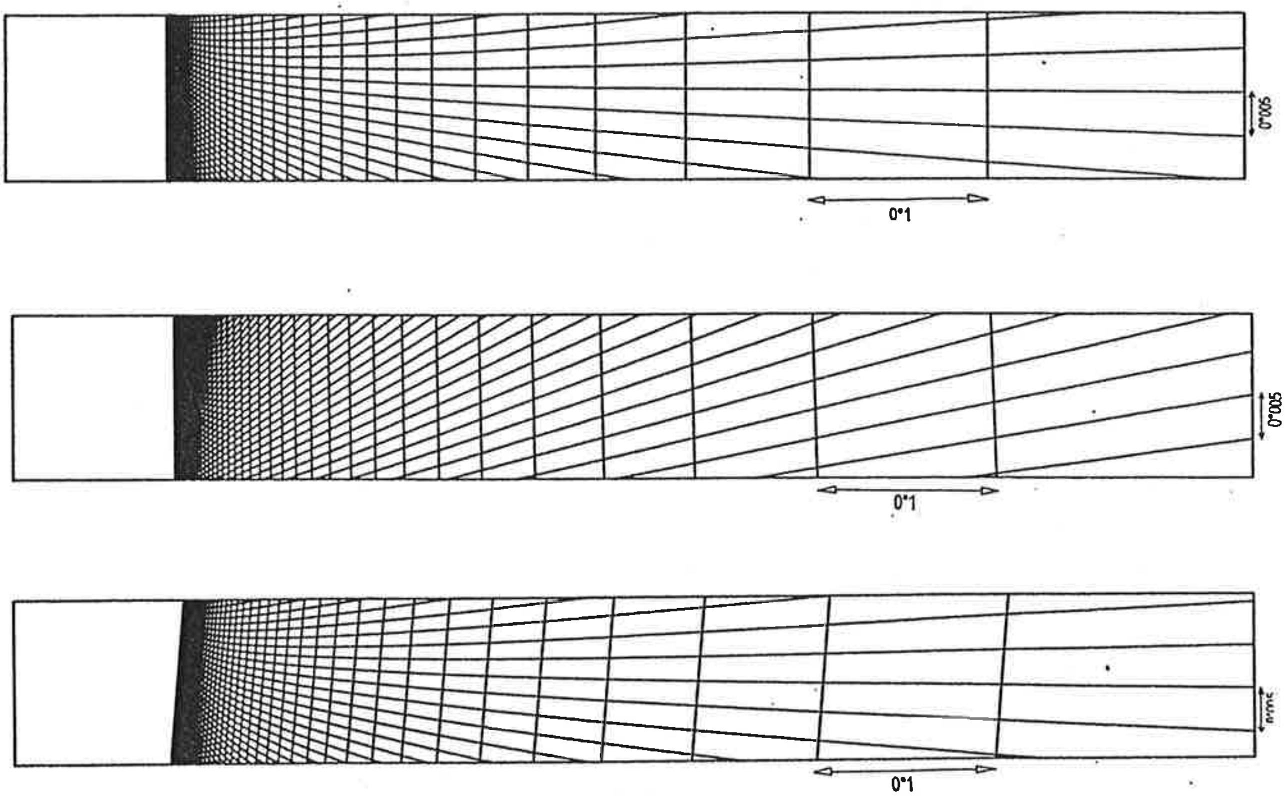

Figure 5: Sector-scan panoramic geometry of the grid of meridians and parallels, using a scan angle of 0° to 30° from a flight altitude of 15,000m above the ground and 72" focal length.
(b) with an aircraft yaw angle of 5°.
(c) with an aircraft tip angle of 5°.

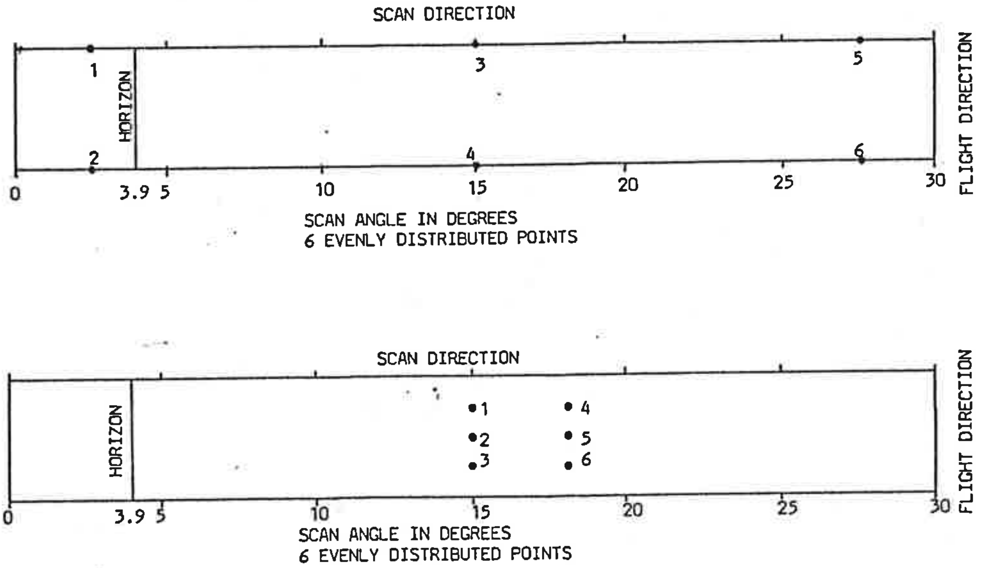

Figure 6: Ground control distributions for the numerical accuracy predictions. (a) 6 evenly distributed points; (b) 6 clustered points.

- 0° to 30° scanning angles (0° at the horizon);
- film format of 37" x 5";
- angles of view: 30° x 4°.

On the ground we assume two cases of ground control points:

(a) a distribution across the field of view (Figure 6 (a));

(b) a control point cluster in an area of interest (Figure 6 (b)).

Anticipated limitations

From a photogrammetric point-of-view, the pan sector scan geometry does not lend itself to robust solutions. The angles of view are small in cross-track, and extremely small in flight direction. We therefore do not anticipate any high accuracies.

A rule-of-thumb would normally permit one to anticipate a 1:10,000 accuracy in precision photogrammetry. At a scan angle of 30 below the horizon, and a 15,000 flight height, this relates to 3 m on the ground.

This accuracy is not realistic due to:

- The very small angles of view;
- The kinetic imaging geometry with changing camera position and attitude angles while a scan takes place;
- The difficulty in identifying ground points--the image scale may be only 1:17,000, but the image is taken through a 30km atmosphere. Therefore haze will affect identification of targets.

An image identification error of +/-1mm will translate into a +/-17m on the ground if the image scale is 1:17,000 (at 30° scan angle); and into +/-160m on the ground if the image scale is 1:100,000 (at 3° below the horizon). This is the order of magnitude of errors on the ground for comparatively very large image identification errors.

Errors of target position

Computations were performed varying the image identification accuracy. As a result the target positions have errors as shown in Figures 7 (a) and (b), for the two ground control arrangements of Figure 6.

Details of the photogrammetric solution are beyond the scope of this paper. It should be noted, however, that the computations permit a linear change of the attitude angles (tip, roll, yaw) to occur while the scan takes place. The co-linear arrangement of ground points in case (a) requires the mathematical formulations to avoid indeterminate equation systems.

The clustered control points in case (b) permit one to interpolate a point within a cluster with good accuracy. As a target comes to lie outside the cluster that accuracy deteriorates. However, it is a well understood principle of photogrammetric mensuring technology to avoid any form of extrapolation.

Errors of reconstructed aircraft position and attitude

The PI may not care about the camera position and attitude; however, the computations of target positions produce a by-product in the form of the camera/aircraft position and attitude angles for each image frame.

Figure 8 illustrates that these accuracies are poor. This is no surprise since we have to deal with very narrow bundles of optical rays.

Of interest may be the stability of the solutions. The question is about finding a valid computational result or not. The result depends on starting out with some assumptions about the aircraft position and attitude. Figure 9 is an attempt at showing when a mathematical solution to the positioning problem may fail. This may only be the case when the approximations are 30 km or more of their true values.

Conclusions

Images of the Earth's surface are increasingly in a digital format and subject to digital image processing. However, there is also good reason for a variety of film images to be available into the future. Computer technology can also be very helpful in the analysis of film images. This fact has long been demonstrated in analytical plotter photogrammetry.

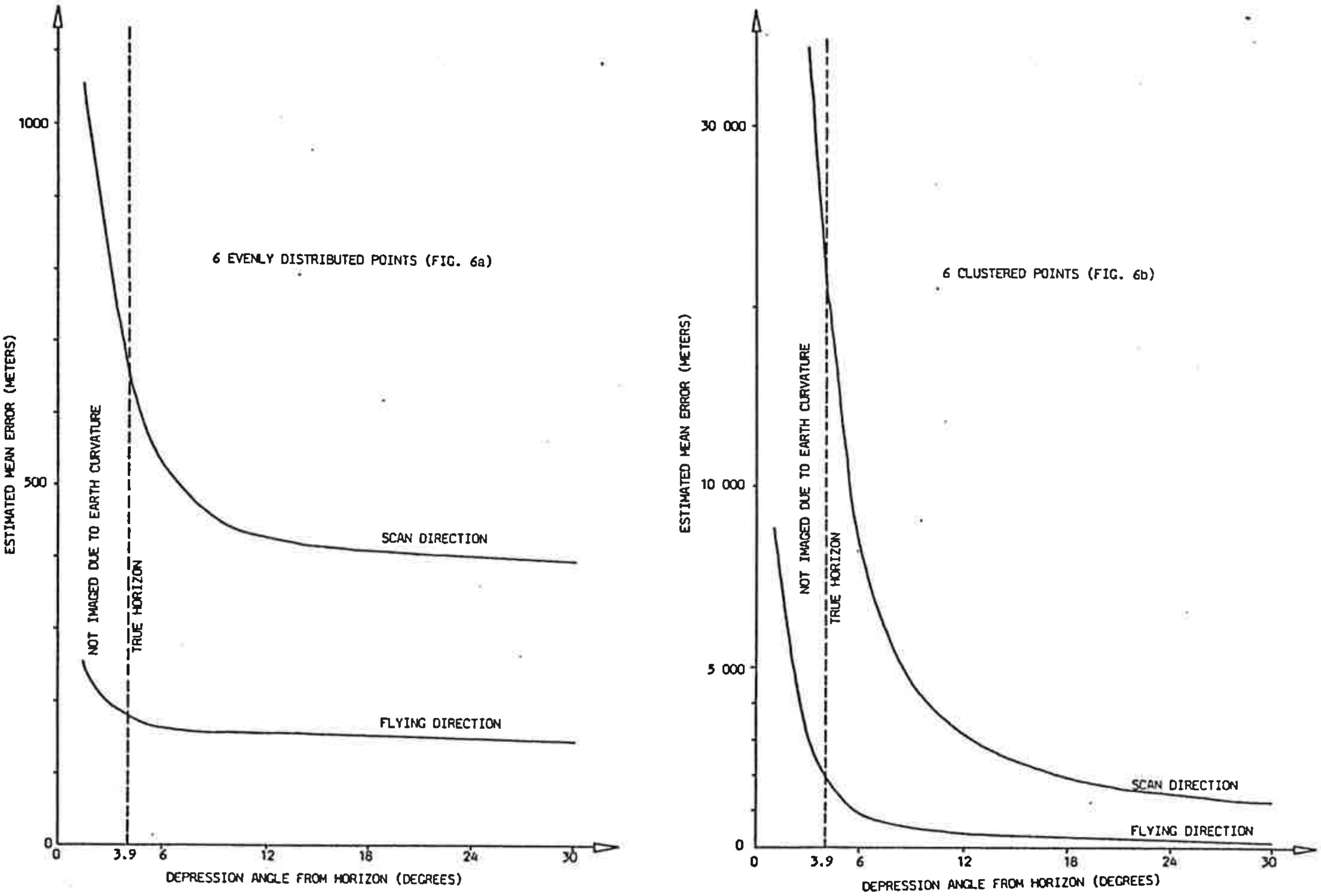

Figure 7: Image identification accuracy versus target position accuracy with the ground control points of Figure 6. Flight height 15,000 m above ground, scan angle of 0° to 30°, 72" focal length.

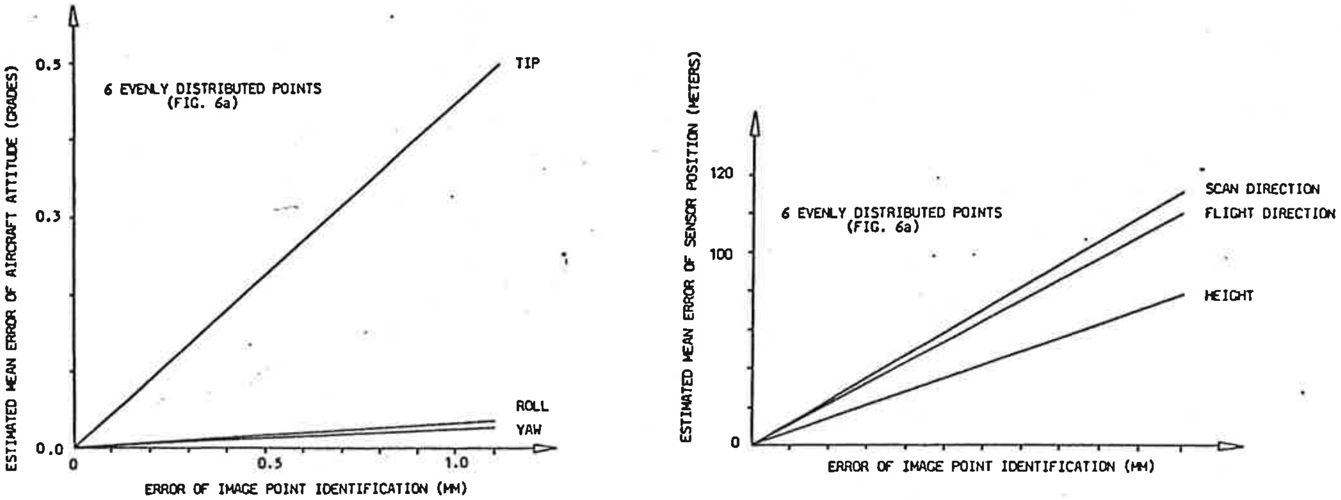

Figure 8: Image identification accuracy versus accuracy of reconstructing aircraft flight position and altitude with the ground control points of Figure 6. Flight height 15,000m above ground, scan angle 0° to 30°, 72" focal length.

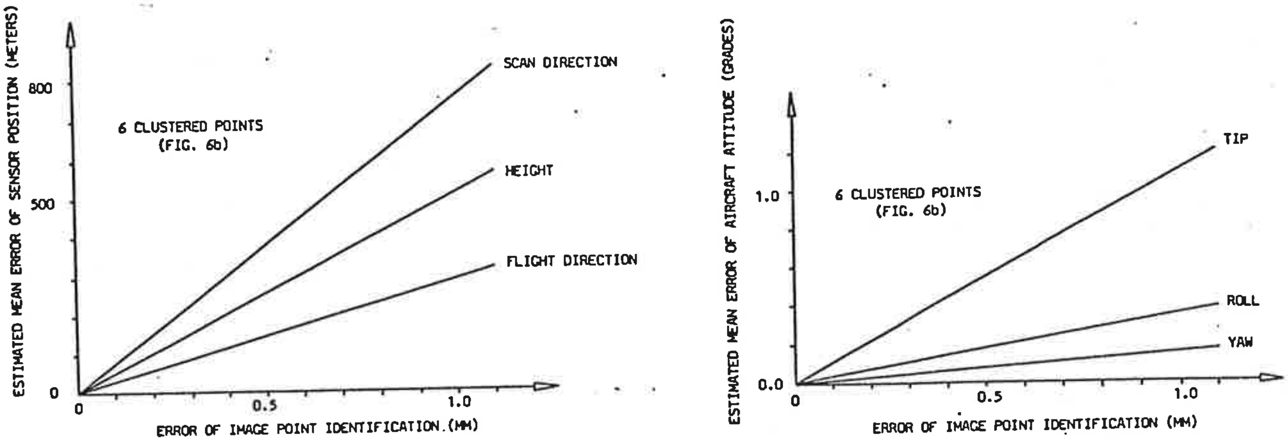

Figure 8: Image identification accuracy versus accuracy of reconstructing aircraft flight position and altitude with the ground control points of Figure 6. Flight height 15,000m above ground, scan angle 0° to 30°, 72" focal length.

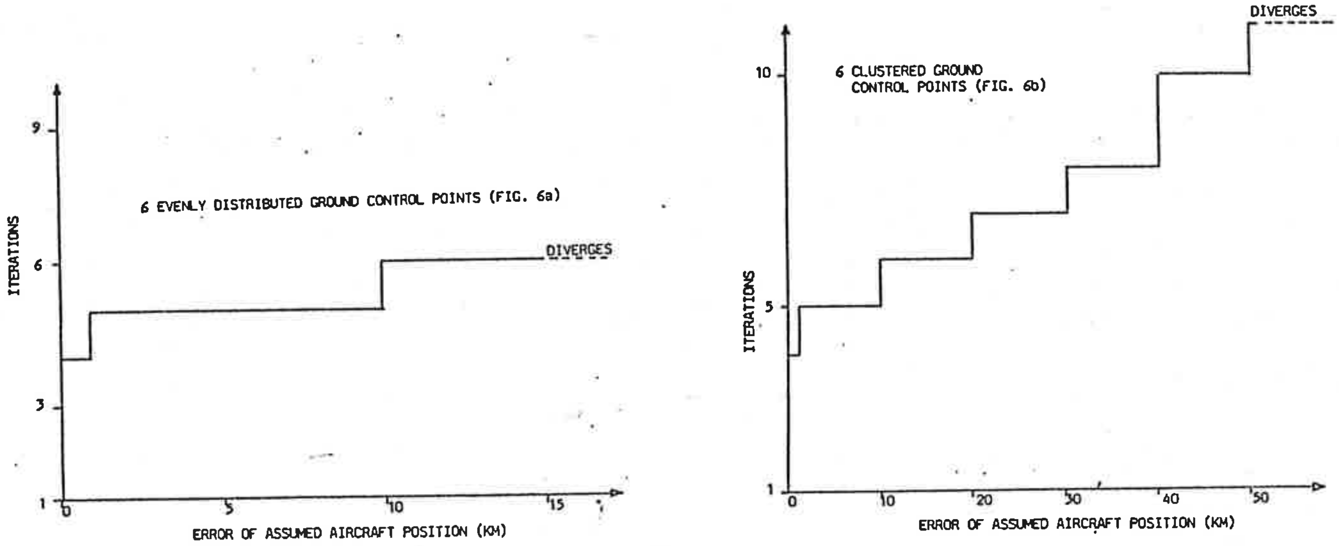

Figure 9: Computational interations versus errors of approximate aircraft positions; same assumptions as in Figure 7.

The photo-interpreter has recently been confronted with an increasing number of computer-assisted stations for the interpretation of analog film images. This paper presents a particular such system, VIDARS, of the Richards Corporation, that not only supports the PI with computer assists in his traditional measuration tasks of target dimensions, but it specifically provides a set of tools to determine absolute target position.

The paper discusses one such set of mensuration capabilities as they relate to the sector-scan panoramic camera. The paper shows that this camera system--although not designed nor appropriate for measuration of absolute coordinates--can be used for such tasks on the VIDARS equipment.

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