MAPPING CAMERAS IN THE EROS PROGRAM

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Abstract: Wide-angle film-return frame cameras, such as are common to aircraft use, have been defined for space use in both 6-inch and 12-inch focal lengths. Narrow-angle cameras producing a near-orthographic telemetered image are also considered important for planimetric mapping, map revision, and thematic mapping. A third mapping system involves telemetered telescopic images of the area obtained from two widely separated satellites in geostationary or geosynchronous orbit. All three systems are considered potentially important to the mapping of the Earth and its resources.

INTRODUCTION

For the Earth Resources Observation Systems (EROS) Program of the Department of the Interior to achieve its goals, pertinent phenomena on or near the Earth's surface must be detected, identified, and positioned.

Positioning involves maps which are made in an endless variety of scales and forms. However, if the features depicted are, for the given scale, accurately located in either 2 or 3 dimensions with

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respect to the projected Earth's surface, then the map is one of scaling accuracy.* To produce such a map, cameras with specified metric properties must be used to obtain images under further specified conditions. There are at least three different sets of cameras and imaging conditions which can produce maps of scaling accuracy, and the future holds promise for a good many more. Both 3-dimensional (topographic) and 2-dimensional (planimetric) maps are considered, but in both cases this discussion is limited to maps of scaling accuracy.

CONVENTIONAL CAMERAS

For several years the cartographic community has supported the use of wide-angle film-return mapping cameras for surveying the earth from space. The standard 6"-focal-length mapping camera is one candidate, but there are obvious advantages in going to a longer focal length. The so-called "NASA Photo Team" (1), the National Academy of Sciences (2), and recently Fred Doyle, speaking as a member of the U.S. Geological Survey (3) have all recommended a 12"-focal-length mapping camera for space. Two image formats have been proposed, 9 by 14.5 inches and 9 by 18 inches. The former, with a narrower field of view, requires relatively simple optics and provides a more uniform image but, of course, requires a reduced base/height ratio as compared with the conventional mapping camera. The camera of 9" by 18" format, when mounted with the long axis parallel to the flight direction, provides a base/height ratio identical with that of the conventional camera. It has also been proposed to mount the 9" by 18" camera with the long axis perpendicular to the direction of flight, but with the camera tilted to provide convergent coverage. This involves a pair of fixed cameras or one that tilts fore and aft sequentially. This mode will provide the same width of flight line as a conventional camera and as large a base/height ratio as desired, but it also involves all the disadvantages of oblique photography.

Mapping cameras of 18" and 24" focal length have been built, but since 9" is now considered a maximum practical film width, the long-focal-length cameras thereby lose their wide field of view and the associated characteristic of a strong intersection angle of corresponding rays from two vertical camera positions. Insofar as the

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* A map of scaling accuracy is one which complies with formal standards. In the United States these standards require that not more than 10% of well-defined features (with some exceptions) be more than 0.02 inch out of their true projected position at map scale.
wide-angle characteristic is considered paramount, there are certainly practical limitations on mapping the Earth from space and even from very-high-altitude aircraft. Professor E. H. Thompson summarized the arguments against mapping the Earth from space in his editorial in the April 1970 issue of the Photogrammetric Record (4). All concerned with space mapping should certainly read and be familiar with the arguments he presents. He states, "It is absurd to suggest that it is possible to use satellite photography for topographic mapping." I will leave it to people like Fred Doyle to specifically answer Thompson by analyzing the full topographic mapping potential of a 12"-focal-length camera in orbit. However, scales of 1:50,000 and contour intervals of 20 meters certainly appear possible with a precision plotter and quality photographs. Granted, 20-meter contouring is not adequate for many areas of large-scale mapping, but it is certainly applicable to medium-scale mapping badly needed in undeveloped and developing areas of the world. Moreover, mapping techniques with photographs taken by 12" cameras are basically conventional.

The supplemental use of higher resolution cameras, such as a 24"-focal-length panoramic camera, has also been proposed as part of a mapping system (1, 2, 3). Through correlation techniques, the panoramic image can be used to extend the application of the system to larger scale mapping even though a panoramic camera is not basically a mapping camera.

NARROW-ANGLE VERTICAL CAMERAS

Another consideration is that topographic mapping, to which Prof. Thompson addresses himself in the editorial cited, is becoming an ever-decreasing element of the comprehensive mapping problem. A good percentage of the more important areas of the Earth are either already topographically mapped or programmed for topographic mapping. Maintaining the currency of maps and also thematically portraying specific spatial phenomena—and changes thereto—are the real mapping challenges of today, and such mapping does not require a conventional topographic mapping camera.

For planimetric mapping (line and photo), the revision of planimetry, and thematic mapping, what are the camera-system characteristics desired? Certainly the internal geometry must result in a distortion-free image, or at least one that is definable and subject to correction by optical means. The camera position and attitude must be known or definable. The system must produce an image of suitable spatial resolution, which calls for a longer focal length as the camera height increases. The system should also have photometric fidelity and resolution, and of course produce an image compatible with data-processing requirements. There are two things that such mapping does not require: one is
stereocoverage, and the other, related thereto, is the strong angle of intersection for corresponding rays. In fact, the single most important characteristic of a camera to be used for planimetric mapping is probably orthogonality. To achieve orthogonality, a camera must be pointed at right angles to the object scene and should also have a very narrow field of view, unless the object scene approximates a true plane. Since the Earth's surface is not a true plane, the narrower the field of view, the better. What we are looking for is a vertical image in which all objects appear in their true horizontal positions regardless of elevation differences. Such images can be directly used to correct and update planimetry on line maps, and, what may be more important, the image itself can be readily transformed into a map product of acceptable horizontal accuracy.

Cities well illustrate the problem of planimetric mapping of an area that is obviously not a plane. A conventional 6"-focal-length mapping photograph is hardly suited for planimetric mapping of a city as illustrated by figure 1. Seeing the sides of buildings may be esthetically pleasing, but we must consider the areas that are masked by these same buildings and therefore cannot be mapped. To map Manhattan by conventional photogrammetric means, it is literally necessary to center flight lines on each of the avenues—unless one flies so high that the resolution is lost.

The next figure illustrates a city as photographed with a 24-inch-focal-length camera on the same 9" by 9" format. Although the photos are of different cities and of slightly different scale, they illustrate the point in question. Note that, for comparable resolution and scale, the condition of orthogonality is being approached as the focal length increases. At the 24" focal length image, streets and even sidewalks can be seen clear to the corner of the photos, whereas in the 6" image this near-orthographic condition occurs only near the center. Obviously the orthographic condition, so desirable for planimetric portrayal, negates the value of such narrow-angle photographs for height determination, which depends on perspective displaced images to resolve the vertical dimension. What then would be the perfect image for planimetric mapping of a city? It would be a vertical photo taken with a geometrically precise telescopic camera from a very high altitude. I am not proposing that we fly telescopes to map our cities at this time, but the principle should not be forgotten as space systems become available.

In mountainous areas, terrain relief causes image displacement just as a tall building does. Figure 3 is a portion of a medium-scale space photomap in which practically the entire image has been used. Because the Apollo 9 Hasselblad camera used had a relatively narrow field of view, the image was fitted to a conventional line map with an accuracy of register that approaches the resolution of the photography—perhaps 200 to 300 meters as printed. If a 6"-focal-length mapping camera had
Figure 1. The corner of a 9x9-inch photograph of an urban area at about 1:7,000 scale as imaged with a conventional 6"-focal-length mapping camera.

Figure 2. The corner of a 9x9-inch photograph of an urban area at about 1:7,000 scale as imaged with a narrow-angle 24"-focal-length mapping camera.
Figure 3. Portions of 1:250,000-scale maps: A. photomap with contours, B. photomap without contours; C. line map.
been used on Apollo 9 instead of the Hasselblad, only the center portion of the photo could have been used in a photomap of this type. Relief displacement towards the edge would have been excessive. The Hasselblad lens has a focal length of only 80 mm, but for the Apollo and Skylab missions a camera of 457 mm (18") has been obtained. Although the altitude will be nearly double that of Apollo 9, photos from this camera should further illustrate the practicality of planimetric mapping of the Earth from space.

So far the cameras mentioned are all based on film return, but there is no reason to believe that a telemetered signal cannot be converted into a geometrically acceptable image. Imagery from the meteorological satellites is constantly improving, and the vidicons and scanners planned for the Earth Resource Technology Satellite (ERTS) promise to have a still higher degree of geometric fidelity. The day is rapidly approaching when imagery from video imagers and scanners can be directly applied to planimetric and thematic mapping which involves time-variant phenomena as well as fixed Earth features. However, in all these cases we are talking about narrow-angle vertical or near-vertical cameras which will produce orthogonal images.

**STEROIIMAGES FROM TELESCOPES**

The third mapping approach involves the use of telescopes in a stereoscopic mode. Thompson (5) refers to the problems of mapping the Moon from the Earth, but it is worth noting that the Moon's surface was actually mapped topographically, with a contour interval of 300 meters, from photos taken with Earth-based telescopes. Since no real control was available and the size and shape of the Moon were then ill defined, the mapping is relative and not up to accepted accuracy standards. Moreover, the angle of intersection of corresponding rays was limited by the Moon's libration, which is only about 16°. However, we should now consider turning this telescopic mapping concept around and applying it to the earth. If two image-recording telescopes can be suitably positioned in space and aimed at the same area of the earth, the basic elements of a topographic mapping system are established.* The field of view of the telescopes may be only a few minutes of arc, but the separation of the telescopes establishes a base which provides the all-important angle of intersection of corresponding rays. A satellite 36,000 kilometers above the Earth in circular equatorial orbit is stationary with respect to the Earth's surface. This means that its position can be determined with a high degree of precision. The attitude of a telescope aboard such a satellite can be precisely fixed by reference to the stars or to control points on the Earth. The Earth's atmosphere causes far less disturbance

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* The same result could theoretically be achieved with a single telescope obtaining images from two widely separated locations, but such a system involves complex positioning problems.
in the visible spectrum when the viewpoint is outside looking in rather than inside looking out. Moreover, telescopes in geostationary orbit would be only about 1/13 as far away as the Moon. Figure 4 indicates the geometry involved in such a system, which has been described elsewhere (5, 6).

Can telescopes of suitable size be put into space? They certainly can and are, in fact, being built today for NASA's astronomy (0AO) program. A reflecting collector 1 meter in diameter has already been built for this program, and 2- and 3-meter mirrors are being designed. The optical industry states that such telescopes can be built and orbited with the optics maintaining diffraction-limited characteristics. If the instruments substantiate these claims, the Earth's surface would be resolved (at the photography nadir) to about 20 meters with a 1-meter collector, 10 meters with a 2-meter collector, and 7 meters with a 3-meter collector. Perfect optical conditions are assumed with these figures, but a figure of 10 meters can certainly be defended with the largest collector. The topographic mapping capability of such a system would require a complete analysis, including telemetry of the signal, but since the basic geometric conditions are nearly ideal, determination of vertical position to the same precision as the resolution

Figure 4. A six-satellite geostationary or geosynchronous system.
may be expected. Contouring would probably not meet requirements for large-scale maps, but a 20-meter contour interval seems feasible. All such mapping would fundamentally be related to the center of the earth rather than a local datum, thus providing another argument in favor of Earth-centered universal mapping, which has been discussed elsewhere (7). Moreover, it is possible to carry out such mapping without any control whatsoever in the area to be mapped. However, if control points in a local datum are observed, the mapping can also be adjusted to the local system. Please note that I am not recommending a geostationary satellite system for mapping purposes alone, as the system would have applications far beyond cartography. Nevertheless the potential of the system for cartographic use is real and should be thoroughly examined. It would be distressing to see an expensive Earth-sensing geostationary (or geosynchronous) system built and then not be usable for mapping merely because those concerned had not defined their requirements.

SUMMARY

Although space systems involve sensing from distances generally beyond 200 kilometers, they certainly have applications to mapping. The types of imaging systems proposed are as follows:

- A film-return wide-angle camera system of 6" or preferably 12" focal length, from which topographic (and planimetric) maps can be compiled by conventional methods. This camera perhaps will be supplemented by a panoramic camera of longer focal length.

- Vertical or near-vertical narrow-angle imagers and scanners at nominal space altitudes, from which the telemetered signals can be applied to planimetric and thematic mapping, particularly with respect to time-variant phenomena.

- Telescopes spaced in geostationary or geosynchronous orbits, two of which can provide stereoscopic coverage of the Earth’s surface.

Let us not discount mapping as an application of the space program; all three of these systems deserve to be given proper tests before we make a judgment.
REFERENCES

1. Proposal for an Integrated Group of Photographic Experiments for Manned Earth Orbital Missions (Apollo Application Flights); Multilith proposal of the NASA Photographic Team to NASA of December 1, 1965.


