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Television from Space

It is expected that photogrammetrically corrected space TV pictures will form an important element in the future Earth Resources Satellite data outputs.

(*Abstract on next page*)

INTRODUCTION

TELEVISION IMAGING systems have been used for several years to transmit video pictures from unmanned spacecraft. At present two systems (ESSA-APT and ESSA-AVCS) are being used by meteorologists on a daily operational basis, while many close-up pictures have been obtained of the surface of the moon (by Ranger and Surveyor), and Mars (by Mariner). The latest program for which a television imaging system is proposed is an Earth Resources Satellite, which will include three high-resolution television cameras, each operating in a different spectral band.

In many applications, such as land-use surveys, the data from the satellite will be correlated with information from other sources, such as topographic maps. This correlation process is simplified if the satellite data is of good photogrammetric quality; that is, if it has constancy of scale and geometric fidelity. Unfortunately, television systems are subject to photogrammetric error, and preprocessing of the data is necessary if the desired photogrammetric quality is to be achieved.

Several papers have been written in the past on the subjects of the errors in space television systems, and the techniques that can be used to perform the corrections.[1-8] This paper presents a brief survey of the referenced work and then goes on to deal specifically with a high-resolution system intended for the Earth Resources Mission. The limitations of existing techniques for handling the greatly increased amount of data generated by the satellite are discussed, and a technique that results in the generation of photographic hard copy with good photogrammetric quality is described. An important feature of the technique described is that it operates in *real-time*; that is, at the same rate as the data is generated. The errors that are likely to occur in the complete system and the accuracy which would be desirable are also discussed.

SOURCES OF PHOTOGRAMMETRIC ERROR

> *It is not well done, but you are surprised to find it done at all.* (Samuel Johnson).

This uncritical attitude towards the pictures obtained from the first space television systems was replaced by a realization that it would be necessary to improve both photogrammetric and photometric fidelity, if maximum use was to be made of the pictures received. In this paper we are concerning ourselves specifically with the photogrammetric


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errors; as far as photometric corrections are concerned it is sufficient to mention in passing that if we wish to make precise measurements of scene reflectance (or scene brightness) it is necessary to perform corrections over the area of a picture and from picture to picture.[9]

The causes of the photogrammetric errors that arise in the end product fall into three groups: those due to the sensing system (including the final display mechanism), those due to the platform on which the sensor is mounted (the spacecraft), and those due to the viewing geometry.

A very detailed theoretical analysis of sensor errors was presented at the 34th (1968) Annual Meeting of the American Society of Photogrammetry by Dr. Wong,[7] and it is not intended to repeat the material presented then. We will, however, be discussing some actual measured distortion values in the course of this paper.

Photogrammetrists are very familiar with the errors due to instabilities in the sensor platform. Fortunately it is possible to control the attitude of a spacecraft to a much higher precision than that of an aircraft, while the accuracy with which the orbital elements can be computed enables a precise determination of altitude to be made. It must be realized, however, that because of the much greater altitudes at which a spacecraft operates, a relatively small attitude error can still result in a large absolute error in terms of ground position.

What we have referred to as *viewing geometry error* in a television system basically reflects the problem of converting a spherical into a plane surface. (In line-scanning systems, additional errors arise as a result of the scanning geometry). In the Earth Resources Mission, the area covered by each photograph (100×100 nautical miles) is relatively small, so the use of the flat earth approximation does not introduce significant error. For those missions using cameras which cover a wider field of view, such as in meteorological applications, the earth's curvature introduces a significant distortion, and corrections must be made for this.[1]

Hence, if we wish to apply the output of these space television systems, it is essential to establish both the magnitude of the various errors and a technique which will enable them to be reduced to a satisfactorily low value in the final hard copy.

ABSTRACT: *The Earth Resources Satellite will include three high-resolution television cameras, each operating on a different spectral band. In many applications, such as land-use surveys, the data will be correlated with topographic maps. However, television systems are subject to photogrammetric errors, and pre-processing of the data is necessary if the desired photogrammetric quality is to be achieved. The high-resolution system of the Earth Resources Mission must be processed in real time including corrections for photogrammetric errors such as scale, skew, roll, yaw, pitch, earth rotation, etc.*

ACCURACY REQUIREMENTS

It will be seen later that accuracy requirements are intimately related to the scale chosen for the display of the data, and therefore consideration must first be given to the range of scales for which satellite pictures are suitable. The calculations used in this section are based on the proposed operating parameters for an Earth Resources spacecraft.

At the nominal altitude of 500 nautical miles, the field of view of each camera covers a square 100 nautical miles on a side (608,000 feet). Doyle[10] provides a criterion for determining the extent to which a picture should be enlarged. This reference states: "A useful criterion to apply is that the photograph can be enlarged until its resolution is equivalent to about 20 line pairs per millimeter. This will present all the information which the human eye can extract without enlarging the map scale by magnification." The limiting resolution of the sensor (6,000 lines) would lead to a picture size of 6×6 inches, which corresponds to a scale of 1,200,000:1. Enlarging the picture to 7.2×7.2 inches results in a scale of 1:1,000,000, which is rather more convenient, as data on the picture can be directly correlated with that on a 1:1,000,000 map. At this scale a picture element has a linear dimension of 0.0012 inch. Measurements by Blackwell[11] indicate the ability of the eye to resolve a visual angle of 0.6 minutes of arc, which corresponds to a viewing distance of seven inches. It would seem that a scale of 1:1,000,000 would be optimum for the display, because further enlargement would not increase the amount of detail visible, whereas a smaller scale would require magnification to extract all the information contained in the picture.

In considering the accuracy required for the pictures, it would appear desirable to conform to the same standards that are required for topographic maps, because maps are likely to be the most common source of data to be correlated with the pictures. The United States map accuracy standards require an accuracy of 1/50th inch for 90 percent of the *well defined* points which can be located with precision of 1/100th inch.[12] When related to the pictures in terms of limiting resolution elements, this corresponds to an accuracy of 17 video elements for objects which can be located to a precision of 8 video elements.

The standards define a *well defined* point as one that is easily visible on the ground. If we assume an intrinsic contrast of 2:1 as one criterion for meeting this condition, atmospheric luminance will reduce this to an apparent contrast of 1.6:1. With this contrast target, the limiting resolution of the system is reduced to 2,700 lines, or 0.0027 inch. The degradation of sensor resolution that occurs in viewing low-contrast targets under low light-level conditions will not therefore significantly affect the precision to which a point can be plotted.

Doyle[10] calls for an accuracy of 300 meters (1,000 feet) and a resolution of 50 meters (150) feet) for a scale of 1:1,000,000. On the final hard copy, this corresponds to an accuracy of 0.012 inch and a resolution of 0.0018 inch. The accuracy that Doyle considers necessary is rather higher than the figure given above, but if the inaccuracies that will be introduced in the transfer of the data from the initial hard copy to the final output (annotated maps for example) are taken into consideration, Doyle's figure probably represents a better target accuracy than that derived from the mapping accuracy standards.

PHOTOGRAMMETRIC ERRORS IN THE EARTH RESOURCES SATELLITE SYSTEM

We have previously divided the errors that occur in the satellite system into three groups; those due to the sensor, those due to the sensor platform, and those due to the viewing geometry. We will discuss in some detail the various effects that give rise to these errors, placing particular emphasis on measured or computed values, rather than a theoretical analysis.

CAMERA ERRORS

Unfortunately the camera is a major contributor to the overall system error, and as its performance may change during its working life, we are faced with a calibration as well as with a distortion problem. In a paper presented last year, Dr. Wong analyzed the various sources of error in a television system without including actual values. In practice we are more concerned with the combined effects of the errors, rather than attempting to determine the magnitude of their individual components. For this reason we will be dividing the sensor errors into four classes:

1. *Scale*, defined as deviation from the nominal overall picture size.
2. *Skew*, defined as lack of orthogonality between frame and line scan, resulting in the scanning of a parallelogram.
3. *Nonlinearities*, defined as variations of scale over different sections of the picture.
4. *Geometric Distortion*, defined as distortions of the geometric positions between points on the picture.

The basic differences between scale and skew distortions on one hand, and nonlinearities and geometric distortions on the other, is that the error in the first instance is constant over the whole of the picture, and in the second instance varies from position to position within the picture.

The performance specified for the sensors to be flown on the first Earth Resources Spacecraft dictates the following significant parameter values: size, ±2 percent; skew ±0.5 degree; and image distortion 1 percent. (Image distortion includes both nonlinearities and geometric distortion.)

Although these values are approximately the same as those that have been employed for the existing meteorological series of television cameras, the resultant distortions at the output of the system will be at least an order of magnitude less, because the narrow field of view required for the Earth Resources mission will result in much less lens distortion. Figure 1 shows comparative measurements of distortion on a wide angle (100°) lens and a narrow angle (11.5°) lens. Actual measurements on the television cameras used on meteorological missions indicate that electronic (electron-optic, scan waveform, etc.) distortions of less than 0.5 percent are currently being achieved.

SENSOR PLATFORM ERRORS

Altitude Variations. The specified orbit of the Earth Resources Spacecraft approximates very closely a circle (the specified maximum

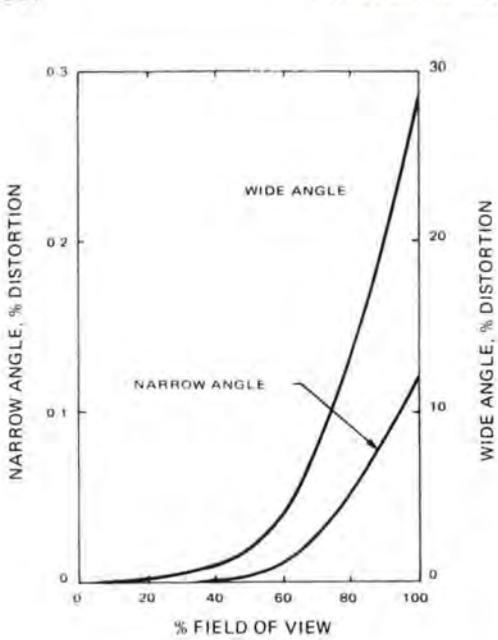

FIG. 1. Lens distortion.

eccentricity would result in a deviation of ±½ nautical mile). As a result of the oblateness of the earth, the actual spacecraft-geoid distance will vary during the orbit. However either the Clarke Spheroid or the International Ellipsoid can be used as a reference, as the differences between the two will have a negligible effect on the scale of the final product.

Where the spacecraft is operating with zero altitude error, the effect of variations in the earth-ground difference is to introduce changes in the scale of the final picture. In the operating system the factors discussed in the previous paragraph can result in a maximum uncorrected error of 0.1 inch. After corrections for these errors have been performed, the inaccuracies in the measurement of the orbital characteristics and the variations between the reference geoids can result in a maximum residual error of approximately 0.009 inch.

Topography. Variations in the altitude of various points within a picture can result in significant positional errors in the final output. Corrections for topography are extremely difficult, and would require the use of adjacent pictures (both along- and across-track). The maximum error introduced by topographic factors would be 0.01 inch.

Attitude Errors. The attitude control system on the spacecraft ensures that the maximum attitude deviation in any axis of the spacecraft motion will not exceed 1 degree. The actual errors can be determined by retrospective measurements to a precision of approximately 0.1 degree. These deviations will result in both absolute and relative positional inaccuracies in the final data. (An *absolute* error is an error which occurs if the ground coordinates of points in the picture are computed from knowledge of the subsatellite point at the time the picture was taken. A *relative* error occurs if the relationships between the individual points in a picture are distorted.)

Motion around each of the three axes will introduce a different form of error in the display; in addition two or more disturbances may be present simultaneously. The nature of the error will also change with time; for example we have the interchange between roll and yaw errors which occurs cyclically during the period of an orbit.

For the purposes of this paper, the magnitude of the errors introduced by each effect will be considered independently. The figures that are introduced are based on a maximum error of 1 degree in each axis. This figure is very conservative, and a pointing accuracy of 0.3 to 0.5 degree is more likely to be achieved in practice. Because the ground position error is proportional to the attitude error for small angles, the magnitude for other attitude errors can easily be determined.

Roll Error. The geocentric angle corresponding to a roll error of 1 degree is 9 minutes of arc. The center of the picture will therefore be displaced by 9 nautical miles from the subsatellite point. This is the absolute error resulting from the attitude error. In addition, the picture is subject to significant relative errors.

A 1-degree roll error will result in the display of a section of the earth corresponding to a trapezoid with the parallel sides parallel to the subsatellite track. Individual points will be subject to a relative error of up to ±555 feet across track and 615 feet along track. These errors correspond to 0.0065 inch and 0.0075 inch, respectively, in the final hard copy.

Yaw Error. Yaw error will cause a rotation of the picture about the nadir. The center of the picture will remain at the correct point, and the other points will retain their correct position relative to each other. Errors in absolute position of up to 1.2 nautical miles will be present if compensation is not made for the yaw error.

Pitch Error. The figures given for roll error also apply to pitch error, except *along track* should replace *across track*, and vice versa.

Effect of the Earth's Rotation. Although the earth's rotation will not cause the picture to be distorted, it is necessary to take the rotation into account in relating the picture to its correct position on the earth. As a result of the rotation of the earth, the roll axis of the spacecraft is not, in general, parallel to the subsatellite track. If the sensor is aligned to be parallel to the roll axis, the result is essentially the same as a yaw error. The magnitude is however, considerably greater than the yaw error we have previously considered, and is plotted in Figure 2. It will be observed that the magnitude depends on the latitude of the subsatellite point at the time the picture was taken. Although similar to yaw error, the translation between roll and yaw error during the period of the orbit does not occur, and the sense of the error is always in one direction.

Combination of Attitude Errors. The actual errors that will be present in the final displayed data will result from a combination of the attitude errors in each of the three axes. If a relative error exists between two points, at least one of them will also have an absolute error. However any number of points may be in absolute error, and yet still be in the correct relative positions. As far as the display is concerned it is only necessary to correct for relative errors, because compensation for absolute errors can be readily achieved in the subsequent processing. Thus, it is not necessary to correct for yaw error.

Viewing Geometry Distortion. Normally, where the earth is viewed from satellite altitudes, the curvature of the earth will result in a relatively large distortion. Fortunately the narrow field of view that will be observed by the Earth Resources cameras will minimize this problem.

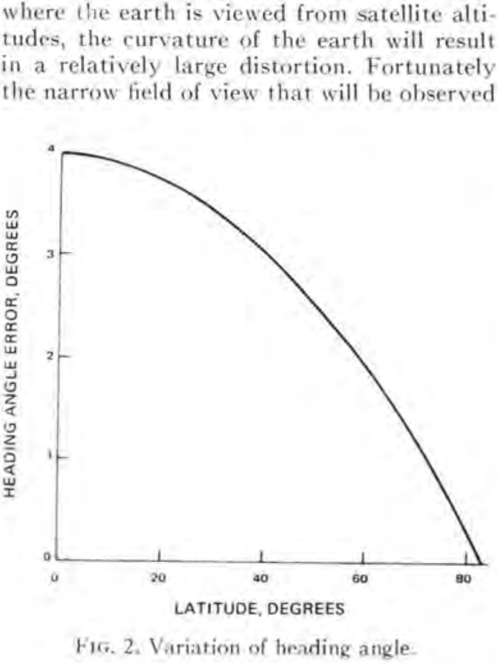

FIG. 2. Variation of heading angle.

The 100×100-nautical-mile coverage of each picture gives a measurement across the diagonal of 141 nautical miles. This corresponds to a geocentric angle of 2 degrees 20 minutes (a half-angle of 1 degree 10 minutes). The error that results from the deviation from a plane surface is given by the difference between the tangent of the geocentric half angle and the magnitude of the angle expressed in radian measure.

For the application being considered, this error corresponds to approximately one-half a video element.

Summary of Errors. Based on a 100×100 nautical mile area to a scale of 1:1,000,000:

Altitude Errors	
Orbital	±0.15 in.
Topographic	±0.010 in.
Geoid	±0.002 in.
Attitude Errors (Relative Errors only).	
Roll	
Across-track	±0.0065 in.
Along-track	±0.0075 in.
Pitch	
Across-track	±0.0075 in.
Along-track	±0.0065 in.
Sensor Errors	
Lens	±0.007 in.
Camera	
Size	±0.16 in.
Skew	±0.03 in.
Distortion	±0.08 in.

TECHNIQUES FOR CORRECTION

Existing techniques are based mainly on the use of a relatively large digital computer to perform the corrections. Calibration information, obtained prior to the launch, and measurements of a reseau pattern engraved on the vidicon faceplate, enable the magnitude of the errors to be determined. The distorted picture is digitized and stored within the computer, the relative positions of the digitized elements within the picture then being rearranged to correct for the distortions.

In addition to removing sensor distortions, it is also possible to rearrange the individual elements to correspond to the position they would occupy if the corresponding ground coordinates were converted to one of the standard map projections. Thus the meteorological data generated by the ESSA-AVCS series of satellites is processed by the NESC to produce outputs in both a polar stereographic and a Mercator map projection.[3]

Reduction of sensor nonlinearity by a factor of 5:1 has been achieved using these tech-

TABLE 1. NUMBER OF VIDEO ELEMENTS CONTAINED IN ONE FRAME

System	*Size (TV lines)*	*No. of Elements*
Mariner IV	200×200	40×10^3
Ranger P	290×290	89×10^3
Surveyor	600×600	360×10^3
ESSA-AVCS	800×800	640×10^3
ERS	6000×6000	$36{,}000\times10^3$

niques.[5] In addition to correcting for sensor distortions, it is possible to relate the stored data to its actual ground position, by using information as to the time at which the picture was taken, and introducing corrections to compensate for spacecraft attitude errors. Accuracies of 5 nautical miles have been achieved in the meteorological satellite program.[1]

One factor which is common to all the processes is the large volume of data that has to be processed. Table 1 shows the number of video elements contained in one frame (one picture) of some typical space television systems. Mention should be made of the outstanding work being performed at the NESC, which processes approximately 150 pictures each day. An indication of the magnitude of data that will have to be processed on an Earth Resources mission is obtained when it is realized that the spacecraft is capable of generating an average of 680 pictures each day, each of which contains more than 50 times as much information as a meteorological photograph. On this basis alone, the data processing load will be approximately 250 times that currently handled by the NESC.

PHOTOGRAMMETRIC CORRECTIONS IN AN EARTH RESOURCES MISSION

Of the photogrammetric errors that have been considered in a previous section, those due to attitude and altitude errors may be readily corrected using conventional techniques[12] providing adequate orbital and attitude data is available, or a source of ground truth is present which can be correlated with the data contained in the picture.

It is in the correction of camera errors that we are required to adopt alternate techniques. When we are handling data from an Earth Resources satellite, our approach must be conditioned by the high rate at which the data is being received. We have previously mentioned the rate of 680 pictures per day which can be generated by the spacecraft. This corresponds to one picture to be processed every three and a half minutes, or (expressed in another way), we must correctly position a video element every six microseconds. Although it would be dangerous to draw too close an analogy, currently ESSA is processing pictures at a rate of one element every 860 microseconds, using a CDC 6600 computer.

Actually, if the data are to be processed at the same rate as they are being generated, it is necessary to operate on eight elements every microsecond; however, the data is received discontinuously, so if necessary, a lower processing rate can be adopted without introducing a backlog of work. Although the Earth Resources data does not have the same degree of urgency as, for example, meteorological data, it is still desirable to be able to process the data at least at the average rate at which it is received, otherwise in a very short time the output will be subjected to such a delay as to compromise seriously its usefulness.

At present there is only a limited number of display devices capable of converting the high resolution signals from the television sensor into a suitable hard copy form. One of these is the Laser Beam Image Reproducer, and it is this device which forms the heart of the photogrammetrically corrected display system. A simplified sketch of the Laser Beam Reproducer is shown in Figure 3.

Basically the image is built up by intensity modulating the deflecting laser beam, with the line structure being generated by the use of a rotating mirror deflection system while the individual lines are obtained by driving the table (or in an alternative approach, feeding the film) at the appropriate rate.

Three alternate approaches were considered for the generation of a photogrammetrically corrected display. These were:

1. Controlling the rate of mirror rotation and table (film) feed rate to correctly locate the individual points in the final hard copy.
2. Storing a complete frame of data, and replaying it so that the individual points are correctly positioned, while maintaining a constant rate of mirror rotation and table drive.
3. A combination of (1) and (2), in which a single line of data is stored and the mirror is rotated at a fixed rate, while the table (film) drive rate is varied during the period of each frame.

VARIABLE MIRROR AND TABLE DRIVE RATE

The problem of deflecting a laser beam is generally recognized as one of the major limitations in the usefulness of laser display devices. "The principal disadvantages (of laser displays) are their exceedingly low effi-

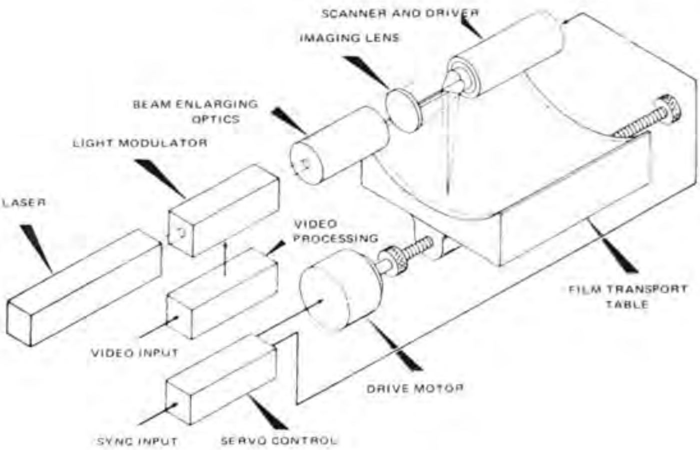

FIG. 3. Laser beam image reproducer, schematic representation.

ciency . . . and their lack of a suitable, low-inertia deflection method" Senf.[13] At present low-inertia systems using, for example, the variable refraction effect in Potassium Dideuterium Phosphate (KD*P) crystals can be used in low-resolution displays, although there are several major practical problems involved, such as the power required to drive the prisms and piezo-electric effects.

For high-resolution systems, deflected (galvo-type) or rotating mirrors are generally used, and it is this latter approach which has been used in the LBIR. Rotating mirror-deflection systems have the advantage that, because of their relatively high inertia, they are generally less subject to perturbations, and hence have a high positional accuracy. On the other hand, this high inertia makes rapid modulation of the scanning rate to permit positional corrections in the line direction very difficult. Galvo-type devices can be modulated at high rate (up to 13 kHz), but are inherently less accurate.

In the frame direction, the rates are naturally much lower. Provided that the variation of table feed rate required is not too great and that the servo drive has sufficient bandwidth, control of the table feed rate is usually satisfactory for the correction of positional errors in the frame direction.

FRAME STORAGE TECHNIQUES

Time buffering essentially retains the linear scanning features of the LBIR and rearranges the relative positions of the individual points in the received data by the use of an intermediate storage medium, so that they are finally displayed in the correct positions.

If linear scanning is retained, it is necessary to use a storage medium to which access can be obtained completely asynchronously (that is, at times determined by an external device), irrespective of the relative positions within the store. This immediately rules out the use of analog or digital tape as a storage medium, because the time required to access a point depends on the position relative to the previous point.

The only other suitable analog storage medium is film. For a number of reasons, storage on film is unsuitable. For example additional noise is introduced in the signal when a flying spot scanner is used to read out the data from the film. For this reason subsequent discussions will be limited exclusively to digital storage.

The technique of digitizing and storing a complete frame of data and rearranging it in the correct sequence is basically that used at the NESC for the production of the cloud maps. However the increased amount of information contained in one frame of EROS data imposes a significantly greater processing problem.

The limiting resolution of the 2-Inch Return Beam Vidicon Camera—the high-resolution TV camera proposed for EROS—is 6000 lines. To provide an accuracy of 1 percent it is necessary to digitize to 7 bits. The total number of bits per line is then 42×10^3. If a complete frame of 6000 lines is considered, the total number of bits per frame is approximately 250×10^6.

Based on 6000 samples per line, a sampling rate of 8 samples per microsecond is required if the data is to be processed in real time. At 7 bits per sample this corresponds to a data rate of 56 bits per microsecond.

Analog-to-digital and digital-to-analog con-

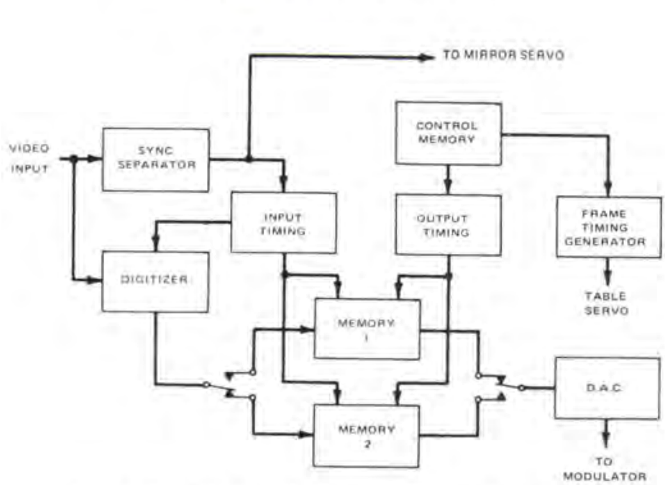

FIG. 4. Simplified block diagram of correction system.

verters are available which are capable of operating at this rate. However the large numbers of bits that must be stored makes the storage of a complete frame of data uneconomical if we wish to operate in real time (the cost would be approximately 5 million dollars). On the other hand, if we consider the use of more economical storage, such as disc or drum, the processing rate is so low as to lead to an excessively long time (typically several hours) to process one picture.

Combination of Line Storage and Rate-Modulated Table Drive

The approach which most economically provides the required degree of accuracy involves a combination of the two previously described techniques. We can store a line of data at a time, subsequently reading it out at a variable rate to ensure the correct position of the elements within a line. At the same time, we can correct in the frame direction by varying the rate at which the table is driven. We then have a flexible system which provides a high degree of accuracy and the advantage that it operates at the same rate as the received data, so no backlog of processing should arise. Figure 4 shows the elements of such a system.

The analog data is first digitized in a high-speed analog-to-digital converter at a rate of 8 samples per microsecond (6000 samples per line). Groups of samples are assembled into larger words before their storage in a core memory (the formatting of the individual samples into longer words permits a slower memory to be used). After a complete line of data has been stored, the storage of the sampled incoming data is transferred to a second store. The contents of the second store is then read out. Each word is broken down into individual samples, and each sample is transferred in turn to a digital-to-analog converter (one possible modification to the display is the inclusion of a digital modulator, which would make the digital-to-analog converter unnecessary). The times at which the words are read out from the memory and transferred to the digital-to-analog converter are under the control of the control unit, which varies the rates so as to ensure the correct positioning of the points within the line. At the same time, the control unit generates synchronization pulses for application to the table drive circuits. The rate at which these pulses are generated is varied so as to ensure correct positioning of the individual lines throughout the frame.

The correction data for the whole of the frame must be stored by the control unit. We can visualize the data as a matrix which for the various positions in the frame contain the information relating to the rate at which the data is to be read into the digital-to-analog converter, and also the rate at which table drive pulses are to be generated. Although this may seem a formidable amount of information to be stored, the problem is made rather easier to solve by the fact that the range of rates over which both signals have to be generated is relatively small, and hence it is only necessary to store the difference between the nominal rate and the actual rate required, where the same correction data can be applied to relatively large areas of the frame.

Correction System Performance. Analysis of the performance that can be achieved by the composite correction system just described shows that it can correct to a very large extent for the photogrammetric errors arising in the television system. Table 2 shows the initial errors and the errors that remain after corrections have been performed is given below. This is based on a 100×100 nautical mile area to a scale of 1:1,000,000. These compare favorably with the required accuracy for National Map Standards: 0.020 inch, and for Doyle: 0.012 inch.

Sources of Calibration Data

The extent to which photogrammetric errors can be corrected is very dependent on the accuracy to which these errors can be measured, and hence an accurate source (or sources) of calibration data is essential.

One major source of information is, of course, measurements made on precise calibration targets prior to the launch of the spacecraft. These measurements can yield valuable data, but of course only relate to the performance of the system prior to launch.

A second source of information is the reseau pattern that is normally engraved on the faceplate of the vidicon. Here, of course, the information relates to the actual operating conditions, but gives no information on errors which may arise prior to the vidicon faceplate. Also if we provide a sufficient number of points to give the required accuracy, it may result in obscuring the very information for which we are looking.

Table 2. Errors Remaining after Corrections are Applied

	Initial Error (inches)	*Residual Error (inches)*
Altitude Errors		
Orbital	±0.15	±0.007
Topographic	±0.010	±0.010
Standard Ellipsoid	±0.002	±0.002
Attitude Errors (Relative Errors Only)		
Roll		
Across-track	±0.0065	±0.001
Along-track	±0.0075	±0.001
Pitch		
Across-track	±0.0075	±0.001
Along-track	±0.0065	±0.001
Sensor Errors		
Lens	±0.007	±0.001
Camera		
Size	±0.16	±0.001
Skew	±0.03	±0.001
Distortion	±0.08	±0.007
Root-Sum-Square of all Errors		±0.015
Root-Sum-Square of all Except Topographical Errors		±0.012

A third approach is to view automatically a calibration target which is inserted in the field of view of the camera automatically at certain times during operation. This is a possibility, although the additional complexity is a source of concern.

A final source of calibration information is the ground itself. Many parts of the world have been mapped to a high degree of accuracy, and when these areas are photographed, correlation between known ground coordinates and photographic positions will provide a great deal of information on both sensor system distortions and spacecraft orbital and attitude inaccuracies. As sensor performance is unlikely to change rapidly during its operating life, this procedure need only be performed rarely.

Conclusions

Although in their raw state, space television pictures are subject to significant photogrammetric errors, it is possible to correct to a great extent for these, and the resulting product will have an accuracy comparable to that to be expected from alternative sources of ground truth. Where necessary, existing ground truth may be used as calibration data for the spacecraft system. It is expected that photogrammetrically corrected space television pictures will form an important element in the Earth Resources Satellite data outputs.

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Coming ISP Symposiums

Comm. I—Columbus, Ohio, U.S.A.; May 25–28, 1970.

Comm. II—Munich, Germany; Sept. 16–19. 1970.

Comm. III—London, England; July 26–28, 1971 (tentatively).

Comm. IV—I.T.C., Delft, The Netherlands; Sept. 9–11, 1970.

Comm. V.—Paris, France; Sept. 21–23, 1970. To be followed by a joint meeting of the Council and the Commission Presidents, Sept. 24–26.

Comm. VI—Bratislava, Czechoslovakia; Sept. 28–30, 1970 (tentatively).

Comm. VII—Dresden, East Germany; Sept. 10–16, 1970.