N82 28729

7.8 GEOMETRIC ERROR CHARACTERIZATION AND ERROR BUDGETS*

Eric Beyer, General Electric

This discussion describes the procedures used in characterizing geometric error sources for a spaceborne imaging system, and uses the Landsat-D Thematic Mapper ground segment processing as the prototype. It should be noted that software has been tested via simulation and is currently going through tests with the operational hardware as part of the operational system evaluation prelaunch, so that we can thoroughly characterize this system with respect to its geometric performance before we launch it. In addition, there is a substantial effort, both on the part of General Electric and NASA-Goddard in postlaunch evaluation of this data. With respect to geometric performance and radiometric performance the requirements for this system are being taken very seriously.

There are two requirements for Landsat-D Thematic Mapper as well a pro-cessing, which relate to the geodetic accuracy. Figure 1 displays t cess whereby we can match back to a standard map as well as provide tempor istration, and band-to-band. There are some significant caveats in these areas which are important to the users. For one, Landsat is not a mapping system, we don't view it that way. We are providing a system that will meet certain geodetic rectification requirements if we are provided maps that have no errors in them. That obviously is not the case. Therefore, much of the attention in Landsat-D has been directed towards temporal registration. That is we want to be sure that we are self-consistent, that our images will overlay with high accuracy.

The requirements for geodetic registration is .5 pixel, again with its major caveat, and there is another caveat which has to do with adequate numbers of ground control points. One other that says this is to be done without consideration of topographical variations. Thus, this is the performance expected if you have a flat earth for temporal registration and the ground track and attitude control of the spacecraft were exactly repeatable past to past. There has been very little concern about band-to-band accuracy with the multispectral scanner, mostly because due to its design it has exceedingly good band-to-band accuracy. Once you get the focal plane base plate properly designed along with the scanning mechanism, there is very little opportunity for band-to-band misregistration with the MSS. The Thematic Mapper has a much larger spread to its detectors and much larger time between various bands being imaged, so there is much more opportunity for band-to-band registration errors. As Jack Engel has pointed out, the current instrument has very good band-to-band accuracy. There are features in the ground processing that will significantly improve that. For the Thematic Mapper after processing, it should be possible to achieve something well down below a 10th of a pixel band-to-band accuracy.

The single scene accuracy requirement can be characterized as:

*Edited oral presentation.

0.3 PIXEL TEMPORAL (90%) X

$$\frac{42.5 \quad \text{RAD}}{\text{PIXEL}} \times \frac{(1\ )}{1.645(90\%)} \times \frac{\text{SINGLE SCENE}}{2 \text{ TEMPORAL}} = 5.48 \text{ RAD } (1\ )$$

$$= 3.9 \text{ METER } (1\ )$$

We are essentially dealing then with the Gaussian-type error performance, so I can convert one-to-one sigma by the Gaussian transformation 90% to one sigma for temporal registration. Given we do our processing down to the point where the errors are uncorrelated from scene to scene, we are roughly talking about a factor or square root of two for a single scene. That translates to 5.5 microradian, a little more than an arc second, four meters total error budget. All errors have to be significantly smaller than that. At 30 meters with subpixel accuracy specified this way we have an extremely challenging job.

Figure 2 describes the Landsat-D processing system. The characteristics of the Thematic Mapper and the Spacecraft and the Tracking Data Relay Satellite Systems on that spacecraft provide essentially all constraints of spacecraft design. You don't have much flexibility in spacecraft design. We first looked at the Thematic Mapper as a big MSS and we are going to process it as an MSS. We started down that path about three years ago doing error analysis and every time we would examine in detail some of the errors we were horrified. It finally got to the point were we were about 3 pixels temporal registration and growing. At that point in time, we went to the Landsat-D project and said something has to be done, either the specs have to be changed or we have to redesign the processing system, from a system point of view. That was the first test of that 0.3 pixel, and it would have been much easier at that point in time to say 0.3 pixel was not really required. That requirement has, however been maintained. What I am going to describe now is an overview of the changed design, which essentially we've been going through the last two years.

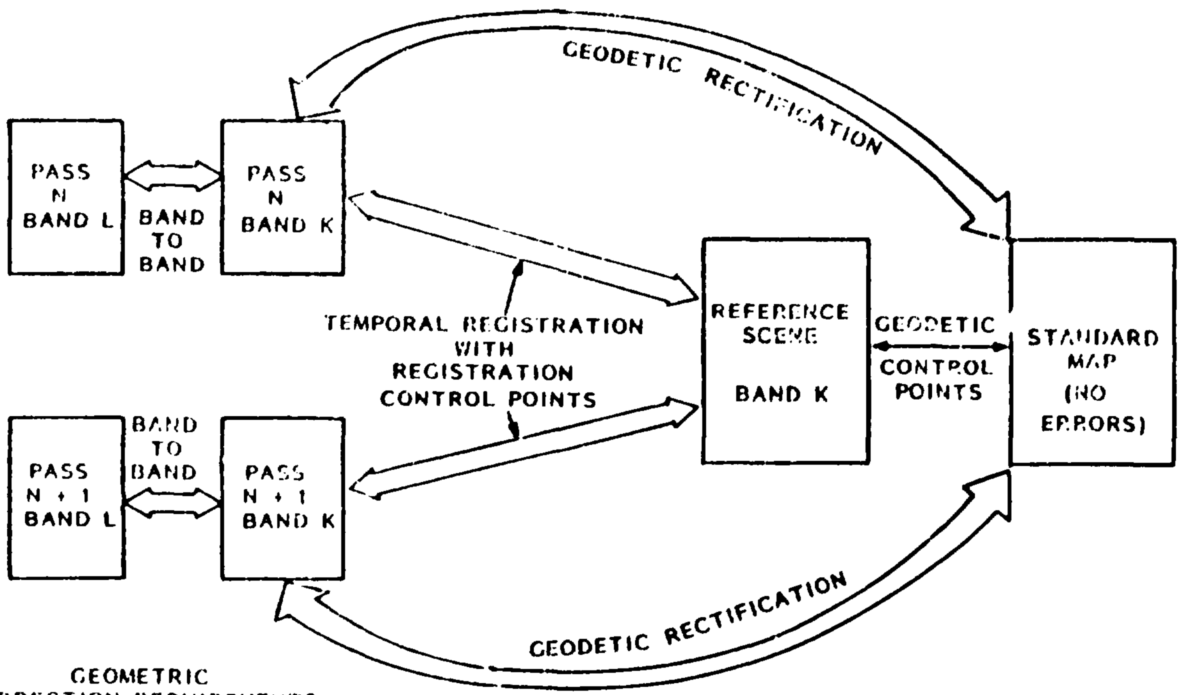
In our attempt to meet the registration goals, we had to get involved in the workings of the Thematic Mapper. We had to get in there and really understand how that worked and apply our processing directly to the inner workings of that instrument. We could not hold the platform steady to an arc second or a fraction of an arc second to achieve a 1-arc-second total error budget. The solution there was to measure. We installed a small angular displacement 3-axis package on the Thematic Mapper; it cannot be mounted any place else on the spacecraft because of structural dynamic effects. It's one draw back is that it is essentially a high-pass device, and the electronics we build for it has a band of 2 Hz to 125 Hz; it does not capture the low-frequency end. That shortcoming was alleviated by incorporating some of the hardware that was already on the spacecraft, namely the attitude control drivers which have a bandwidth of somewhere just above 0 Hz to 2 Hz nominally. An onboard computer performs functions of sampling the gyros as part of its attitude control function; it estimates the gyro drift, gives us initial attitude estimates, and it is the source of an ephemeris if the GPS system is giving the ephemeris to the OBC, which then sends it down to us, and sometimes an uplink of ephemeris also comes to us for ground processing through the onboard computer. A formatter was added, which is essentially a piece of hardware that takes samples of the angular displacement sensor and sends it down on a telemetry link called payload correction data. That data set is all the information external to the

Thematic Mapper needed to perform Thematic Mapper Processing, both radiometric and geometric.

There are certain pieces of additional data that are very important. We know that the scan mirror is not perfectly repeatable in the Thematic Mapper. That was determined after extensive testing by Hughes of the Thematic Mapper scan mirror mechanism. In order to characterize the scan mirror it was determined that more than just the starting and end locations were needed. We needed an evaluation point in the middle of the scan. So the data that is sent down is the scan start time, which allows us to coordinate the scan mirror positions with all the other measurement systems on the spacecraft. The scan direction first-half second-half scanner essentially tells us how the scan profiles are behaving in time. In the ground processing, we extract the scan information out of the wideband data. Payload correction processing is the process that takes the scan mirror information, as well as all the other attitude and ephemeris related information, and generates systematic correction data which will essentially remove all the high-frequency internal distortions when applied to the imagery. At that point of time we have not captured some significant low-frequency errors relating to ephemeris alignment, time, errors, and low-frequency attitude errors. Those are captured by ground control points (Figure 3) used to adjust the data and to derive what we call geodetic correction data, which is an identical form, but improved values (see Figure 4).

In the meantime, off-line, there is a very high speed reformating and radiometric correction applied to the imagery in parallel to generate what we call archive imagery. Archive imagery is available as a product for the TM; it includes reformatted imagery with the data appended to it. The next step in processing is to actually perform the resampling based on this product for the TM; it includes reformatted imagery with the data appended to it. The next step in processing is to actually perform the resampling based on this data. We do the mapping from the input space to the map coordinate outboard space.

Figures 5 and 6 describe the error budget. In review, systematic correction data is data which does the mapping from input space to output space, but control points have not been included. Control points remove some very large errors, but they are low frequency. Ephemeris uses the worst case, a 2-day predict to which we had to design. This time is the result of the $\pm$ 20 millisecond clock or absolute time. Attitude control as .01° effective meters, 1 sigma, is an alignment which is a rather large number. This is essentially a fixed bias, and I know here that with minimal amounts of processing, that number can be reduced very substantially in ground processing and indeed that will be done. But immediately after launch, we could have alignment errors that large. So we are talking about rather large uncertainty here, so there is no hope of knocking all of these down to anything less than that without using ground control points. The ground control point processing is substantially different than previous processing for ground control points in its estimation technique in that it is a common filter smother-type processing. We have developed both noise models and dynamic models for all these errors and they are included in the processing. The advantage of doing that is that we can develop the processing technique that is significantly less sensitive to control point distribution. One of the major problems that plagues many of the current processing systems is that if you have to have an extremely good distribution of control points, you better not have any control points that are in serious error because it will substantially affect polynomial fits. With this technique we have a very graceful degradation in performance as we change the locations into non-optimal positions and we can propagate through extended periods that don't have control points. So if there is a group of scenes that have a number of control points at the top, then ten scenes later a number of control points, we are not necessarily going to meet our accuracy requirements in between, but we can come very close to it, as we can verify performance by propagating these errors, via the dynamic models of the filter smoother estimation technique.



GEOMETRIC
CORRECTION REQUIREMENTS
90% OF THE TIME

GEODETIC	0.5 PIXEL
TEMPORAL	0.3 PIXEL (REGISTRANT TO REFERENCE)
BAND-TO-BAND	0.3 PIXEL

Figure 1.. Geometric Accuracy Specifications

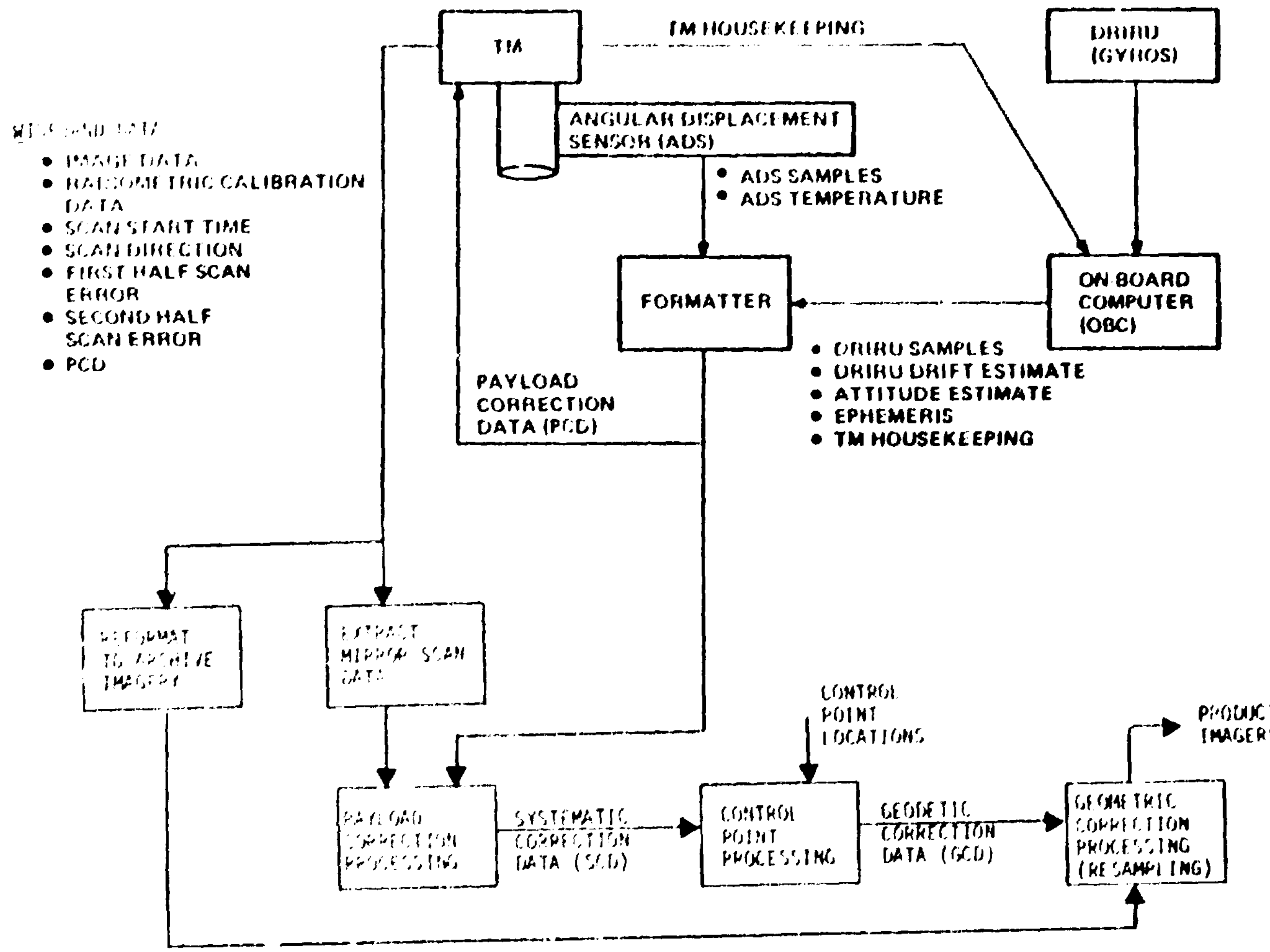


Figure 2. Thematic Mapper Geometric Correction

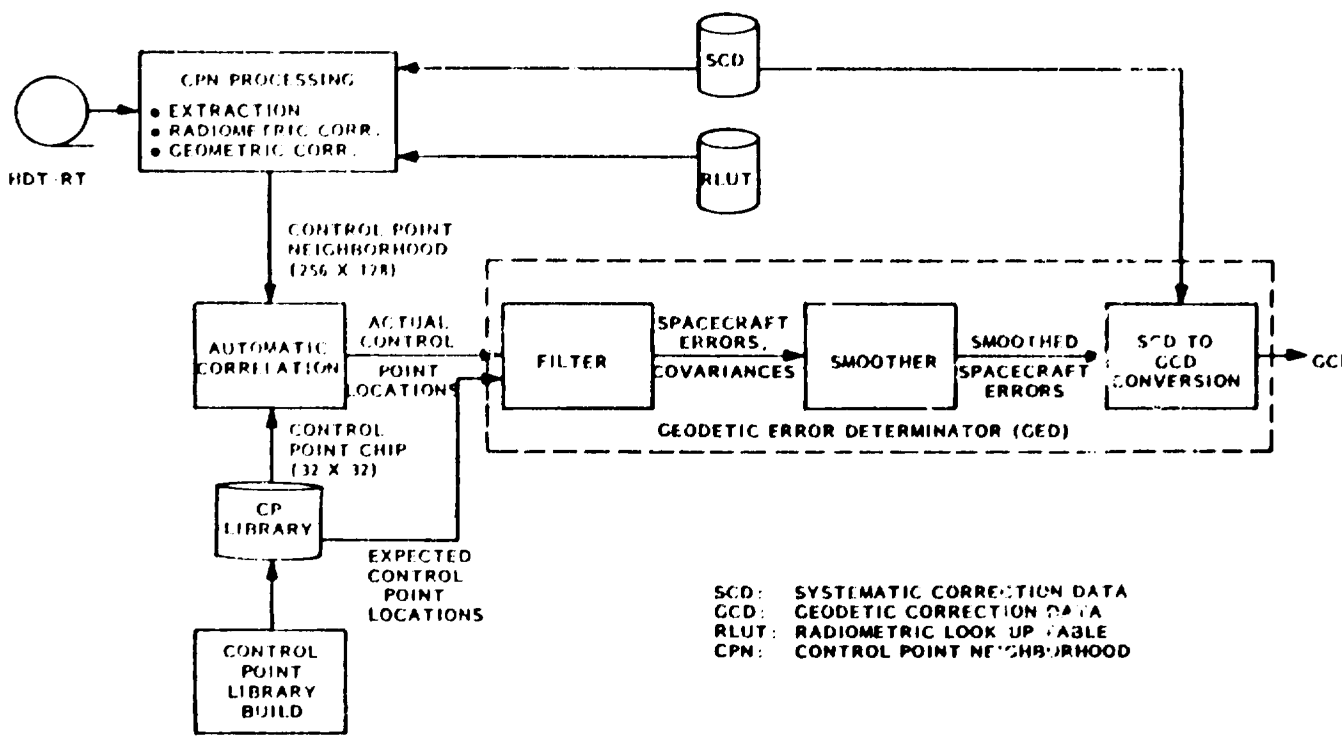


Figure 3. Control Point Proc‹ssing

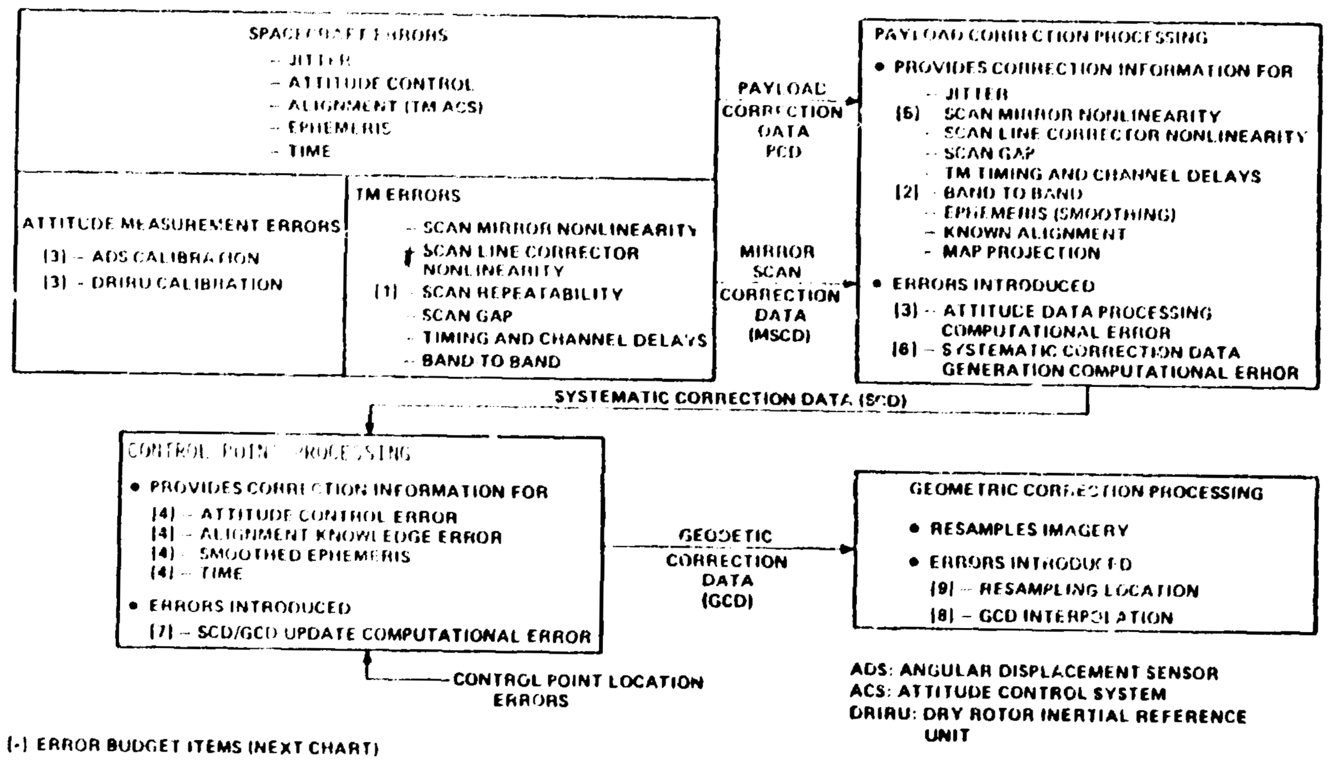


Figure 4. Thematic Mapper System Geometric Errors

ERROR SOURCE	CROSS TRACK ERROR*	ALONG TRACK ERROR*	ITEM NUMBER (PREVIOUS CHART)
• THEMATIC MAPPER			
– SCAN REPEATABILITY	$.165\sqrt{2}$	$.165\sqrt{2}$	1
– BAND TO BAND	$.048\sqrt{2}$	$.039\sqrt{2}$	2
• SPACECRAFT			
– JITTER	$.094\sqrt{2}$	$.094\sqrt{2}$	3
– ATTITUDE, EPHEMERIS, ALIGNMENT, TIME RESIDUAL	.165	.165	4
• GROUND PROCESSING			
– SCAN NONLINEARITY CORRECTION	$.082\sqrt{2}$	0	5
– SYSTEMATIC CORRECTION DATA GENERATION	$.055\sqrt{2}$	$.055\sqrt{2}$	6
– CONTROL POINT PROCESSING	$.055\sqrt{2}$	$.055\sqrt{2}$	7
– GCD INTERPOLATION	$.055\sqrt{2}$	$.055\sqrt{2}$	8
– RESAMPLING LOCATION	$.014\sqrt{2}$	$.014\sqrt{2}$	9
• TOTAL (ROOT-SUM-SQUARE)	.369	.348	
• SPECIFICATION	.3	.3	

*RESIDUAL ERROR AFTER PROCESSING

Figure 5. Thematic Mapper System Temporal Registration Error Budget In Pixel (42.5 Microrad) 90%

ERROR SOURCE	CROSS TRACK (METERS 1σ)	ALONG TRACK (METERS 1σ)
EPHEMERIS	100	500
TIME		80
ATTITUDE	123	123
ALIGNMENT	427*	855*
TOTAL (ROOT-SUM-SQUARE)	455 (25 PIXELS 90%)	1001 (55 PIXELS 90%)

*SUBSTANTIAL REDUCTION WILL OCCUR AFTER POSTLAUNCH CALIBRATION (205 METERS (1σ))

Figure 6. Geometric Error In Systematic Correction Data (Approximate)