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Registration of Heat Capacity Mapping Mission Day and Night Images

An affine transformation, employing water bodies as control, gave the most satisfactory results.

ABSTRACT: *Registration of thermal images is complicated by distinctive differences in the appearance of day and night features needed as control in the registration process. These changes are unlike those that occur between Landsat scenes and pose unique constraints. Experimentation with several potentially promising techniques has led to selection of a fairly simple scheme for registration of data from the experimental thermal satellite* HCMM *using an affine transformation. Two registration examples are provided.*

INTRODUCTION

THE TECHNIQUE of thermal-inertia mapping (Watson, 1971; Watson *et al.*, 1972; Pohn *et al.*, 1974; Watson, 1975; Kahle *et al.*, 1976; Price, 1977; Pratt and Ellyett, 1979; Watson, 1981b) requires co-registering of images acquired at different times to construct temperature-difference and thermal-inertia images. In addition, refinements to use topographic corrections (Gillespie and Kahle, 1977; Miller and Watson, 1977; Watson, 1981a) and to compare thermal data with other data bases, such as Landsat images and geophysical and geologic maps, require further registration to a topographic base. Thermal images have some unique characteristics that make this registration process more complex than registration of standard photographs and Landsat images. The inherent temporal behavior of the surface temperature, which depends on albedo, thermal and emissive properties, and slope, elevation, and moisture effects, makes the scene appear substantially different on day and night scenes. Texture and topography often are portrayed in an entirely different manner on thermal images acquired at different times during the day and night (Sabins, 1969; Rowan *et al.*, 1970; Offield, 1975). The selection of reproducible control points associated with various features thus can be a difficult task and one subject to substantial error. For example, mislocation of a feature on an image with respect to a corresponding topographic ridge can result in a topographic correction being applied with the wrong sign! The Heat Capacity Mapping Mission (HCMM) data also presents an additional problem because the 500-m digital resolution masks many distinctive features—primarily cultural—that can be seen on the 80-m resolution Landsat data.

Errors resulting from the misregistration between images and among images and various data bases have been discussed previously (Miller and Watson, 1977). The purpose of this brief paper is to describe our current experience with the registration of HCMM data and to suggest the use of a simple method for registering the data that we have found to be more accurate than the registered products currently being made available.

METHOD

We experimented with iterative registration, with using drainage-intersection maps for control, and with cross correlation techniques, but none were found to be satisfactory. The procedure finally used to register the image pairs was to select control points and to map the night thermal image to the daytime thermal and reflectance images

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using an affine transformation on a 1300 by 1100 pixel image. The resulting image registration was accurate to better than two pixels (RMS) and does not exhibit the significant misregistration that we have noted in the temperature-difference and thermal-inertia products supplied by NASA.

The affine transformation was determined using simple matrix arithmetic—a step that can be performed rapidly with matrix hardware on a minicomputer such as a Hewlett-Packard HP9845.*

Consider a set of control points x_i, y_i in the day image and the corresponding points x_i', y_i' in the night image. A best-fit affine transformation can then be computed: that is,

$$\text{let } \mathbf{S}' = (x_i, y_i)$$
$$\mathbf{S} = (x_i, y_i, 1)$$

Then the desired affine transformation

$$\mathbf{T} = \begin{pmatrix} a & d \\ b & e \\ c & f \end{pmatrix}$$

satisfies the matrix equation $\mathbf{S}' = \mathbf{ST}$ and thus

$$\mathbf{T} = (\mathbf{S}^T\mathbf{S})^{-1}(\mathbf{S}^T\mathbf{S}') \text{ where } \mathbf{S}^T \text{ is the transpose of } \mathbf{S}.$$

* Use of trade names is for descriptive purposes only and does not constitute endorsement by the U.S. Geological Survey.

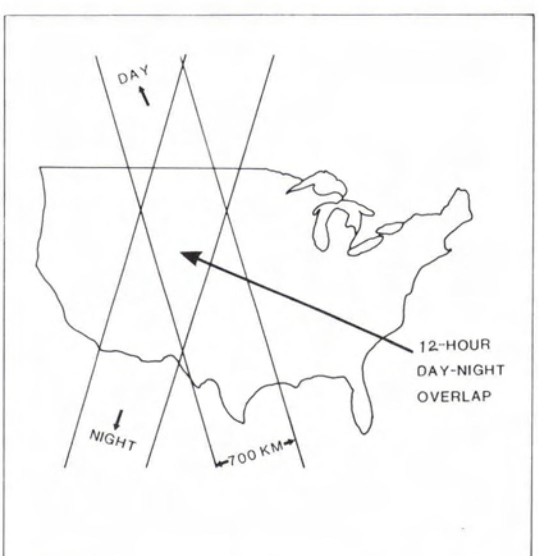


FIG. 1. The day and night orbital tracks of the HCMM satellite are inclined with respect to each other, and the area of overlap is a diamond. For this example, the scan lines are inclined at an angle of about 30°.

RESULTS

The affine transformation provides a rotation correction for the inclined day and night orbital tracks (see Figure 1), an origin shift, and a scale change. Our previous experience with aircraft data has suggested the need to correct for platform instabilities due to pitch, yaw, and roll of the aircraft, and this has required non-linear or piece-wise linear corrections. We did not find this necessary with the two HCMM image data sets that we have analyzed. Presumably the satellite, being more stable, is less subject to these effects.

The two most important considerations in selecting control features are that they are readily identifiable on both day and night data and that their locations cover the scene. We experimented with selecting different types of features as control points. The best features—those more reproducible on both day and night data—were the water-dam interfaces of reservoirs. Distinctive outlines of other water bodies were also reasonably identifiable. Drainages and topographic features were found to be the least reliable due to changes in their day-night appearance. In the first registration example (Figure 2), nine water body features were used as control. In the second example (Figure 3), few water bodies exist, and only three of the six selected control features were water-associated. The other three points are topographic features. The accuracy of identifying these features was in part estimated by the magnitude of the residual errors. A high residual was indicative of the feature being misidentified. Figure 4 shows an example of the control vectors (a) and of the residuals (b) from the Powder River Basin scene registration.

We discovered that a simple transformation was satisfactory over large parts of an entire image in two relatively arid regions of the western United States, using a few accurately determined control points at bodies of water. The procedure should be more easily applied in other areas where bodies of water are likely to be more abundant. A listing of the computer program to perform this registration is provided in Figure 5.

Automatic registration using cross-correlation failed when we attempted to apply it to one site because of a pronounced topographic grain that produced a significant error along the direction of the grain.

Some sample results of our registration efforts are provided to illustrate the method and its simplicity. Figure 2 shows the transformed night image compared with the day image and the original untransformed night image. The second example is the Cabeza Prieta, Arizona, area in Figure 3. Day, night, and thermal-inertia images are pre-

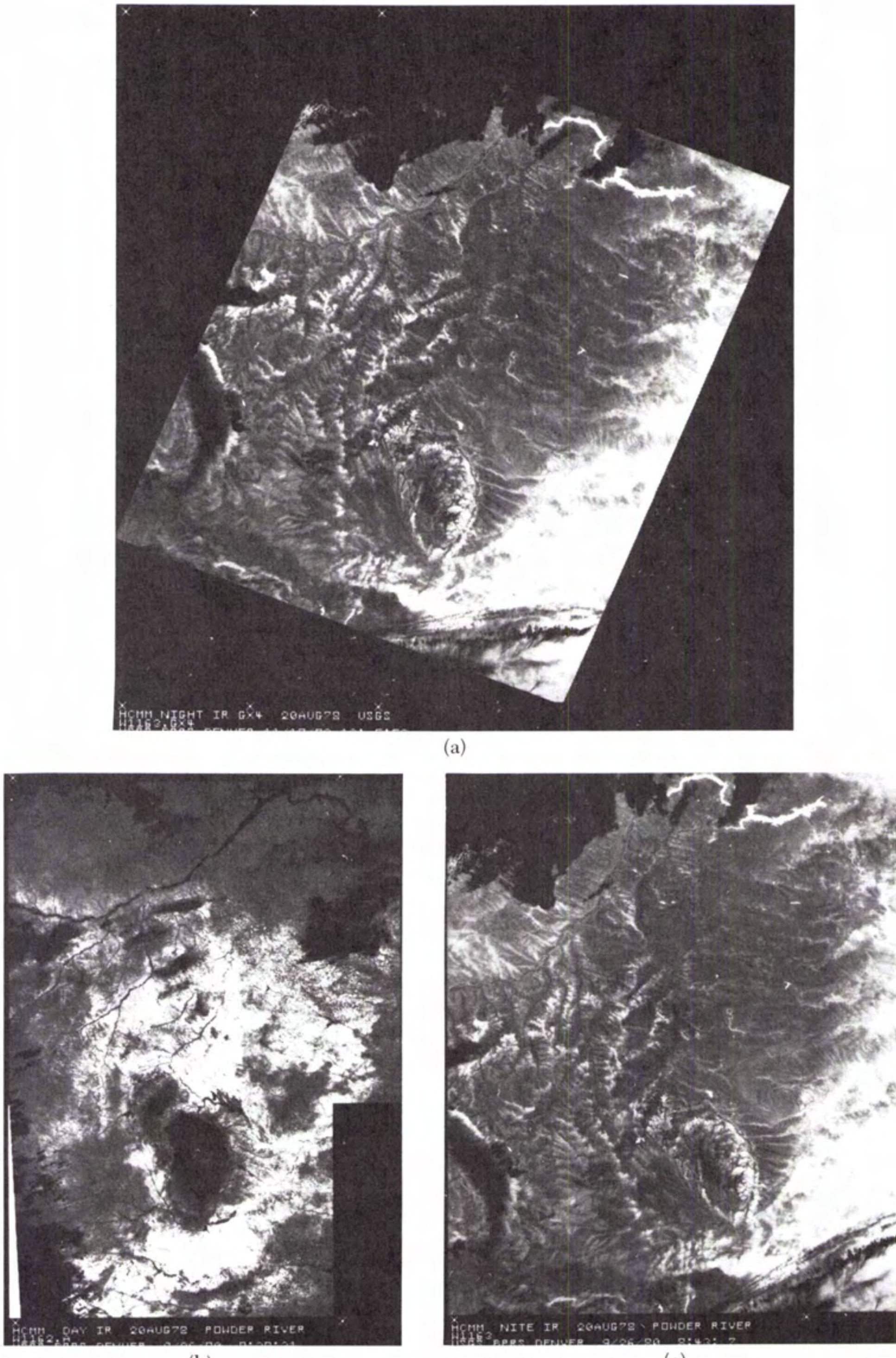
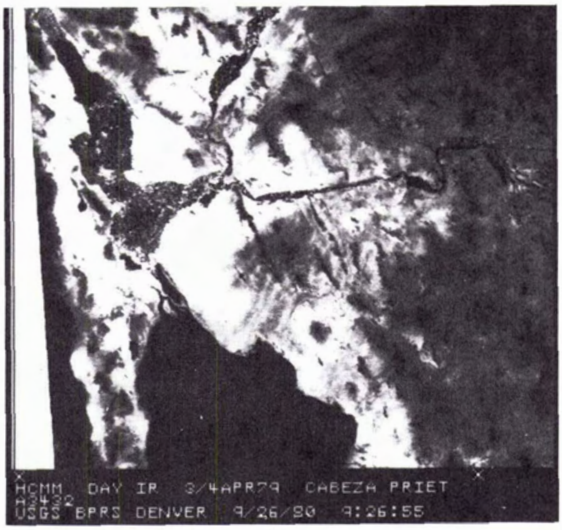
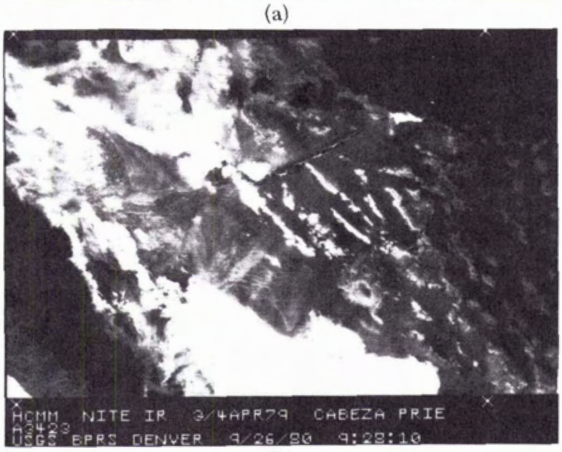


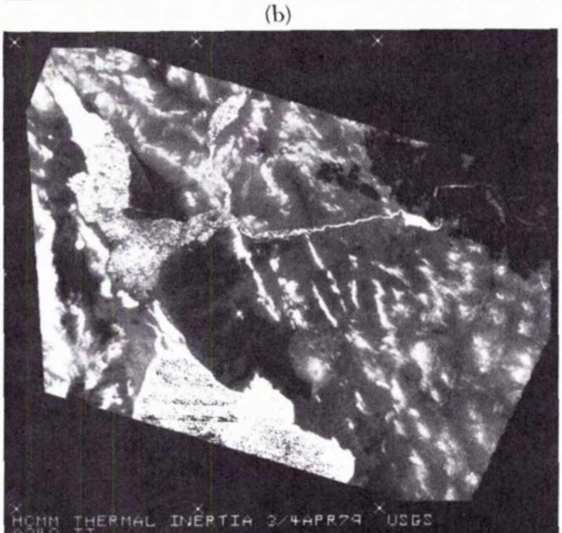
FIG. 2. Images of the Powder River Basin area, Wyoming. Figure 2a is the transformed night thermal image, Figure 2b is the day thermal image, and Figure 2c is the original night thermal image. The scale of the original images is approximately 1:5,000,000. The Bighorn Mountains, Wyoming, are to the lower left, the Black Hills, South Dakota, are near the bottom center, and the large body of water at the top of the scene is Lake Sakakawea, North Dakota. Significant changes in the appearance of the landscape are evident between the day and night images. The most apparent aspect of the affine transformation is a rotation; however, there are also scale changes in both directions. The usual convention of light associated with high values and dark with low values was employed. Extensive cloud cover is present in the upper left hand corner of the night image and the lower left hand corner of the day image.



(a)



(b)



(c)

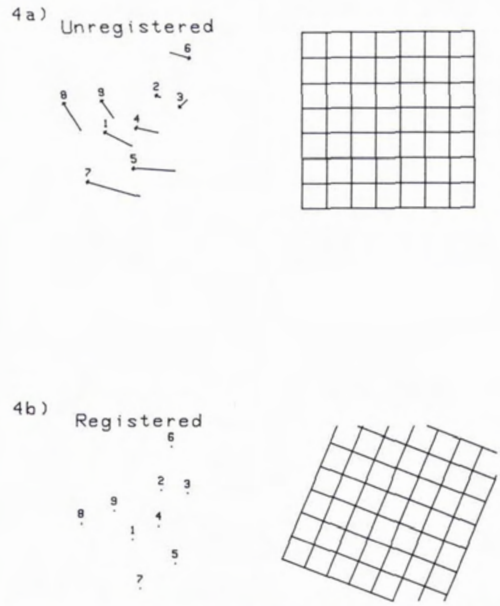


FIG. 4. Registration vectors between two sets of control points for the Powder River Basin area, Wyoming. Figure 4a shows the vectors between the day and night images. Figure 4b shows the residual vectors after applying the affine transformation. Maximum residual is 2 pixels.

sented, the latter being computed from the registered day thermal, night thermal, and reflectance images using a new algorithm (Watson, 1981b). Figure 4 presents a comparison between the original control vectors and their residuals after applying the method to HCMM data of the Powder River Basin, Wyoming, area.

ACKNOWLEDGMENTS

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FIG. 3. Images of the Cabeza Prieta area, southwestern United States and Mexico. Figure 3a is the day thermal image and Figure 3b is the night thermal image and Figure 3c is a thermal inertia image constructed by applying a model to registered day-thermal, reflectance, and night thermal images. The scale of the original image is approximately 1:5,000,000. The Gulf of California is at the bottom of the scene and Salton Sea, California is in the upper left corner. Clouds are present in the upper right hand corner of the night image.

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      PROGRAM GEOMX4
C..... ***************************************************************
C.....
C..... REMOTE SENSING ARRAY PROCESSING PROCEDURES
C..... U. S. GEOLOGICAL SURVEY, DENVER, COLORADO
C..... BRANCH OF PETROPHYSICS AND REMOTE SENSING
C..... DON L. SAWATZKY
C.....
C..... ***************************************************************
C
C     GEOMX4 GENERATES A RECTIFIED IMAGE FILE FROM A DISTORTED IMAGE
C FILE AND FROM COEFFICIENTS FOR RECTIFICATION, R AND S, DETERMINED FOR AN
C AFFINE TRANSFORMATION OF THE DISTORTED FILE.
C INPUT FILE STRUCTURE CONSISTS OF A HEADER RECORD CONTAINING TWO
C INTEGERS FOR LINE LENGTH, LENREC, IN PIXELS AND NUMBER OF LINES,
C NORECS.  NORECS NUMBER OF DATA RECORDS FOLLOW, EACH RECORD CONTAINING LENREC
C BYTES OF 8-BIT DATA.  OUTPUT FILE HEADER RECORD CONTAINS TWO INTEGERS OF LINE
C LENGTH, NPXOUT, AND NUMBER OF RECORDS, LMAX.  INPUT PARAMETERS, IPIXIN AND NPI
C XIN, ALLOW TAKING A SUBSET OF THE INPUT FILE.  OUTPUT PARAMETERS LMAX, MNPIX
C , AND MXPIX ARE SELECTED ON THE LINE LENGTH OF THE INPUT FILE AND DEGREE
C OF ROTATION REQUIRED FOR RECTIFICATION.  SECTIONS OF THE OUTPUT FILE OF LENGTH
C LMAX AND CONTAINING PIXELS MNPIX TO MXPIX ARE GENERATED BY ONE OR MORE ITER
C ATIONS OF THIS PROGRAM.  SECTIONS ARE CONCATENATED IN SUBSEQUENT PROCESSING.
C SECTIONING THE OUTPUT FILE IS DONE IN RESPONSE TO THE MESSAGE: "INBUF ARRAY
C TOO SMALL."
C
C.....DECLARATIONS
      REAL R(3),S(3)
      LOGICAL*1 INBUF(200000),OUTBUF(3000)
      INTEGER FCBIN(35),FCBOUT(35)
C.....
C.....SET PARAMETERS
      WRITE(6,99)
99    FORMAT(1X,'ENTER PIXEL/LINE COEFFICIENTS ':)
      READ(5,96) R,S
      WRITE(6,98)
98    FORMAT(1X,'ENTER INPUT FIRST PIXEL, NO. PIXELS')
      READ(5,96) IPIXIN,NPIXIN
      WRITE(6,97)
97    FORMAT(1X,'ENTER MAX. OUTPUT LINES,MIN/MAX PIXEL ':)
      READ(5,96) LMAX,MNPIX,MXPIX
96    FORMAT(G16.0)
C.....
C.....OPEN DATA FILE TO TRANSFORM
      READ(8) LENREC,NORECS
C.....SETUP WORK ARRAY
      NRECS=MIN(200000/LENREC,NORECS)
      MXLINE=NRECS
      MNLINE=1
      J1=LENREC*MOD(I,NRECS)+1
      J2=J1+LENREC-1
      DO 90 I=1,NRECS
90    READ(8) (INBUF(J),J=J1,J2)
C.....
C.....OPEN OUTPUT DATA FILE
      NPXOUT=MXPIX-MNPIX+1
      IF(NPXOUT.LE.3000.AND.NPIXIN.LE.3000)GO TO 110
100   STOP ' ?DATA FILES EXCEED BUFFER WIDTH.'
110   WRITE(9) NPXOUT,LMAX
C.....READ/WRITE LOOP
      DO 210 LINE=1,LMAX
      DO 200 IPX=MNPIX,MXPIX
      INPX=R(1)*(IPX) + R(2)*(LINE) + R(3)
      IF(INPX.LT.1.OR.INPX.GT.NPIXIN) THEN
      OUTBUF(IPX-MNPIX+1)=.FALSE.
      ELSE
      INLINE=S(1)*(IPX) + S(2)*(LINE) + S(3)
      IF(INLINE.LT.1.OR.INLINE.GT.NORECS) THEN
      OUTBUF(IPX-MNPIX+1)=.FALSE.
      ELSE
C.....CHECK LIST FOR SCANLINE IN WORK ARRAY
      IF(INLINE.GE.MNLINE.AND.INLINE.LE.MXLINE) GOTO120
C.....ELSE READ SCANLINE INTO LIST AND WORK ARRAY
      IF(INLINE.LT.MNLINE) STOP'INBUF ARRAY TOO SMALL!!'
      DO 115 I=MXLINE+1,INLINE
      IREC=MOD(I,NRECS)*LENREC
115   READ(8,REC=INLINE) (INBUF(J),J=IREC+1,IREC+NPXIN)
      MXLINE=INLINE
      MNLINE=MXLINE-NRECS+1
120   OUTBUF(IPX-MNPIX+1)=INBUF(LENREC*MOD(INLINE,NRECS)+INPX)
      ENDIF
      ENDIF
200   CONTINUE
210   WRITE(9) (OUTBUF(J),J=1,NPXOUT)
C.....
C.....FINIS
300   STOP
      END
```

FIG. 5. A listing of the computer program to perform registration.

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