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A Computer System for Geosynchronous Satellite Navigation

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ABSTRACT

A computer system specifically designed to estimate and predict Geostationary Operational Environmental Satellite (GOES-4) navigation parameters using Earth imagery is described. The estimates are needed for spacecraft maneuvers while predicts provide the capability for near real-time image registration. System software is composed of four functional subsystems: (1) Data Base Management, (2) Image Processing, (3) Navigation, and (4) Output. Hardware consists of a host minicomputer, a cathode ray tube (CRT) terminal, a graphics/video display unit, and associated input/output (I/O) peripherals. System validity is established through the processing of actual imagery obtained by sensors on board the Synchronous Meteorological Satellite (SMS-2). Results indicate the system is capable of operationally providing both accurate GOES-4 navigation estimates and images with a potential registration accuracy of several picture elements (pixels).

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A COMPUTER SYSTEM FOR GEOSYNCHRONOUS SATELLITE NAVIGATION

1. INTRODUCTION

The NASA Goddard Space Flight Center has developed, for the past several years, a diversified and comprehensive set of applications computer systems. These systems typically include a minicomputer, image displays, a variety of individual applications programs, a high degree of user interaction, and users from diverse disciplines. For example, the Atmospheric and Oceanographic Information Processing System (AOIPS) is utilized by discipline scientists from such diverse fields as meteorology, oceanography, and Earth resources to extract information from remotely sensed images (1). The Domestic Information Display System (DIDS) performs statistical analysis of demographic data for use during policy analysis and decision making (2). Under development are the Landsat-D Assessment System (LAS) and the VISSR* Atmospheric Sounder (VAS) Processor (3, 4).

LAS is being designed to analyze and display Earth scenes imaged by Landsat-D satellite sensors, especially the Thematic Mapper. The VAS Processor will extract meteorological information from multispectral images taken by sensors on board the GOES-4 satellite.

This paper describes a particular segment of the VAS Processor entitled the VAS Navigation Package (VAS/NAVPAK) System. Its purpose is the extraction of satellite orbit and attitude parameters from imagery for both mission operations and annotation to subsequent imagery for concurrent registration. The system software/hardware are discussed in some detail. Finally, system validity is demonstrated by processing actual imagery taken by sensors on board the SMS-2 satellite.

*Visible Infrared Spin Scan Radiometer - a multispectral sensor on board the Synchronous Meteorological Satellite (SMS) and Geostationary Operational Environmental Satellite (GOES) series. The VAS sensor is an upgraded version of the VISSR.

2. SYSTEM SOFTWARE

The software for the VAS/NAVPAK system is composed of approximately 220 routines with a total of 20,000 instructions. The majority of this code is written in double precision Fortran IV Plus;* however, a few routines concerned with data base control are in assembly language. Core storage restraints necessitate that the software be arranged in an overlay structure during execution. The software is divided into four functional subsystems: (1) Data Base Management, (2) Image Processing, (3) Navigation, and (4) Output. Each is under the control of the system executive and intra-system communication is via global common areas and data files. Figure 1 depicts the arrangement. Software specifications may be found in (5).

The Data Base Management (DBM) subsystem permits use, modification, and maintenance of system data files. These files, residing on disk or tape, contain the data, constants, and the pointers needed by other subsystems during execution. Files can be direct access, sequential, or link listed but need a directory. The image coordinates and navigation parameters files are two examples. Approximately 35 routines comprise the DBM subsystem.

The Image Processing subsystem displays, manipulates, and processes VAS sensor images to create image coordinates used as observations by the Navigation subsystem. Hardware constraints limit the size of a video display to a 512 square subimage. Zooming and resampling algorithms are available to enlarge any area of interest within a subimage. Within this area, any conspicuous geographical feature, e.g., a river junction, with known geodetic coordinates qualifies as a potential landmark. The manual or automatic positioning of a cursor upon this landmark determines its image coordinates. An entire data file of image coordinates of carefully selected landmarks can be established in this manner. Thereafter, this file is placed under the control of the DBM subsystem for eventual transfer to the Navigation subsystem. The Image Processing subsystem contains some 75 routines.

*The Digital Equipment Corporation (DEC) supported version of American National Standards Institute (ANSI) Fortran.

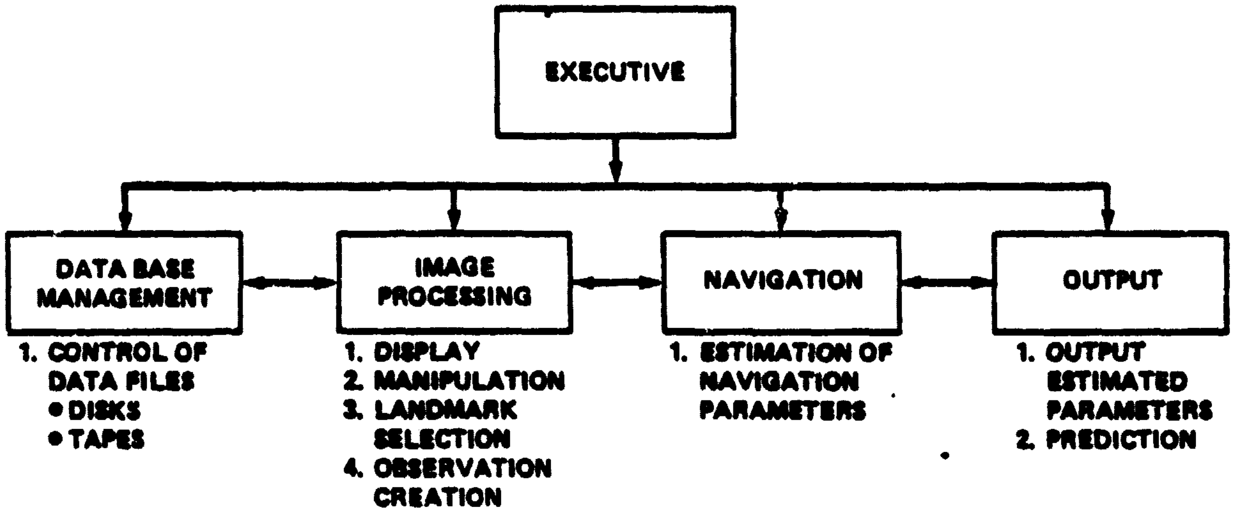

Figure 1. System Software

The Navigation subsystem uses the image coordinates created in the Image Processing subsystem to estimate in the least squares sense the GOES-4 navigation and VAS sensor misalignment parameters at some epoch. Navigation parameters include satellite orbit and attitude. The estimates with their uncertainties and the residuals of image coordinates are computed for each iteration. These estimates are subsequently output to the CRT tube for immediate analysis by the user or to system files under control of the DBM subsystem for storage. This subsystem contains approximately 80 routines.

The Output subsystem assembles, propagates, and outputs estimated parameters to buffers for transmission to another facility. These parameters are subsequently used to annotate incoming VAS sensor video data. The annotated information will permit near real time registration of VAS images. Such capability is particularly helpful for rapid and accurate determination of geodetic coordinates of temporal phenomena such as clouds or sea swells. There are 30 routines within this subsystem.

3. SYSTEM HARDWARE

System hardware consists of a Digital Equipment Corporation (DEC) PDP-11/70 host minicomputer, a CRT terminal, an International Imaging System (I^2S) Model 70/E graphics/video display unit, three direct access RPO6 disk drives, and two 9-track magnetic tape drives. See Figure 2.

The PDP-11/70 is a medium scale general purpose minicomputer employing an enhanced version of the basic upwardly compatible PDP-11 architecture. Principal components include (1) a Central Processor with an Arithmetic/Logical Unit, 16 general purpose registers, and a processor status register, (2) numerous off-line devices, (3) a Floating Point Processor, (4) Main Memory, and (5) two data buses. These buses allow the sending, receiving, or exchanging of data without Central Processor intervention or buffering in memory. The standard word length is 16 bits although the Floating Point Processor employs 32 or 64 bits for single or double precision calculations, respectively. The maximum accessible memory is two megabytes. The entire machine is controlled by an RSX-11M Operating System which permits real time multiprogramming and tasking. Detailed descriptions of both the minicomputer and the operating system are available (6).

The CRT terminal features an illuminated screen and detachable keyboard. The various menus needed by a user to drive the system interactively appear on this screen. The terminal represents the primary user/system interface.

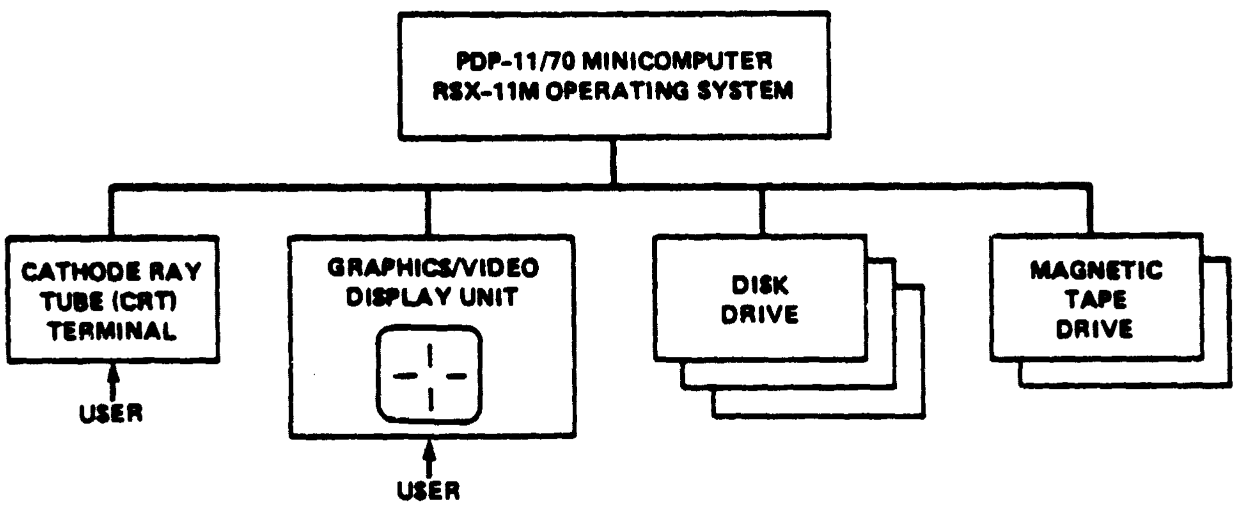

Figure 2. System Hardware

The graphics/video display is actually configured as an independently operating image computer and display terminal. However, within this system arrangement, it operates in a supporting role. The unit contains its own software for color display of multi-spectral or temporal imagery. This unit provides a secondary user/system interface. The three disk drives are direct access and contain removable packs of 176 megabyte storage capacity each. Access time is 36 milliseconds and data transfer occurs at 1.24 microseconds per byte. Two of the three disks are dual ported with other applications computer systems. The two tape drives can access digital data recorded at a density of 800 or 1600 bytes per inch (bpi). Tape storage capacity is 32 million characters at 1600 bpi. Complete and detailed system hardware specifications are available (7, 8).

4. SYSTEM VALIDITY

In order to assess the ability of the system to extract accurate navigation parameters from sensor derived images within an operational GOES-4 mission environment, the system processed a subset of the actual observations taken by cameras onboard the SMS-2 satellite from May 2 through 18, 1979. The orbit and mission scenario of the SMS-2 and GOES-4 satellites are similar and thus any processing of such data would constitute a valid assessment. The processing involved not only testing the validity of the modelling within the software but also the functioning of the various hardware components.

Figure 3 depicts the observation distribution and density. Epoch refers to the time of least squares estimation. The observations consist of the lines and elements within an image. Each vertical line denotes the number of observations extracted from a particular image on a given day. Approximately 290 observations from 79 images over the 16 day period were extracted. This averages to 18 observations per day. From these observations, three separate intervals consisting of the 4 days immediately preceding each epoch were chosen for least squares processing. The results for each interval were remarkably similar. Such similarity attests to system consistency. With an initial observational noise of one pixel (equivalent to 1/2 mile image resolution) the nominal covariance values indicate that the SMS-2 state parameters are recoverable to approximately

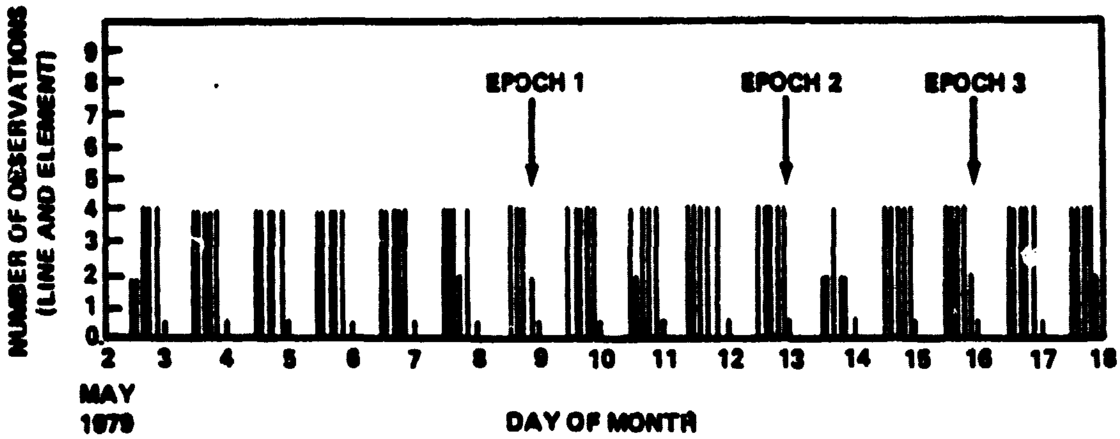

Figure 3. Observation Data Set

1 km in position and 30 cm/s in velocity. The attitude parameters of spin axis declination and right ascension are recoverable within 0.003°. Furthermore, the near zero observation residuals in both line and element with an uncertainty of 1.2 pixels indicate an excellent least squares fit. These results are similar to those obtained by another software system used for extensive SMS/GOES data processing. Thus, the results indicate the VAS/NAVPAK system is capable of meeting the navigation requirements of the VAS Experiment of the GOES-4 mission.

Finally, an effort was undertaken to determine the ability of the system to provide accurate annotation data for near real time image registration. Such capability is particularly useful for registration of images of dynamic natural phenomena. The estimated navigation parameters were predicted from epoch over an arbitrarily chosen period of 5 days. Figure 4 displays the results. A strong linear relationship exists between both registration errors and time with the element component exhibiting the greater sensitivity. The epoch error of 1.2 pixels has approximately doubled and quadrupled for line and element, respectively. These predicted registration errors may be extrapolated for an even longer time interval.

5. SUMMARY

This paper has described an applications computer system designed to provide navigation parameters during the VAS experiment of the GOES-4 mission and also annotation data for near

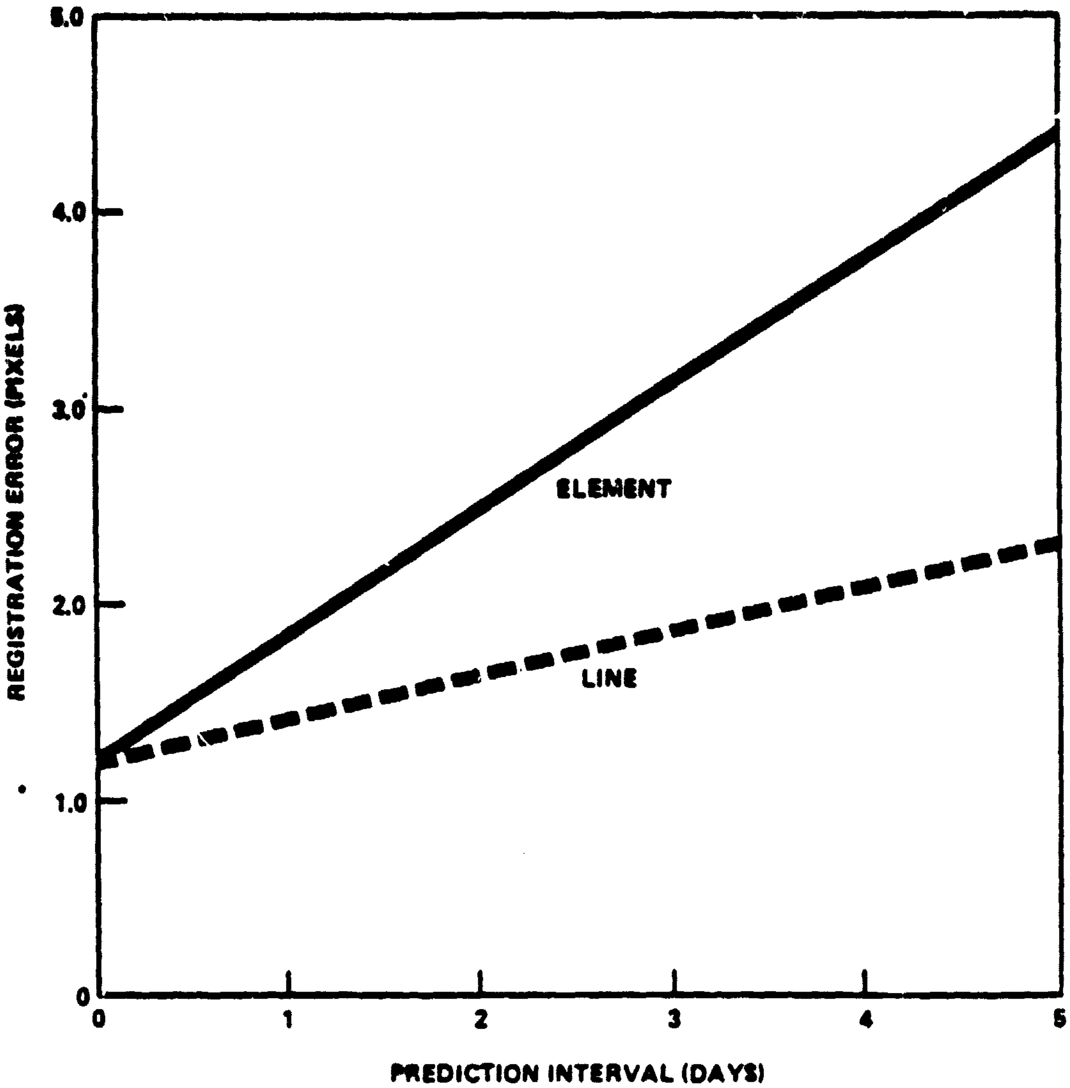

Figure 4. Registra... Error Versus Prediction Interval

real time image registration. The four functional subsystems of the software and the principal hardware components are characterized. The ability of the system to fulfill its two principal objectives is verified by results obtained from processing actual SMS-2 satellite imagery.

6. ACKNOWLEDGEMENTS

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