MISSION PLANNING FOR SHUTTLE IMAGING RADAR - C (SIR-C) WITH A REAL-TIME INTERACTIVE PLANNING SOFTWARE*

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ABSTRACT

The Shuttle Imaging Radar - C (SIR-C) mission will operate from the payload bay of the space shuttle for 8 days, gathering Synthetic Aperture Radar (SAR) data over specific sites on the Earth. The short duration of the mission and the requirement for real-time planning offer challenges in mission planning and in the design of the Planning and Analysis Subsystem (PAS). The PAS generates shuttle ephemerides and mission planning data and provides an interactive real-time tool for quick mission replanning. It offers a multi-user and multi-processing environment, and it is able to keep multiple versions of the mission timeline data while maintaining data integrity and security. Its flexible design allows one software to provide different menu options based on the user's operational function, and makes it easy to tailor the software for other Earth orbiting missions.

Key Words: mission planning, software, timeline, space shuttle, graphics, operations

1. INTRODUCTION

Shuttle Imaging Radar - C (SIR-C), together with the X-Band Synthetic Aperture Radar (X-SAR) of Germany, is a mission currently scheduled for three flights on the space shuttle, the first of which will be in October 1993. The second and third flights are scheduled in two different seasons of 1995 and 1996.

SIR-C's instrument is a Synthetic Aperture Radar (SAR). It will operate from the shuttle's payload bay, gathering 50 hours of data over numerous sites, and it will return with the shuttle after each flight.

The data returned from this mission will provide the science community with simultaneous multi-frequency, multi-polarization, and multi-parameter radar imagery from space. A complete science plan is documented in the SIR-C Science Plan (Ref. 1).

Each flight of SIR-C will last 8 days. Mission operations will be performed from a Payload Operations Control Center (POCC) at the Johnson Space Center (JSC). Due to the short duration of the mission, 24-hour continuous operations is planned. Timely replanning and quick responses to real-time anomalies are essential to the success of the mission.

The Planning and Analysis Subsystem (PAS) is a part of the SIR-C Mission Operations System (MOS) currently in development at the Jet Propulsion Laboratory. This paper will describe the SIR-C mission planning scenario and the design of PAS which supports that scenario with a multi-user, multi-processing environment using interactive software which allows real-time replanning.

2. MISSION PLANNING SCENARIO

Pre-flight mission planning activities are currently under way to develop a baseline mission timeline. Datatakes are a major part of the baseline timeline, which also includes playbacks of recorded data and live downlinks. During the mission, these datatakes will be replanned as necessary based on the navigation data received from JSC.

Major perturbations to the orbit, such as shuttle attitude maneuvers required for the mission and trim burns which may be required to maintain the mission trajectory, contribute to relatively large uncertainties in orbit determination by JSC Navigation. The errors in atmospheric modeling at SIR-C's low average reference altitude of 215 km further contribute to the uncertainties in orbit prediction. These errors quickly propagate to greater uncertainties as a function of time. Preliminary analysis has indicated that after 6 hours of orbit propagation, the science requirement of imaging a site within ±4 km 90% of the time will not be satisfied.

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In order to meet the site imaging accuracy requirement, SIR-C mission replanning will be performed in two stages: long-term planning in 12-hr cycles to update the planned datatakes in the baseline timeline, and real-time planning to update the radar parameters for each datatake scheduled during the long-term planning cycle.

Every 12 hours, an ephemeris will be generated with the most current navigation data from JSC. This ephemeris data, which will span from the beginning of the planning cycle to the end of the mission, will be compared against the current baseline ephemeris. The extent of the differences found from this ephemeris comparison, the status of data collection from the start of the mission, and any new mission constraints will be incorporated into the long-term replanning of the datatakes scheduled for the next 12 hours. Some planned datatakes may be deleted, some new ones may be added, and some may be updated with parameter changes.

The portion of the mission timeline updated during the long-term planning cycle is then verified and updated again during real-time planning. With the navigation data received from JSC on the average of once per orbit, approximately every 90 minutes, ephemeris data for the next few hours are generated and used to update the radar setup parameters for each upcoming datatake. Deletions and additions of datatakes are not a part of nominal real-time planning activities, although the real-time planner must be able to perform such activities if it becomes necessary in the event of an anomaly.

The updates to the timeline planned during the long-term planning cycle are approved by the appropriate persons of the SIR-C operations team as well as by JSC. Once signed off, they are incorporated into the approved timeline, which is used by the entire operations team to carry out their responsibilities.

3. FUNCTIONAL REQUIREMENTS AND DESIGN CHALLENGES

The development of the Planning and Analysis Subsystem (PAS) was presented with some interesting design challenges. While the PAS must provide the tools necessary to perform the functions described in the planning scenario above, it must also satisfy the needs of the entire operations team, who must be able to view the approved mission timeline at all times.

To support the mission planning activities, the PAS must perform high precision calculations for generation of mission planning data, must present the data to the users such that right decisions and tradeoffs can be made efficiently, and must provide a quick response time for real-time replanning.

Some of the major functions of the PAS include processing of the state vectors from JSC, generation of ephemeris data and mission planning data, providing tools to develop a timeline of events, graphical displays of ground tracks, sites, and radar swaths against a world map, calculation of radar parameters, and constraint checking.

It must be able to maintain the approved timeline while the changes to the datatakes are planned, approved, and finally incorporated into the approved version. And since there are two planners, a long-term planner and a real-time planner, who are both making updates to the approved timeline, the PAS must be able to keep their activities separate from each other, and furthermore, keep their activities separate from the approved timeline data until the changes are ready to be incorporated.

There are several users of the PAS who must have the write access to specific mission data in order to support mission replanning and operations activities. All other users must be prevented from writing to the mission data. It is crucial that the write access to the data is strictly enforced.

The mission planning data, as well as the approved mission timeline data, must be viewable by each position on the operations team, and the set of data viewed by one position can be different from that viewed by another depending on the functions of the positions. It is also possible, during the mission, that an anomaly may result in a change in one's operational position, requiring that person to have access to the tools necessary to perform the functions of the new position. The provision of the appropriate software tools must be accomplished very quickly to minimize interruptions to the mission planning process.

The goal was to develop one PAS system that provides the necessary control of the software and the data to guarantee its security and the integrity, has the flexibility required to support a very dynamic mission planning and operations scenario, and has the adaptability for responding to anomalies.

4. SYSTEM ARCHITECTURE AND DESIGN

The PAS system consists of a computer network, a central database, and software tools to aid in mission planning. Described below are some of the major features of the PAS system which satisfy the functional requirements and provide answers to the design challenges.

4.1 Computer System and Data Storage

The PAS operates in a local area network which includes one host computer and several workstations which communicate with the host via ethernet.

One operational copy of the PAS software and the data reside on the host, and they are accessible by all workstations in the network. This configuration allows all users to have access to the most current data as they are continually updated. It also guarantees that all users are using the same version of the software

Some of the data in the host computer are stored as ASCII files, but most of the data are housed in a relational database. The database environment and the PAS software together control the multiple user data access in order to ensure data integrity and security.

The PAS fully utilizes the multiple windowing capabilities of the workstations as well as colors and controls using the mouse. These features increase user productivity, which is an important consideration for quick real-time replanning.

4.2 Central Database and Data Access Control

The PAS has a central database which is located on the host computer, and it holds most of the mission planning data and the timeline data. The data are organized into many tables with specific links defined in order to provide faster response time for more time consuming activities.

All users of the PAS are assigned to one of several groups, and each group has different access privileges to the database. The read access to these tables is granted to all groups, but the write access to each table in the database is limited to those groups responsible for maintaining the data in that table. In most cases, the write access to a table is limited to only one group.

The database also serves as the main interface between the software modules. The input data to each module are read from the database, and the output data are written back to the database, either to be read by another module or to be displayed to the user.

4.3 One PAS for Multiple Users

The software modules are integrated into one software package with a top level menu that reads the user id, retrieves the group to which the user is assigned, and presents only those menu options that are granted for that group. This design of the PAS allows one software to be used by several users performing different functions.

If a user is reassigned to perform the functions of a different group, one entry in one table is modified to assign the user to the new group. In less than a minute, this user will have a new set of menu options allowing him/her to have the tools necessary to perform the new functions.

Figure 1 shows a small portion of the PAS top level menu and illustrates the differences between the menu options displayed for two different groups.

The menus are designed to support multi processing, with the number of processes and the types of processes selected by the user. Two users in the same group, although they have access to the same menu options, can choose to initiate only those processes applicable to their operational function. With this flexible design, the PAS display can have several forms, each tailored to the specific needs of each user. An example is shown in Figure 2.

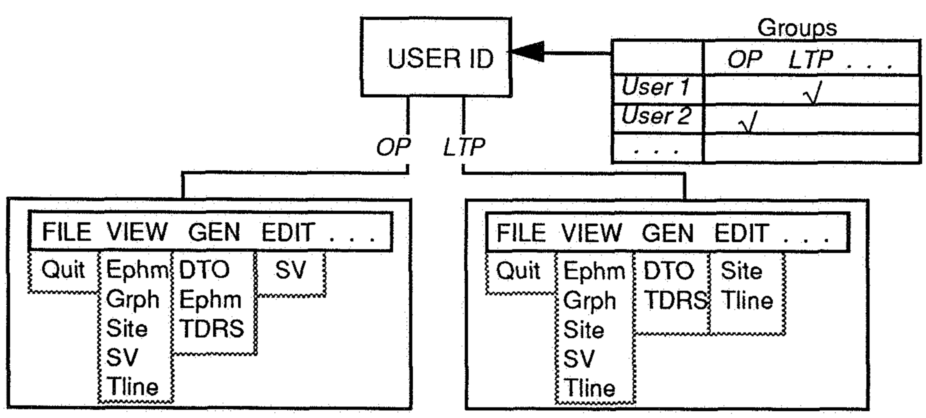

Figure 1. PAS Main Menu Example

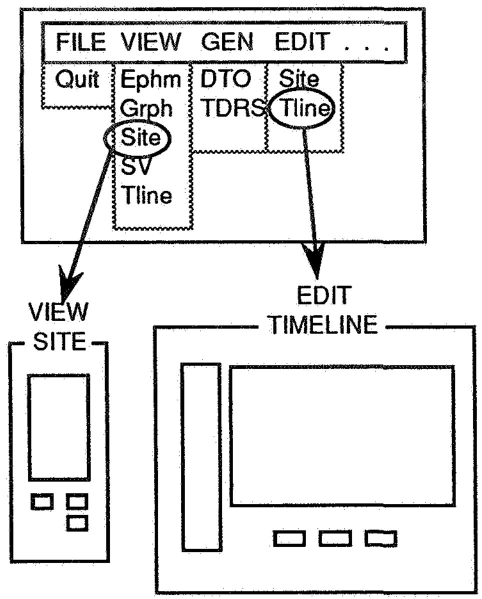

Figure 2. An Example of User Defined Multi-processing

4.4 Timeline Development Tools

The timeline development process begins with an arrival of the navigation data from JSC and ends with an approved timeline from which the commands are generated.

After the navigation data are electronically received from JSC, a coordinate transformation is performed to make it compatible with the coordinate system used by the PAS, and then it is stored in the database. User-selected state vectors from the database are read into an orbit propagator which generates the ephemeris data as well as the ground track data and stores them in an ASCII file. Certain parameters from the ephemeris file are ported into the database so that they can be manipulated easily.

Sites selected by the SIR-C Principal Investigators are stored in the database also. These data can be updated interactively using the site editing module.

The site data and the ephemeris data are used by another module which determines the datatake opportunities by calculating the geometry necessary to image the sites. These datatake opportunities, which are stored in the database, can be viewed, sorted, searched, and finally selected as datatakes.

Once an opportunity is selected as a planned datatake, the links between the different types of data are utilized to present complete information associated with a datatake. For example, the link between the opportunity data and the site data is used to retrieve the requested radar setup parameters for that site. The module which calculates the radar setup parameters uses the requested values as an input to determine the optimal radar setting for that datatake.

Since all data will be recorded onto tapes on board the shuttle, sophisticated tape management modules are available to automatically assign datatakes to tapes and plan tape loading and unloading events. The automatic tape assignments can be modified using the manual mode. Playbacks of data recorded on tapes are easily planned by displaying the content of the tapes and selecting the datatakes to be played back. Useful tape information, such as the percentage of each tape used, is readily available to the user.

Figure 3 shows the data storage, the external interfaces, the processes, and the interfaces between the processes described in this section and in sections 4.5 to 4.8. Note that this diagram illustrates only the functions discussed in this paper; it does not represent the entire PAS system.

4.5 Constraint Checking

Constraint checking, which is a very important part of mission planning, is also supported by the PAS. It is used to resolve conflicting activities, to check against power and energy constraints, and to verify tape assignments. The availability of Tracking and Data Relay Satellites (TDRSs) is also checked when data playbacks or live downlinks are planned.

Any violations to the mission rules are flagged by the software, and the generation of commands will not be initiated until the timeline either passes the constraint checks or the flags are acknowledged and overridden by the user.

4.6 Graphics Displays

The PAS has color graphics displays which provide the user with visual representations of the mission.

The mission planning data, such as ground tracks, sites, and potential radar swaths can be displayed graphically against a map of the world. Several options are available to tailor the display to the needs of the user. These options include zooming into a small area on the map, selection of overlays, labeling of orbit numbers and times, and output to a printer and a color plotter. One of the options most useful for the SIR-C mission is the capability to plot datatakes directly from the timeline, which will be used to plot daily coverage maps before, during, and after the mission.

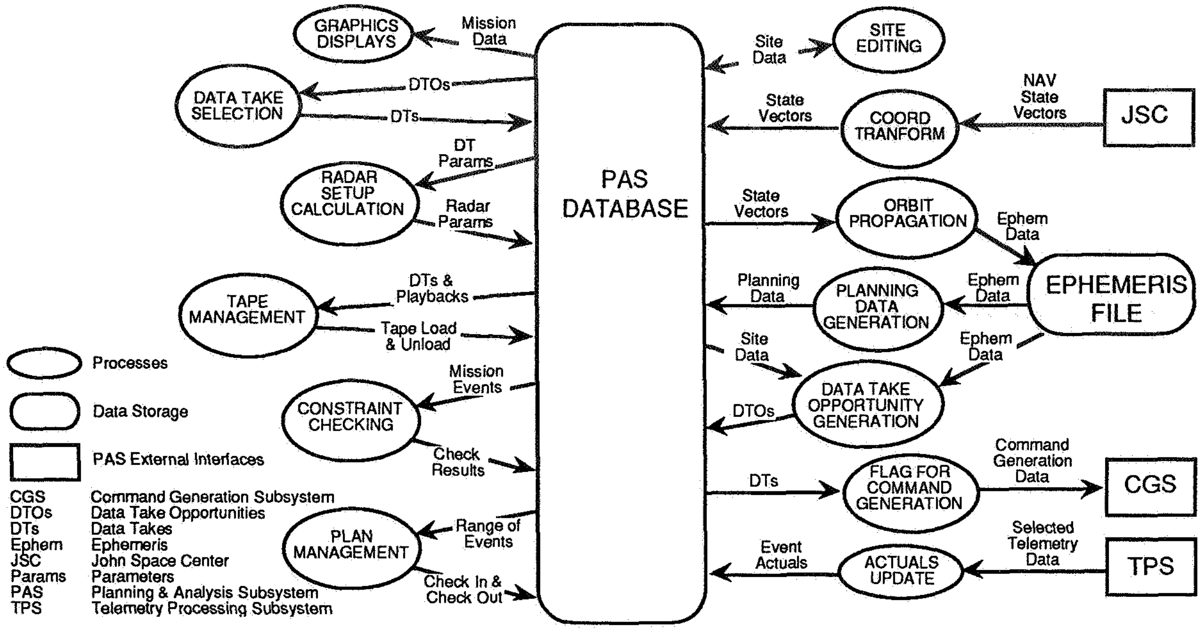

Figure 3. PAS Mission Planning Functional Diagram

All mission events stored in the database, both executed and planned, can be displayed on a graphics timeline. Colors are utilized to distinguish events and to alarm constraint violations. To assist users in planning certain activities, also shown on the same display is information such as TDRS availability and whether the shuttle is in daylight or night.

Color graphics is also used to display the power used for each datatake and the energy consumption as a function of time. This display provides an overview of the power and energy status, therefore allowing the user to make appropriate decisions if the power and energy constraints are violated.

4.7 Working Plan vs. Approved Plan

While the approved plan in the database is used by the operations team, the planners can work on updates to the approved plan in separate working plans. Since there are two mission planners, a long-term planner and a real-time planner, there will be at least two working plans.

When a portion of the approved timeline is identified for updates, that portion is checked out by a planner, and the software marks those events in the approved timeline so that the operations team can see which portion is in the process of being updated by a planner. The software prevents the other planner from checking out the portion of the timeline already checked out by the first planner. Operational procedures dictate that the two planners do not work on the same portion of the approved timeline; the software safeguards against accidental overlaps.

4.8 Updates with Actuals

The Telemetry Processing Subsystem of the SIR-C MOS receives and processes the telemetry data. Some parameters in the telemetry data are routed to the PAS, and they are used to update the events in the approved timeline with the actuals. For example, the datatakes are updated with the actual on and off times as well as the actual tape start and stop identification numbers. These updates are performed immediately following a completion of an event.

Actual energy consumption data are received from JSC every 12 hours, and this information will also be entered into the database and compared against the predicted values. Adjustments in the software parameters can be made if there is a significant difference between the predicted and the actual energy consumption so that the remainder of the mission can be planned with more accurate energy constraints. The adjustments are made by simply updating the software input parameters stored in the database; no changes to the code will be necessary.

Figure 4 is a graphical representation of different stages associated with the timeline. Events are initially planned in the pre-flight baseline timeline; they are then updated during a long-term planning cycle; further updates are made during real-time replanning; and after the execution of the events, they are updated with actuals. At the end of the mission, the timeline becomes the as-flown timeline.

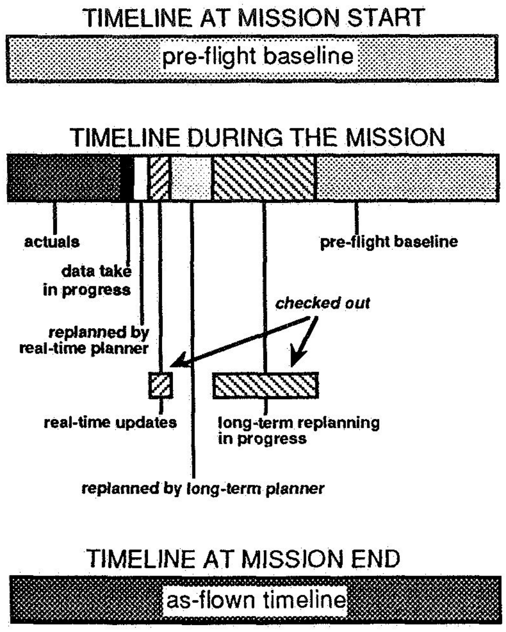

Figure 4 Stages of Mission Timeline

4.9 Parameter Updates in Response to Anomalies

Similar to the way an adjustment is made to the energy consumption software module, other software parameters can be changed to respond to certain anomalies during the mission. Many parameters relating to mission planning and operations are stored in tables in the database, making it possible for quick updates with very little impact to the mission planning process.

For example, there are 16 different Pulse Repetition Frequencies (PRFs) available for SIR-C datatakes. Nominally, all 16 PRFs are considered when calculating radar setup parameters for each datatake. If one PRF becomes unusable as a result of an anomaly, that PRF will be marked as 'not available' in the database, and it will not be presented to the user in the list of possible PRFs.

5. SOFTWARE DEVELOPMENT

The PAS software is currently being developed in a VAX/VMS environment with DecWindows/Motif providing the multi-windowing capability. The database was developed with the Ingres Relational Database Management System, and Ingres Windows4gl is being used to write a majority of the software modules of the PAS. The graphics displays of maps and overlays utilize the VAX Graphical Kernel System (GKS). Fortran is the language used for the 3gl programs.

Two sets of software have been inherited from the Mission Design Section of JPL for the development of PAS: the Vector Library of the Multimission Analysis Software Library (MASL), and the Planetary Observer High Precision Orbit Propagator (POHOP) of the Planetary Observer Planning Software (POPS) (Ref. 2)

The PAS software is developed in small modules. Each module is integrated into one of several applications, and one main application, which provides the main menu, calls other applications as they are selected by the user. This development strategy offers flexibility in software development, simplifies the debugging processes, provides easier software maintenance and configuration control, and accommodates future upgrades and changes.

6. APPLICATION TO OTHER MISSIONS

Although PAS is being developed specifically for the SIR-C mission, many features of the system can be used for other Earth orbiting missions. Some capabilities of the current working version of the PAS have been used to perform preliminary mission design for EosSAR and for other Earth orbiting mission proposals.

Because PAS is flexible and modular in its design, changes necessary to support other missions can be performed fairly easily. The preliminary versions of the SIR-C PAS have been delivered to the X-SAR project, who plans to make modifications and additions to support X-SAR mission planning. SIR-C and X-SAR mission planning will be performed jointly from a Payload Operations Control Center at JSC.

7. ACKNOWLEDGMENT

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