An approach to space mission planning in order to solve the problem of real-time planning by using the planning and scheduling strategy from artificial intelligence area

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The space area community has a strong interest in reducing costs related to control of satellites. However, the cost reduction is a goal difficult to achieve due to some characteristics of the satellite control facilities. In this environment, ground stations send telecommand to satellite during the periods of visibility. Apart from the cost restrictions, the ground stations can track multiple satellites, and consequently, scheduling conflicts may occur between different satellite passes over the same ground station. In particular case of INPE – Brazilian National Institute for Space Research, there is a concern to increase the reliability of mission operations, which in some cases are still manually performed. There is a great demand to implement planning methods and automatic control. Due to this set of requirements, which highlight the complexity of this environment, and the need to reduce costs associated with the satellite control, this paper proposes an architecture consisting of modules that manage the allocation of ground resources for tracking multiple satellites and plan to control operations of these satellites. This architecture adopts concepts and technical planning of the Artificial Intelligence area to generate plans aiming at solving the satellite control problem.

I. Introduction

The use of satellite is strategic for Brazil, due to the necessity of Brazil monitoring vegetation, plantations, rivers and natural resources, National Institute for Space Research (INPE) has as a main objective to improve the space technology by developing and operating satellites.

Currently one of the biggest concerns of the space community is the high cost to keep teams operating space missions. As time goes by, attention is focused on automated solutions to reduce the total cost of the missions by reducing operation teams.

In recent years, INPE has controlled four satellites: SCD1, SCD2 (Data Collection Satellite) and CBERS-2-2b (China-Brazil Earth Observation Satellites), and the French satellite COROT which is tracked by a specific station at northeastern of Brazil (Alcantara), for reception of telemetry and payload. Taking into account that the number of tracked satellites will be increasing in coming years, and the financial resources will be decreasing, the search for automated solution is needed.

The data collection satellites (SCD1 and SCD2) were fully developed by INPE, called as part of the Brazilian Complete Space Mission (MECB). Both are designed to receive data transmitted by automatic stations spread throughout the Brazilian territory and transmit them to the Brazilian tracking stations (Cuiaba and Alcantara). After each pass of a satellite over a tracking station (on average, a pass is approximately 100 minutes) the payload data are transmitted to the Control Mission Center in Cachoeira Paulista, southeast of Brazil, where they are processed and made available to users of the mission.

The CBERS-3 is the third remote sensing satellite jointly developed with China within the program China Brazil Earth Resource Satellites. This satellite will be launched in November, 2012 and will be a polar orbit heliosynchronous, whose main characteristics to go through the same geographical latitude in the same local time, which means under the same conditions of solar illumination. This feature is suited to its mission of Earth observation (imaging).

The Center for Satellite Tracking and Control Center (CRC) is the department responsible for the activities of tracking and control of satellites, which consists of the Satellite Control Center (SCC) in Sao Jose dos Campos, SP and the tracking stations of Cuiabá (CBA), MT and Alcantara (ALC), MA. These three sites are interconnected by a private network, which allows information exchange between these units. The geographic location of the station of Cuiabá provides coverage of all Brasilizian territory. The Alcantara station, located in the Alcantara Launch Center, allows tracking of satellites launched from this center from the moment of injection into orbit.

The communication of the ground control system with the satellite is established by tracking stations when it passes over the region of antenna visibility. During periods of the visibility signal transmitted by the satellite is sent by its antenna providing a downlink communication. The received signal contains the information of the satellite telemetry to reveal your current state of operation. After the establishment of the downlink, the station also provides an uplink, which is used for sending telecommands and implementation of tracking measures (ranging and range rate).

A strategy in the area of ground control of artificial satellites is the planning of operational activities involved in order to use the least resources and generate maximum product of the space mission(scientific, technological data, images, and telecommunications),without compromising the safety of the satellite. This task is complex because it involves decision making.

II. Preparation and Execution of Operation Satellite at INPE

All control actions are planned, coordinated and executed from the CRC. During the periods of satellite visibility the CRC connects to the tracking station, through a network being able to receive data from the visible satellite in real time. Two large software systems have been developed at INPE for the control of its satellites, application software for real-time and orbital dynamics software.

The satellite control is done by a planning generated for each satellite in the form of an operation script routine called in flight operation plan , comprising typically a period that may involve several days and the satellite operational (routine or critical). This planning is based on predictions obtained by crossing the orbital dynamics software that operates in non real time from telemetry data files and tracking measures recorded by the Software application for real time satellite passes.

The software application of real time is dedicated to activities that require direct interaction with the operator of satellites during successive periods of visibility. Implements basically the following functions: i) Receiving, decoding, display and storage telemetry (data transmitted by satellite to inform the state of its subsystems) generated by the satellites; ii) Generation and routing of remote controls (remote commands sent from ground to the satellite subsystems); Implementation of tracking measures.

First, a Passage Plan Prediction (PVP) for a period of one week is generated for each satellite.. Each file contains PVP generated several lines of information, each row contains, among other data: the instant of time (day / month /year, hour, minute and second), the values of azimuth and elevation angles of the satellite at this moment(for the pointing of the antenna toward the satellite GS), the distance between the GS and the satellite, the time variation of this distance and the value of the Doppler shift in frequency of the carrier signal sent to the satellite. The time interval in each line is generated can be set by the user. The CRC uses in its operating activities arrange of thirty seconds between each line of information.

Afterwards, the selection of satellite passes over the GS actually being used by applying a set of criteria. Thus, for example: (i) conflicts of simultaneous passage of more than one satellite over the same GS are solved by applying priority rules screening satellites; (ii) in case of a simultaneous satellite passes over two or more GSs, GS with higher priority will be selected; (iii) for each GS a minimum interval between the end of the passage of a first satellite and another satellite in passage should be appreciated that the passage can be considered useful.

The scenario of typical operation of the satellites controlled by INPE during a pass over a ground station includes the following actions:

1) Implementing measures to calibration of the measuring equipment away before the scheduled time for the beginning of the passage; Reception of telemetry which is a passive action, i.e., the telemetry system is available throughout the passage to automatically receive telemetry sent by the satellite;
2) Sending remote. This action is related to the satellite being tracked. Each satellite has a different set of transmitters.

3) Performing of the Range between the satellite and Ground Station (GS). This action has duration and must be done as many times as possible during the passage, but cannot be concurrent with the action of sending remote. The collected measurements are used in generating the next PVP;
4) Performing of Range Rate of the satellite in relation to GS. This action should also be performed during the entire passage. The measures are also collected entries for the next generation of prediction pass plan.

The plan of flight operation lists chronologically, for a given period, all control actions to be performed on the satellite in each future pass contained in the prediction pass file used as input in the process of generation, such as: remote controls to be sent, telemetry to be monitored and tracking measures to be implemented.

After generation and compatibility of PVPs, the activity generating the FOP is performed for each satellite. The FOP of the planning period is the period covered by the PVP, for one week. FOPs are indicated in all the operations that the operator of the satellite must be carried out before, during and after passing through the satellite. The statement of activities is always done in moments of lines corresponding to the information read by the generator in FOP files PVPs.

The inclusion of these operations in FOP must respect various constraints, such as: (i) a request for measures of distance between the satellite and GS or send remotes may be entered in FOP in moments in which the elevation angle of the satellite is set greater than a predetermined minimum value; (ii) the periods of quiet zone(the transition period during which the satellite communication with the GS stops) must be respected, i.e., no action can be performed during this period; (iii) the minimum time interval after the beginning of the passages that the satellite transmitter(responsible for sending telemetry to the ground)can be connected, and (iv) the minimum duration of a passages that you can send remote controls and/ or implementing measures distance and speed.

III. Flight Operation Plan - FOP

For the generation of FOPs was used as the basis of the items listed below: a) Generate FOPs to satellites controlled by INPE taking into account all the resources and time constraints imposed by the planning problem; b) Allow the operator to choose a whole sequence of passages, which corresponds to a period of one week of a satellite passes over a given GS, or choose a sub-set of passages of this sequence to generate the FOP. c) Allow the operating configuration is changed and applied to a whole sequence of specific passages or passages during the generation of FOP.

The following diagram presents the process of generating **FOP**s, which has as input the file containing the PVP level prediction passes a satellite to a specific station. The PVP files are generated by the software application Orbital Dynamics existing in CRC. The activity of generating files PVP is the first activity in the preparation of satellite operations for CRC. In possession of the file PVP and the options chosen by the operator of CCS, and generated a **FOP** for each satellite pass chosen. The **FOP**s generated can be viewed and edited by the operator.

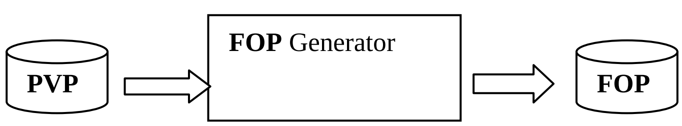

Figure 1. Preparation of Flight Operation Plan

IV. Mission Planning Architecture

The architecture proposed in this paper presents the organization of the Mission Planning System, and interaction with other systems of the control ambient for satellites.

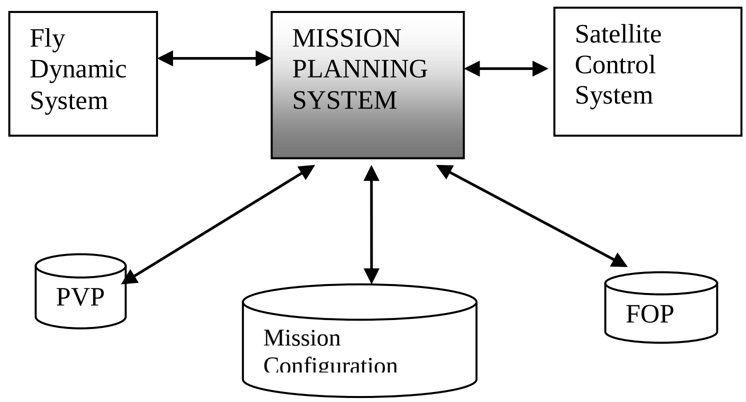

Figure 2. Mission Planning Architecture

The Flight Dynamic System organization generates Prediction Visibility Passages files, known by the acronym PVPs. A PVP data file contains data about future passes of a satellite over a particular ground station, for a period of seven consecutive days. For example, the contents of this file provides for each satellite pass: values of the angles of azimuth and elevation of the satellite to future pointing of the ground station antenna toward the satellite, the date of passage; times of signal acquisition and loss of satellite signal tracking by the ground station.

Satellite Control System CRC offers the service of execution of the operations. These operations are sorted by the time of execution belonging to Flight Operations Plan (FOP) and consist of instances of planning actions.

At each instant of the specified execution time in the FOP, the system triggers the execution of operations corresponding to particular operation through the Telecommand sending. This system also offers the service of the telemetry receiving.

According to resources used by the Mission Planning System organization: the PVPs database stores PVPs files generated by the Flight Dynamics System organization, the database stores settings general data about the satellites and ground stations forming part of the satellite control ambient, and, finally, the database stores the FOPs generated by the mission planning system organization.

The data stored in the configuration database do not refer to a single pass of a satellite, but the set of passages of a satellite earth station on a specific. These data may be, for example, the minimum duration of one passage in order it can be tracked, the duration of the calibration operation, the minimum elevation of the antenna to perform ranging measurement, the minimum elevation of the antenna to perform range rate measurement, the list complete of the telecommand that the satellite accepts and the existence of a period of silence zone.

V. Mission Re-Planning Architecture

The main goal of the re-planning mission is to detect problems and failures during the execution of a FOP, identifying information about the current plan, determine the problems that this causes the plane, generate corrections to change the old plan, verify that the changes made by the corrections not will conflict with the remaining actions of the old plan.

During the execution of an Operational Flight Plan, may be situations of failures and conflicts generated by the plan itself, abnormalities in these situations the system must provide features so you can remake a new plan in real time. A more detailed structure and description of its elements and how they interact is shown below as the main purpose of this work.

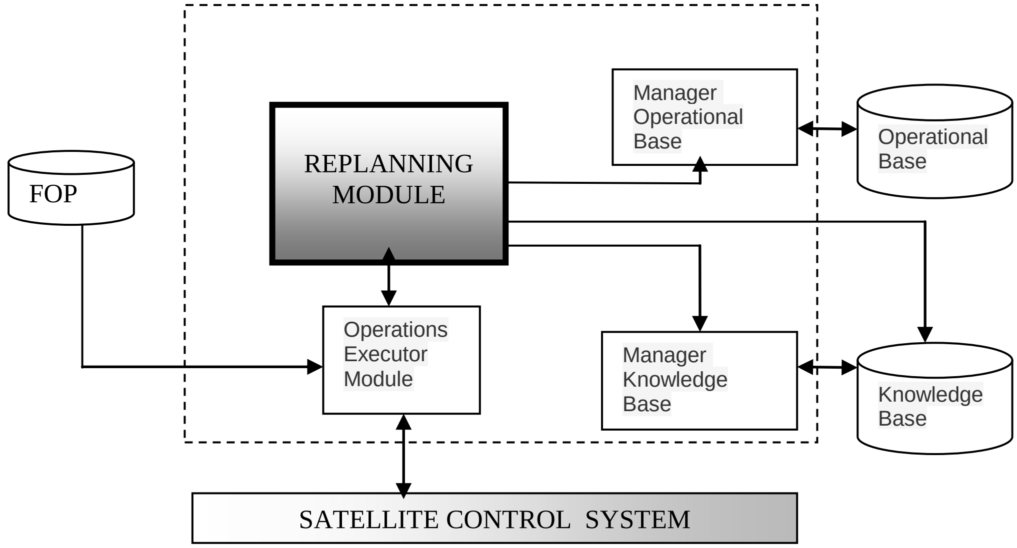

Figure 2. Mission Re-Planning Architecture

Based on Knowledge Engineering and in the current scenario of INPE satellite operation, this paper aims to solve the problem of mission re-planning in the automatic and intelligent way, replacing the decisions made manually by a automatically and intelligently redesign.

The Knowledge Engineering studies the principles and methods for development and construction of Knowledge Based Systems (Knowledge Based Systems - KBS) (STUDER et al., 1998). The KBS's are software that is based on data stored in a knowledge base and usually solve problems using machine inference from the area of artificial intelligence, aiming to assist and or replace human experts in their tasks.

Operational Base allows the insertion, removal and editing of general data related to satellite control ambient, and generates information, called by configuration information, which define the context of each passage of the satellite to be tracked. The configuration information varies with each pass to be tracked and is generated from analysis of general data previously stored in Database settings and data files listed in PVPs.

The Operational Base contains all the configuration parameters of the satellites and the GSs involved in tracking. Two categories of parameters are found on these bases: (i) fixed parameters, i.e. their values are always the same regardless of the passage to be traced and (ii) configurable parameters, i.e. their values can be changed and these changes influence the final results of the generated FOP.

During the development of an intelligent planning agent Norvig (2004), one of the first activities to be performed is the generation of knowledge base. A process for modeling a knowledge base for a domain can use planning language PDDL.

The internal files manipulated by the system are: the Domain file, files problem and database configuration. The Domain file is the file that contains the knowledge base of the satellite tracking domain encoded in PDDL and is generated manually. Problems files are files that are generated for each pass to be tracked and contain the initial state of the ambient of the passage and the objective to be achieved in FOP. These files are generated automatically by the system.

The language PDDL separates the description of parameterized actions that characterize the behavior of the field, the description of the initial conditions and goals that characterize the instance of the problem. The types defined for the domain can be: name of the satellite (satellite), position of pointing, name of the instrument on-board, operating mode of the instrument board to get the image, and others.

The re-planning with of the domain file and problem file, through the application of algorithms and heuristic derivation, is a sequence of actions that meet the proposed objective. It held an automatic generation of a new plan using data from the knowledge base.

VI. Conclusion

In recent years INPE has dedicated research of automatic control for automation of mission, some studies have been developed such as: a)the proposed Gonçalves (2006), that discusses an architecture of a system Planning Intelligent Flight Operation Plans focused the automatic generation of POVs for routine operational phase satellites. b) A Multi-Agent Architecture Planning Control Satellites, was developed by Carniello (2008). That architecture consists of agents that manage the allocation of ground resources for the tracking of multiple satellites and plan the operations control for these satellites. c) Also an experiment was conducted by Tominaga (2010), which consists of a satellite simulator, whose purpose is the validation of software planning operations in experimental flight. The simulator is a system expert-based rules, which updates its internal state from a initial state combined with an event queue.

The development of this work, and modeling studies of the knowledge base of the field of satellite tracking, it was concluded that the application of agent technology planning e Russell, S. and Norvig (2004), for the automation of operations for satellite control is a promising way to reduce operating costs of space missions at INPE in routine operational phase.

It is a fundamental need to the automation of INPE satellite operations. Some results of research works show that AI planning technology is undoubtedly one of the promising and viable ways to meet this need for automation. Despite the limitations shown, technology planning using AI is growing and new solutions are being found in order to facilitate their use in real-world systems.

Appendix A
Acronym List

ALC	Alcantara Station
CBERS	China-Brazil Earth Observation Satellites
CRC	Satellite Tracking and Control Center
CBA	Cuiabá Station
FOP	Flight Operations Plan
GS	Ground Station
INPE	National Institute for Space Research
KBS	Knowledge Based Systems
PDDL	Planning Domain Definition Language
PVP	Prediction Visibility Passages files
SCC	Satellite Control Center
SCD1	Data Collection Satellite 1
SCD2	Data Collection Satellite 2

Appendix B

References

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