PROTOTYPE DATA PROCESSING CHAIN FOR THE SPACE SITUATIONAL AWARENESS (SSA) PREPARATORY PROGRAMME

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ABSTRACT

This paper focuses on SSA's prototype Space Surveillance and Tracking (SST) Data Processing Chain (DPC), providing an overview of the main tasks to be executed, namely: Correlation, Orbit Determination, Orbit and Covariance Matrix Propagation, and Observation Planning Request Generation.

The DPC will be deployed on a Common SSA Integration Framework (COSIF) and is based on a Service Oriented Architecture (SOA). This paper is focused on the architecture of the system. An overview of the capabilities of the operator HMI is also provided.

1 INTRODUCTION TO THE DPC

The eventual Data Centre of the SST segment can be expected to be composed of several functionalities coordinated in order to fulfil an overall objective: Generation and maintenance of a catalogue of Earth orbiting objects, and the utilization of such a catalogue to diminish the risk posed by space debris to both ground infrastructure and operational satellites.

The SSA DC-II activity, in the frame of SSA Preparatory Program, aims to develop some elements of a Pilot Data Centre for SSA. Among these elements are the design, development and deployment of the SST DPC, the Sensor Planning System (SPS) and the Sensor Simulator (SSIM). The DPC is limited to SST processing chain whereas SPS and SSIM address both the SST and Near Earth Object (NEO) segments.

The DPC receives observations coming from the SSIM (in the future, from the real Sensors) as well as orbital information of objects coming from third party providers (mainly operators but also for initialization of the catalogue with TLE data). Observational data can originate from radar and/or optical ground-based sensors as well as optical space-based sensors. This input data is correlated with the objects in the catalogue. The correlation process is based on the comparison of expected observations for an object (according to the DPC's knowledge of planned observations) or the comparison of orbit features.

Orbit determination activities are twofold: initial orbit determination for new objects (those not previously catalogued) and routine orbit determination devoted to merge the orbital information of former observations with the incoming data. Orbit and Covariance Numerical propagation allows the execution of the formerly mentioned activities, and the computation of the accuracy evolution. In agreement with the current definition of the SST requirements, the catalogue is maintained in such a way as to achieve the appropriate accuracy of the orbits (a.k.a. accuracy envelope) necessary for adequate risk evaluation. For that purpose, the DPC requests Observation Planning activities to the SPS for those objects whose orbits need accuracy improvement.

2 DPC DESCRIPTION

The DPC provides the capability to generate and maintain a catalogue of Earth orbiting objects. The use of the DPC for the processing of observation or third party data requires the (almost) sequential use of several SOA services. Fig.1 provides an overview of the sequence of activities performed by the DPC when executing a Processing request. These activities are as follows:

- Ingestion of data with validity checking and persistent storage depending on the entered data type: Observational or Orbit data.
- Correlation of the entered data with the objects/orbits already in the catalogue.

  If the entered data is related to observations, then the orbit determination (OD) activities are executed. After that, the observation database is updated with a qualification of the processed observables. In cases where the entered information is related to third party data, then the orbit determination process is not required.

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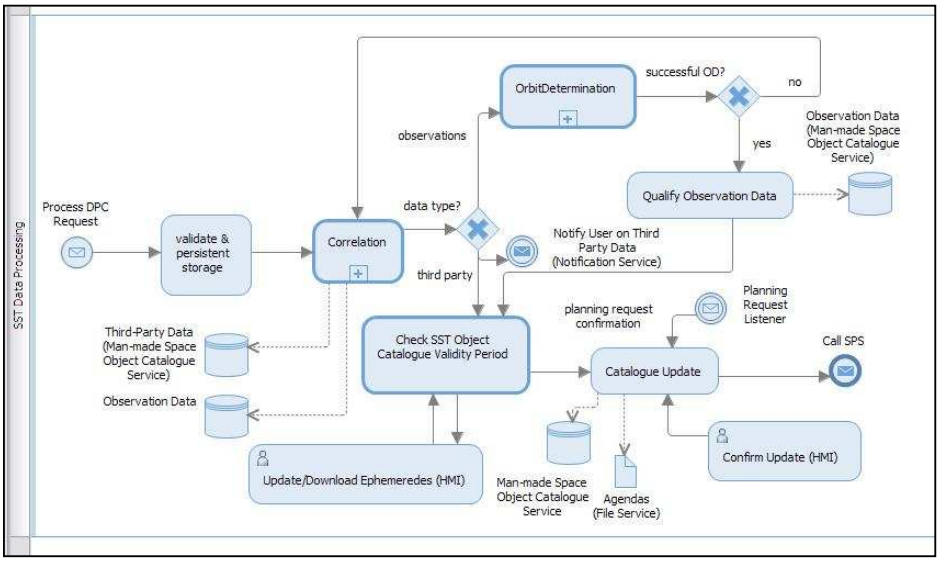

Figure 1. SST Data Processing Diagram, from [2]

- After observation processing with OD activities or after processing third party data, the last update of the object orbit is checked against the accuracy envelope limits (which are defined at configuration level). In the event these limits are violated, the generation of observation planning request will be triggered.
- The catalogue update task is related to the generation of the ephemeris data (time-tagged state vector and covariance), the update of the catalogue data, including the computation of expected observations to come for an object, and the storing of former data into the archive.

Human intervention (through a dedicated HMI) is foreseen at several steps of this process when the DPC is run in manual mode. The events that will require human intervention is defined at the configuration level.

In addition to the purely cataloguing process, the DPC will also provide services for data extraction which are independent of those devoted to the processing of input data. Data retrieval is related to the extraction of orbital data from the databases, or any other stored information as observational data, along with the associated quality information in terms of residuals after fitting process, events, etc. The query for such data extraction can be made directly against the databases through a dedicated section in the HMI.

For the case of extracting orbital information in the form of ephemeris files, the propagation service is needed internally for generating the required output.

2.1 DPC within the Common SSA Integration Framework

The future European SSA system will be a complex system of systems aiming at promoting interoperability and reuse of existing assets. To this end, it was decided to experiment with a SOA approach in the DC-II activity of the SSA preparatory programme.

SOA is a set of design principles used during the phases of system development and integration in computing. SOA-based systems are characterised by the composition of loosely coupled services that are made available as part of a Service Inventory [1].

As part of the SSA Preparatory Programme, a Common SSA Integration Framework (COSIF) is being developed. COSIF ensures a homogeneous SOA approach for SSA by introducing a software platform and a set of design and development guidelines.

In addition to those services directly related to cataloguing activities, the DPC's deployment in COSIF allows the reuse of the SSA Generic Services as well as the Space Weather Services which are also made available via COSIF.

2.2 Main DPC Services

The DPC will expose a number of services (see [2], [3] for the complete description):

- SST Data Processing Service, which is the main interface of the SST Data Processing Business Process.

- Sensor Observation Data Service, which allows the ingestion of Observation Data in the DPC
- Man-made Space Object Catalogue Service, which performs the ingestion of Third-Party data and handles any operation on the DPC Catalogue.
- Correlation Service, which identifies a given Object in the Catalogue associated to the entered data in the form of Observations from sensors or Orbital Data provided by third parties.
- Catalogue Quality Monitoring Service, which monitors the accuracy of the orbital information in the catalogue and generates observation planning requests for objects which do not fulfil the defined accuracy criteria.
- Orbit Service, which performs the propagation of the Orbit and Covariance matrix. This is a service frequently used by other services, as most of the other actions require such propagation activities.
- Orbit Determination Service, which performs all the activities related to Initial and Routine Orbit Determination.
    - Initial Orbit Determination refers to the activity necessary to calculate an orbit from the first observations of an object.
    - Routine Orbit Determination is related to the update of the orbital information, formerly computed, when additional observations of the same objects are processed.
- Data Processing Chain Monitoring Service, which provides the following capabilities:
    - Allowing the retrieval of status (running, not running) information about each of the DPC components.
    - Allowing the Start/Stop of the DPC from scratch.
- Planning Request Listener Service, which provides an interface for submitting asynchronous responses from the SPS to the DPC. This service is invoked by the SPS in order to notify the DPC when the observation planning request is expected to occur and, eventually, whether or not the observation has been successfully executed.

The main services, among those listed above are further detailed in the following section along with some information on the data flow approach and the associated algorithms.

2.2.1 Correlation

The Correlation process [4] is based on the comparison of expected observations for an object [8] or the comparison of orbit features. The sequence of activities performed by the DPC when executing a correlation would be the following:

- In case the entered data is a set of observations, an agenda of expected observations for every object is extracted and compared with the entered information. This agenda is based on the pre-computed expected position in sky of the objects to be checked against the entered observations.
- Selection of the best candidate objects among those reported in the agenda.
- In case at least one candidate is identified where the associated residual is below an operator-defined value (at configuration level), the best candidate is then selected on the basis of the lower residual and a correlation is found and reported.
- In case no candidates are selected or the candidates are associated to large residuals, then initial orbit determination activities are executed to generate a first orbit associated to the entered observations.
- This initial orbit is then computed and compared with the orbit data in the catalogue to look for an eventual correlation.
- If at least one candidate is reported, then the ‘newly-computed’ or the new and catalogued orbits are propagated (normally the stored orbit is propagated up to the date of the new orbit due to the lower associated covariance errors) for comparison of the two state vectors. The associated covariance matrices are also propagated. The corresponding predicted error is used for considering two orbits correlated or not.
- If the comparison of orbits reports a successful correlation, then the process is finished and the observations are correlated with the object in the catalogue.
- The former three steps are also followed for entered third party data.
- If correlation is not possible, the orbit determination activities with all non-correlated observations are executed to search for possible identification.
- If this orbit determination process is successful, a new object is entered in the database and so notified. If the orbit determination is not successful, the observation is treated as a new non-correlated observation and so notified.

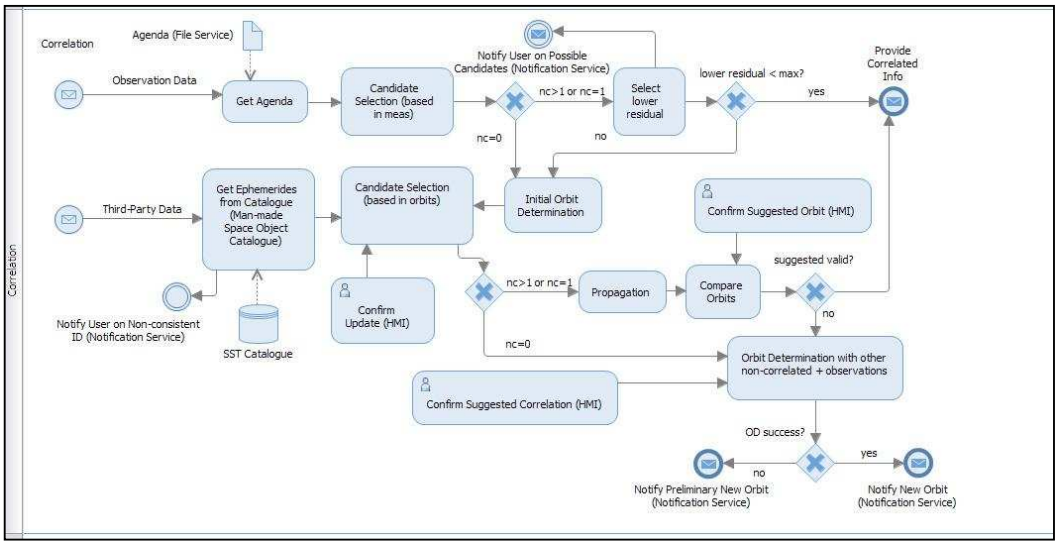

Figure 2. Correlation Diagram, from [4]

2.2.2 Orbit Determination

The sequence of activities performed by the DPC when executing an Orbit Determination would be different depending on the type of entered data [5]. In case observations are entered, two main orbit determination activity types can be executed:

- Initial Orbit Determination Activities, which are based on a short set of observations related to a unique track. In this case, the most suitable initial orbit determination process is executed to obtain the initial estimate of the orbit and its associated covariance matrix.

  Several algorithms for the initial orbit determination process are available. The most suitable one is selected depending on the type of observations (radar or optical) and the length of the observational arc [9].

- Routine Orbit Determination Activities, which are based on the last entered set of observations and a number of previous observations associated to the same object. Using both the new observations and those retrieved from the database, the filtering process (OD) is executed:

  - During the OD process, residuals of this OD process are evaluated and observations are rejected if those residuals are larger than a pre-configured value. Whenever observations are rejected, the filtering process is re-iterated until a successful OD is obtained.
  - In case all observations are rejected, the operator is notified.

2.2.3 Orbit and Covariance Matrix Propagation

This service is one of the main components of the DPC as it is required by other upper level activities [6]. The sequence of activities performed by the DPC when executing an Orbit and Covariance Propagation are the following (up to the final propagation time):

- Set up of the corresponding dynamic model. The forces considered in the propagation in addition to Earth spherical gravitational field are:
  - Atmospheric drag based on the NRLMSISE -00 model. This model requires solar and magnetic indexes that are be provided by SSA's Space Weather services [4]
  - Solar radiation pressure
  - Third body gravitational perturbations (Sun Moon and other planets)
  - Gravity from the Earth: EGM96
  - Solid tides
- Propagation of the state vector at several steps.
- Computation of the transition matrix of the state vector and estimated coefficients (drag and SRP parameters). This transition matrix provides the derivatives of the estimated variables at a time instance with respect to the other estimated variables at a former instance.
- Propagation of the covariance matrix by means of the computed transition matrix.

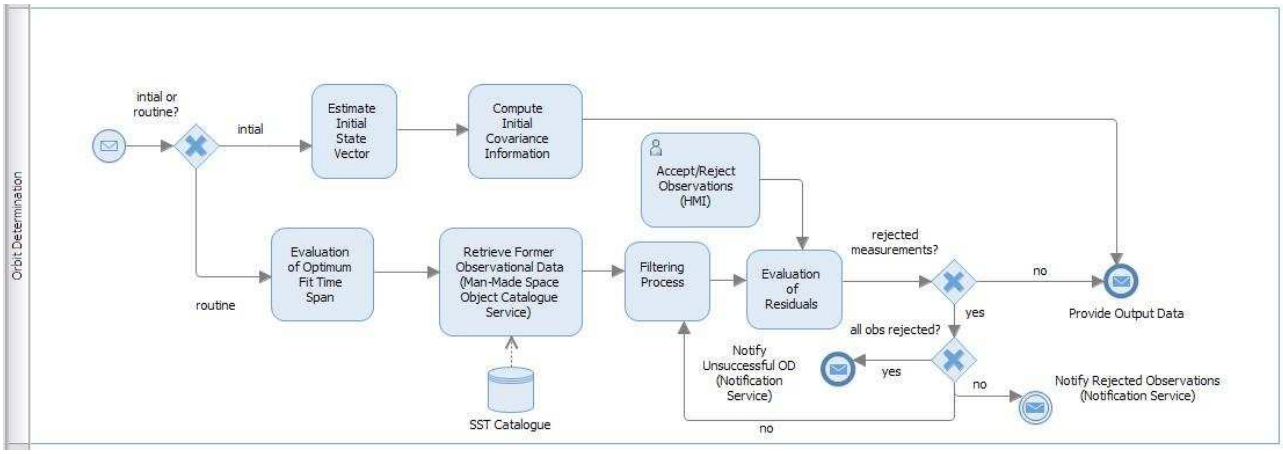

Figure 3. Orbit Determination Diagram, from [5]

2.2.4 Check Validity Period

The sequence of activities performed by the DPC when executing a Check Validity Period [7] are the following:

- Propagate the state vector and the covariance information for the last estimated data set during the validity period (this validity period is to be defined by the operator during a configuration step)
- Check the accuracy of the propagated orbit along the validity period against the predefined limit (defined during a configuration step, where the limits may vary with the orbit type).
- If the accuracy limit is violated:
  - The time of violation is computed by interpolating in the projection of covariance data along the relevant axis
  - The observation request type is defined by means of a look-up table (pre-computed at design level). This look-up table relates the duration of the requested tracking as a function of orbit type and required accuracy improvement
  - Finally, the actual observation planning request is generated, and the DPC operator is notified. The operator may confirm or reject the proposed request
- The previous step is also followed for some objects identified as deserving forced observations on a routine basis. For such cases, the computation of violation time is not required.
- If the accuracy limit is not violated, the process is finished

2.3 DPC Modes

Two possible operation modes are available for the DPC; an Automatic and a Manual mode.

In the automatic mode, the DPC allows the ingestion of orbital and third party data, the correlation, the orbit determination, the update of the catalogue and the request of required observation planning activities with only minimum human intervention. Information on each step decision will be provided to the operator through logs although no operator interaction is needed.

The Manual Mode is intended to provide the operator with information on the individual steps executed along the data processing chain and request his/her confirmation for the decision steps. When the system is running in manual mode, the operator will be requested to confirm the decisions suggested by the DPC software. This mode is intended primarily for operator training and data analysis.

3 DPC HMI

The HMI is composed of several views integrated with the DPC framework. The HMI provides:

- *A login perspective*, which manages authentication and security issues based on the generic SOA related services and a Help Perspective.
- *A configuration perspective* to manage the system in regards to parameters driving the algorithms behind the DPC services (maximum accepted residuals in observations, maximum correlation residuals for object candidate selection, orbit-wise accuracy envelope,...), the HMI and logging issues, the selection of the operation mode, the configuration in regards to time span and time step for default ephemerides files, etc.

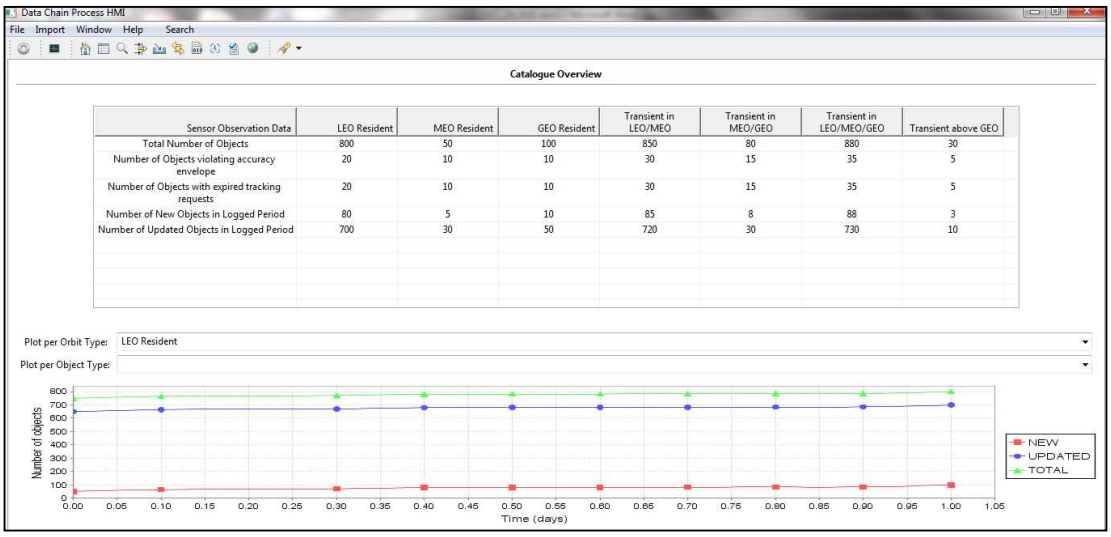

Figure 4. DPC HMI Perspective for Catalogue Overview

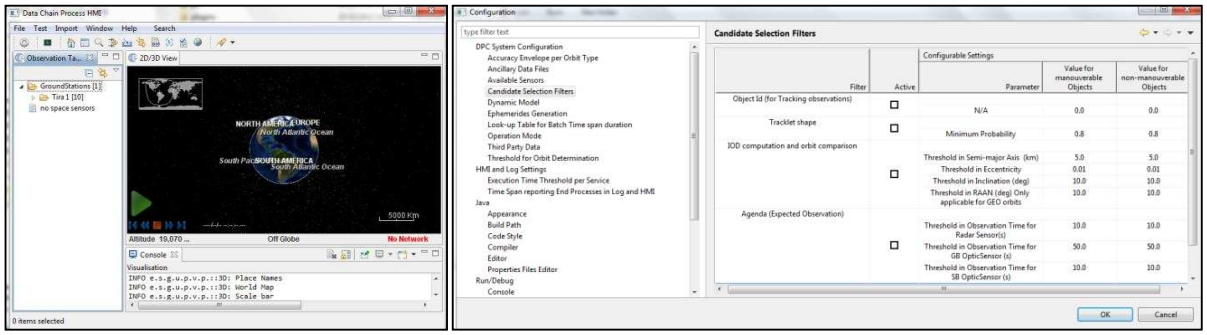

Figure 5. DPC HMI Perspectives for Orbit Visualization and DPC Configuration

- *Monitoring and control perspective*, for starting and stopping the DPC, and monitoring the status of components and processes
- *Visualisation Data perspective* for providing current SST catalogue status, access to the catalogue query functions, and access to the Orbit Visualization functionality

The HMI calls systematically the DPC Monitoring Service for retrieving information on the resource availability and the current status of the activities being executed by the DPC.

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