MERCATOR: A NEW GROUND SYSTEM FOR ORBIT AND ATTITUDE CONTROL

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ABSTRACT

The purpose of this paper is to describe - rather to prove - a new system named Mercator, in development at CNES. Mercator means MEthods and Realizations for the Control of the ATtitude and the ORbit of spacecrafts, from the ground. What is concerned here is then space dynamics ground control.

First, the presentation plan follows the history of the analysis which was performed :

- evaluation from the experience of previous launches

- definition of the objectives.

Secondly, the solutions in terms of hardware and software choices are presented, and at the end, examples of the developped algorithms are shown.

Keywords : ground operations ; orbit attitude control, orbit determination ; attitude determination.

1. INTRODUCTION

After Telecom 1-A and Telecom 1-B launches (August 84 and May 85), an evaluation was made in CNES to improve the orbit and attitude operations.

The first point of this evaluation is that, during the development phase and during the operations, the data processing contraints are too much important with respect to the mission aspects. During the development, the heavy procedure to implement software slows down the application of new methods in operational context and represents a big ammount of improductive manpower. During the operations, the system is heavy to be managed, and difficult to be controlled in any circumstances.

A second statement concerns the role of the software used for space dynamics operations ; this software must not only produce results (maneuvers, orbit/attitude determination), but also help the experts in their analysis, so that they can have a good evaluation of the quality of these results.

A third and major point is relative to the unforeseen degraded cases of mission ; the system must not become inoperative in such circumstances ; it must be still a help for the expert, first by the use of software having a large spectrum of validity, secondly by the use of various diagnosis tools, and, at the end, if necessary, by the possibility to insert additional software.

The last point of the evaluation concerns the number of operating people - to be reduced - and the fact that the systems are practically specific for each model of satellite.

These points led to the analysis and to the choices described in the following paragraphs.

2. OBJECTIVES

At first, the data processing system must be simple. It must allow any operational user to have a complete representation of the system and to control it.

Secondly, concerning the number of operating people, typically three persons must be sufficient to perform a complete positioning phase of a geostationary satellite.

Another objective is that the same system must apply to a wide variety of spacecrafts. From one to another mission, the system must be modified by replacement of elementary modules (concept of tool box). In a first step, this will be achieved for any geostationary satellite.

The workload corresponding to the implementation of a software, must be negligible with respect to the analysis and development work of a method.

The development must emphasize the help for the space dynamics specialists, as well in nominal cases as well in degraded cases. The interactive graphics and diagnosis tools must allow the user to have a complete view of the occuring data, and to extract the maximum of information from them, even if this information is not complete (example = first orbit diagnosis) and leads to rough evaluations.

In degraded cases, the system must allow to insert additional in reserve software without damaging nominal software.

From the performance and security point of view, the data must be smoothed before treatment in order

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to eliminate abnormal data, and to decrease the treatment computation load.

At the end, and these are constant preocupations for any project, the development cost must be minimized ... and the probability of success must be ... maximal.

3. GENERAL CHOICES

3.1 Hardware choices

Due to their qualities relative to computation power, storage capacity and ergonomy, the choice was made of "workstations" computers. These computers can be considered as intermediate (or synthesis...) between micro and mini computers.

The data flow relative to orbit and attitude control is schematized figure 1.

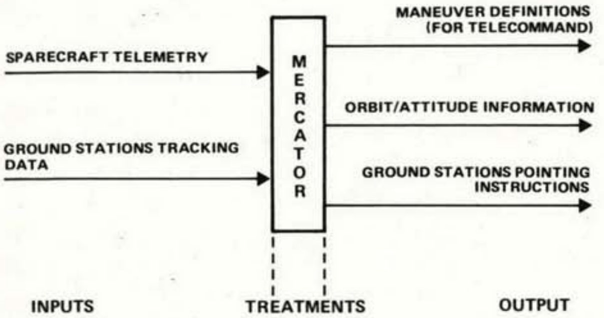

Figure 1. Information Flows

With the selected hardware two workstations are necessary and sufficient to perform the operations.

For redundancy propose, a third is necessary and the three computers have exactly the same configuration. They all receive all the Data (TM - Tracking) (figure 2).

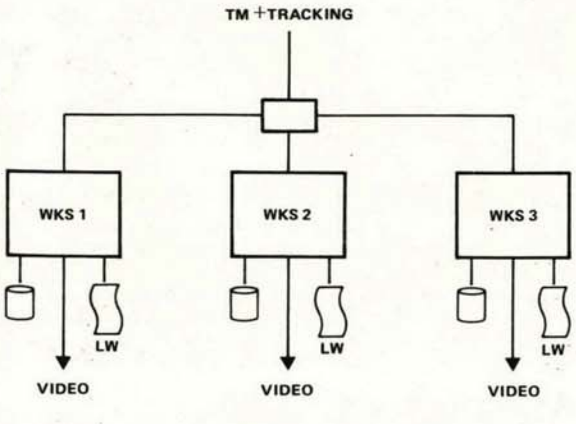

Figure 2. Hardware configuration

A local network links the three computers and allows the exchange of data between them.

3.2 Software choices

As for a possible, standard operating system is used.

Broadly distributed software products are preferred to specifically developped software. This allows to increase simplicity and security ; the use of UNIX operating system allows to solve easily the problems of real-time and off-line software coexistance, the problems of data storage.

The choosen architecture is described in figure 3, in the example of a spinned geostationary satellite :

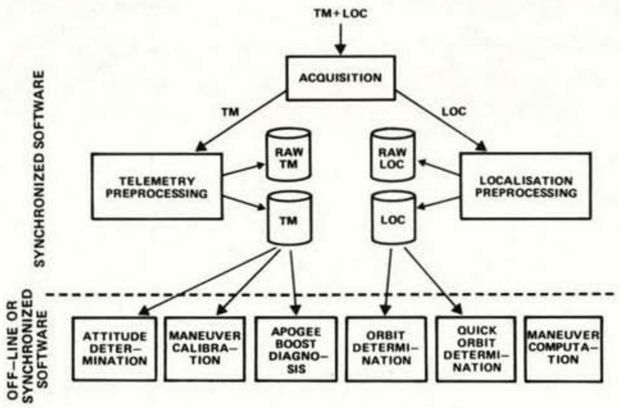

Figure 3. Software Architecture

The telemetry and localization data are acquired and sorted in a first function (acquisition) ; two links are created towards similar functions for Telemetry and Localization which, synchronized with the arrival of Data, perform :

- the raw data storage
- the processing of the data, their smoothing
- the storage of the smoothed data.

This double storage allows to work on smoothed values (gain of performance) but also allows to replay completely any sequence, especially in abnormal case.

All the functions which access to these files can be, in a standard way, as well work in "batch mode" (analysis of a complete period) or in "synchronized mode" (quasi-real time processing). Each function is autonomous with respect to the others, via the multi-window (emulating multi terminals) facilities.

4. METHODS

In this chapter, two typical new development are presented, as an illustration of the objectives of the new system ; the first example concerns orbit determination, and the aim of this new software is to simplify the operations via the use of a single software during the various phases of a station acquisition of a geostationary satellite.

The second example concerns attitude determination and shows how the objectives of robustness, efficiency and help to the user are aimed at in this particular subject.

4.1 Orbit determination

. Objectives : Continuous trajectory determination with a single software during positioning phases of a geostationary satellite. This software starts with the launch injection, passes through the apogee maneuvers, the drift corrections until the station-keeping window is reached.

. It can work either in real-time, automatically, or as batch process.

The method of estimation is a sequential method (figure 4).

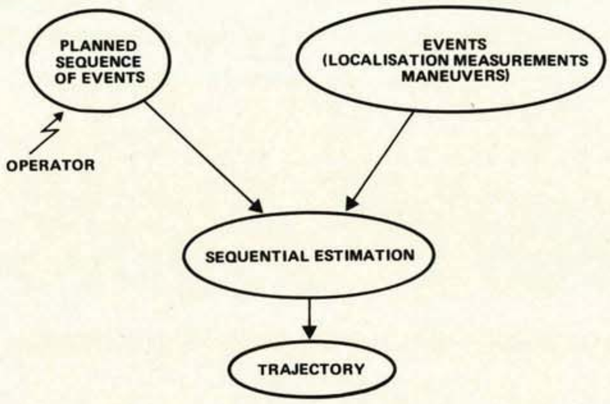

Figure 4. Orbit Determination Principles

. Trajectory description : The used parameters are direct equinoctial parameters, these parameters induce no singularity for

. inclination $\varepsilon\,[0, 180°[$
. exentricity $\varepsilon\,[0, 1\,[$

These parameters are :

. True "longitude" : $l = w + \Omega + v$
(v = true anomaly)

. Semi-major axis a

. Exentricity vector : $\begin{cases} h = e \cos (w + \Omega) \\ k = e \sin (w + \Omega) \end{cases}$

. Inclination vector : $\begin{cases} q = tg\,(i/2)\,.\,\cos\Omega \\ p = tg\,(i/2)\,.\,\sin\Omega \end{cases}$

. Sequential Estimation Method : The used algorithm is a non-linear extended Kalman Filter, with continuous evolution and discrete measurements (figure 5).

- The Prediction is achieved by the use of numerical integration of the Gauss Equations, completely expressed in equinoctial parameters, and the numerical integration of the transition matrix. The algorithm used is Runge-Kutta algorithm at 4th order.

- Depending on the phase, the second number, which represents the perturbing acceleration, includes :

- Transfer orbit : - earth gravitational potential (zonal terms up to degree 6).
- atmospheric drag

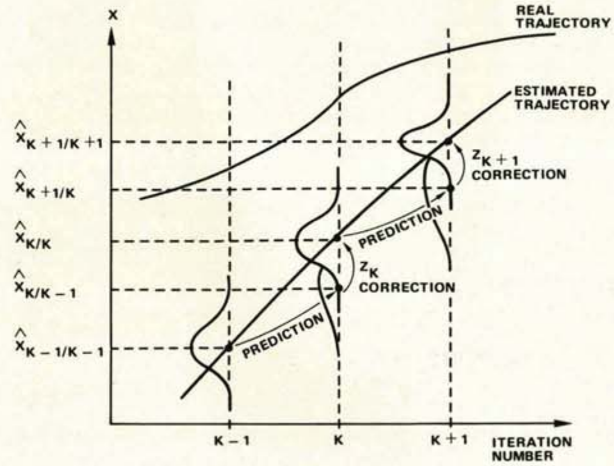

Figure 5. Orbit Determination Prediction - Correction

- Drift Orbit : Earth gravitational potential (zonal and tesseral terms up to degree 4)

- moon and sun potential
- solar radiation pressure.

- Propulsed trajectory (long thrust) :

- the Thrust
- earth gravitational potential (up to J2)

- In case of impulsive maneuvers (powder engine apogee boosts, maneuvers in drift orbit), the prediction takes into account their effect on the state (nominal thrust) and on the covariance (dispersions of the thrust).

- The correction is performed with analytical computation of the partial derivatives (equinoctial parameters) / (measurements).

A factorized form (Biermann Method ref 1, 2) is used for covariance matrix ($P = UD\,U^T$).

4.2 Attitude determination

The attitude determination remains essentially based on geometrical methods. These methods will not be here presented, as they are classical (ref 3) ; we shall limit the presentation to two "peripheral" techniques. The first concerns one aspect of the data preparation. The second concerns the statistical exploitation of the elementary results.

. Data compression :

It follows three objectives :

- to decrease the short-term noise

- to eliminate the outliers (bad data points due to errors)

- to reduce the subsequents treatments.

Least square fitting is not adapted. Indeed an important ratio of outliers can occur : during the first orbit of Telecom 1-A, it was stated that nearly 10% of the measurements were erroneous. Robust methods are then necessary.

We shall distinguish two cases : either the measurements to compress can be considered as constant during the visibility passage ; or this measurement evolves during the same passage linearly with a constant slope.

In the first case, we use a one-Step M-estimate (figure 6) (ref 4), while in the second case the compression is preceded by first an estimation of the slope by the method of the repeated medians (ref 5), and secondly by a translation of the data to a single date.

It is important to note that this kind of smoothing allows up to 25% outliers : the quarter of the measurements can be quite erroneous without affecting really the results.

One Step M-estimate

Data (X_i) i = 1, N

1. Computation of the Median

$$Y_0 = \text{Median}\ (X_i)$$

2. Computation of the median of the absolute deviation

$$S = \text{Median}\ (\,|X_i - Y_o|\,)$$

3. Weighted Mean

$$Y = \frac{\Sigma\, w_i\, X_i}{\Sigma\, w_i}$$

with

$$w_i = G\left(\frac{X_i - Y_o}{S}\right)$$

and

$$G(z) = \begin{cases} 1 & \text{if} \quad |z| \leqslant A \\ A/|z| & \text{if} \quad A \leqslant |z| \leqslant B \\ A * \dfrac{C - |z|}{|z|\,(C-B)} & \text{if } B \leqslant |z| \leqslant C \\ 0 & \text{otherwise} \end{cases}$$

Where A, B et C are constants.

Slope estimation by the repeated median method

Data (X_i, T_i) i = 1, N

1. $B_{ij} = (X_i - X_j)/(T_i - T_j)$ if $T_i \neq T_j$

2. $B_i = \text{Median}_j\ B_{ij}$

3. $B = \text{Median}\ B_i$

Figure 6

. Statistical exploitation of the results : A graphical representation of the results as obtained by the geometrical attitude determination method, and the analysis of the events allow to determine a time interval on which the statistical study will be performed.

For similar reasons as for the choice of robust algorithm for the data compression (presence of out lying results, without hypothesis on their cause), it is hopeful to use other statistical descriptions than the mean and the standard deviation. We shall use :

- For the estimation of the central value : the Median value.

- For the estimation of the dispersion :

  - median of absolute deviation
  - interquartiles range.

- Realistic extrema : first and ninth decile.

The quality of the median estimation is shown in the following table, presenting the median value compared to the reference value of declination for Telecom 1-A and Telecom 1-B.

	Reference Value	Median Estimate
TC1-1 1st Apogee	- 7.50	- 7.3
TC1-A 3rd Apogee	- 7.95	- 8.0
TC1-B 1st Apogee	- 6.45	- 6.4
TC1-B 2nd Apogee	- 7.40	- 7.3
TC1-B 3rd Apogee	- 7.40	- 7.3
TC1-B 4th Apogee	- 7.40	- 7.2

The reference value is determined from the orbit result of the apogee boost maneuver. The apogee 2 and 4 of Telecom 1-A are not exploitable, due to spin axis orientation maneuvers.

5. CONCLUSION

The concepts and methods which were described are still in development. Mercator will be tested first, for Telecom 1-C and TDF-1 launches (87) as back-up and progressively will become the nominal orbit and attitude system used for the next geostationary satellite controlled, at the ground level, by CNES.

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