BRINGING REALISTIC ATTITUDE SEQUENCE MODELING TO NON-EXPERTS

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Abstract: *This paper presents a new way to deal with attitude modeling. It is designed to be able to handle highly accurate models with very complex settings while remaining simple to use, even for non attitude specialists. The representation is split in several layers, for greater flexibility and thereby provides an extensive range of attitude profiles. The core layer is a basic attitude mode similar to what can be found in many attitude simulation tools. Additional layers can be stacked to it, so that additional constraints can be taken into account, and modify the basic attitude (offsets, spin, ...) It is also possible to set up an attitude sequence containing several modes linked together, in which switching from one mode to the next is events-based. Events are triggered automatically and their occurring time is computed on the fly during simulation: the user does not need to know in advance when they are supposed to occur. Numerous predefined events exist, like eclipse entry/exit, field of view entry/exit, orbital events, etc.*

Keywords: *attitude, sequence, simulation.*

1 A user-oriented approach

The space flight dynamics field is one of the many technology fields involved in ground systems. It is used from very early definition phases to the operational life. Being able to accurately perform simulations of a satellite behavior is a key point to design a new system, be it a complete space system or a single on-board sensor.

Attitude modeling is one of the most difficult part of the simulation. It is often difficult to describe complex attitude law profiles, especially when they switch between several different modes according to orbital motion.

Since years CS has been conducting a reflection on a new way to deal with this kind of problems, so that it can be used by non-specialists to simulate a sequence of very complex attitude profiles accurately.

The aim is to have a method for a versatile tool, that on the one hand could be used in different contexts, and on the second hand would allow different levels of complexity.

To deal with complex attitude profiles and sequences, there are usually two options. The first one is to approximate the problem by using the modes available in the simulation tool at hand, even when they are very different from the real modes. This leads to approximate results, which must be fixed by applying some suitable corrective post- processing, taking into account a safety margin to compensate for the less than optimal simulation. The second way is to create a dedicated simulation tool handling the required attitude mode. This implies some project organizational constraints and can have a significant cost. If the study is conducted in the last phases of the project, when the profile laws have already been defined, the team has to be set up only for building the dedicated simulation tool. If the study is conducted during the early definition phases, there is a feedback between the attitude design and the system performances assessment and all teams have to work together throughout the phase.

The method thought up by CS is different from the two previous options. It is designed to fit for early definition-phase as well as for operational phases monitoring. As an example it can be used for *a posteriori* contingency analyzes to understand satellite attitude behavior according to real time telemetry.

The approach chosen to model attitude is deliberately user-oriented. Attitude is described implicitly from its effects rather than from the underlying mathematical representation. The user simply has to define high level constraints like a set of targets and angles to implicitly define the attitude law (see next section). Solving the user description to construct the mathematical model that fulfills the constraints is then done under the hood.

This method can be used by non- specialists to simulate very complex attitude profiles accurately. It leverages the modeling issues for the end user and allows him to assess quickly new ideas.

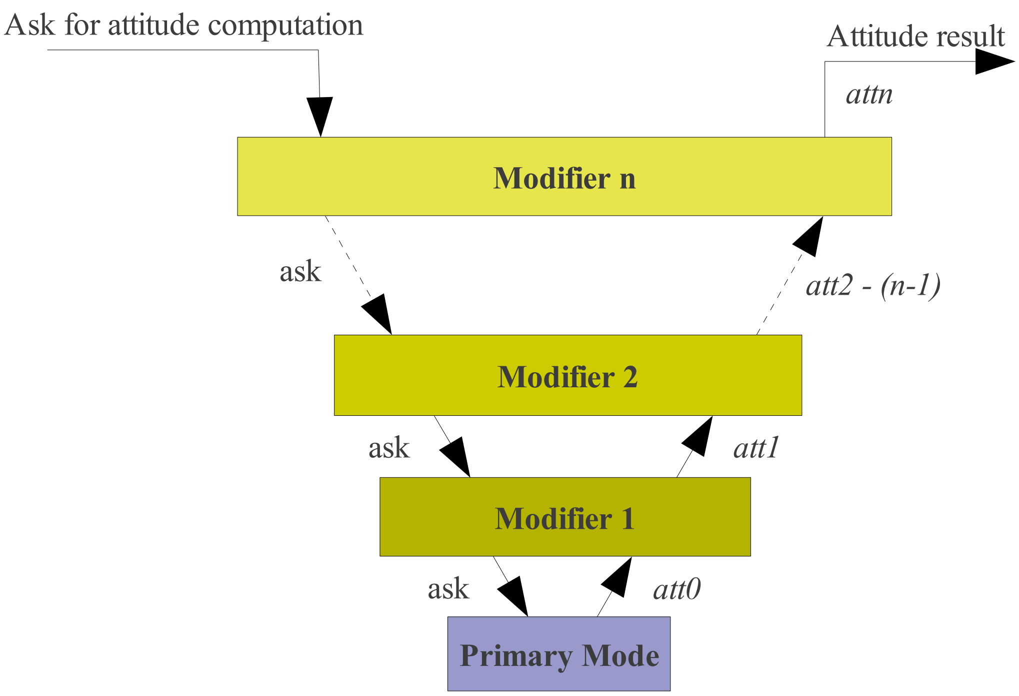
2 From simple to complex attitude laws

2.1 Layered approach

The second goals of this method is to allow different levels of complexity in attitude modeling, and thereby to provide an extensive range of attitude profiles.

Existing tools often provide a limited set of fixed attitude modes, with only a few degrees of freedom, allowing no customization for very specific needs. To comply with very complex operational needs, dedicated modes should be created. For example a pointed attitude which is not a theoretical perfectly pointed attitude but includes offsets with respect to several axes simultaneously.

In order to propose the largest offer of attitude profile laws and to make them flexible and highly customizable, an original concept of attitude modeling has been developed. The modeling concept consists in splitting the attitude definition is several layers. A basic attitude law called “primary” is first defined, similar to what most simulation tools provide (pointed attitude, fixed rotation with respect to different reference frames, …). These primary modes can be used as is for basic needs. They can also be enhanced by stacking additional constraints through what are called “modifiers” applied to that basic law. One or several modifiers can be added, the attitude computation then takes into account the full stack automatically. At each time step, each layer delegates to its underlying layer the computation of a raw attitude, then modifies it and provides it to the upper layer. The final simulated attitude is the result computed by the top layer.



This layered approach is easy to understand by non-specialists and still able to represent complex modes.

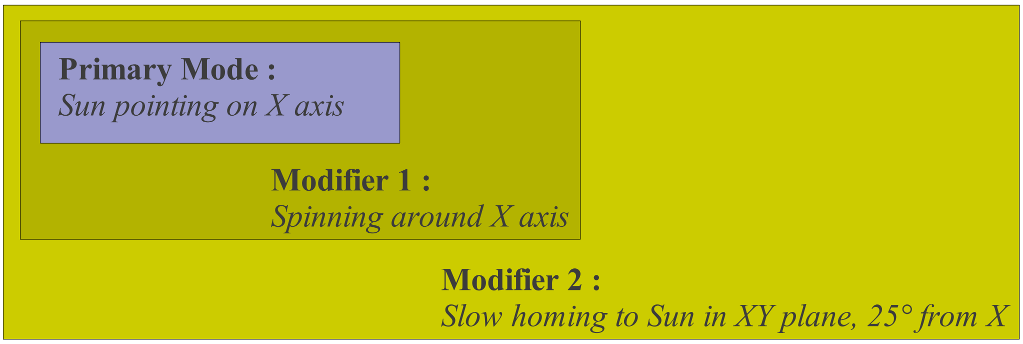
Examples of modifiers are Cardan offsets, fixed rate rotation to simulate spin, phasing targets with slow homing capabilities, yaw steering, yaw compensation, ...

The number of modifiers (i.e. the number of layers) is not limited but often only one or two modifiers are sufficient even for the most specific attitude laws. For example, an Earth-observation mode performing drift compensation would be represented at the first level by simple earth pointing mode, to which a drift compensation modifier would be added.

This attitude computation can be plugged as a back-end of an orbital propagator, in which all reference vectors and frames would be computed, including of course spacecraft position and velocity, but also a whole set of required vectors identified while setting up attitude description. For example orbital momentum, some targets position and velocity, local orbital frames, Earth frame, etc. These vectors and frames are then used as references for attitude computation.

A use case of that modeling method could be the following. During geostationary LEOP operation, a specific mode is used for Earth acquisition phase, the so-called “coning” mode. The principle of this mode is to rotate around Sun direction with an additional offset, with the result that spacecraft axes motions are cones of different apertures. Apertures are chosen so that the Earth sensor will see its target perfectly centered at some point during the rotation. This mode is a breed between a sun-pointed spin-stabilized mode and a fixed offset mode.

With that layered approach, it would be described as follows :



2.2 Direct approach for expert use

For very specific needs, the layered approach may not be sufficient, either because no available modifier suits the need, or because there are interdependencies between the modifiers and the primary mode. In these cases, a direct approach is required. This can be achieved by reusing the marmottes concept. Attitude is defined implicitly by specifying a set of geometrical or/and kinematic constraints and their associated set value.

This concept is not the natural way of thinking so one must get accustomed to it. However, it proved very useful and simple to understand by many people. It also is really simple to try different settings and to mix properties at will. The simplest way of thinking about these properties is to introduce them as looking for invariant properties of the attitude mode. For example, a yaw steering attitude will try to keep the angle between the sun direction and the XY plane null or to a constant value.

Those properties were historically called “sensors measurements”. Their origin can be tracked back to AOCS sensors (Sun sensors, Earth sensors, gyros ...) but have been generalized since then. Now these properties are no more simple sensors measurements and but have been renamed “constraints” as “sensor” had too strong meaning.

Each property fixes a single degreed of freedom, so three properties must normally be used together to define uniquely an attitude, even if it is possible to solve a reduced mode. All types of properties can be mixed together i.e. one can use for example an angle between two vectors and an angle between an angle and a plane and an angular rate to define one attitude.

Marmottes equations solve this problem and computes attitude so that constraints are fulfilled. This method is flight proven since 15 years and has been used extensively for LEOP operations and mission analysis. The constraints are similar in mind to the modifiers in the layered approach, but in that case they are solved all at once, thus allowing coupling. Nevertheless, that approach requires some experience and preliminary design to model the problem. The original implementation of Marmottes model definitions can be adapted in order to make “user-friendly”.

3 Event switching attitude sequence

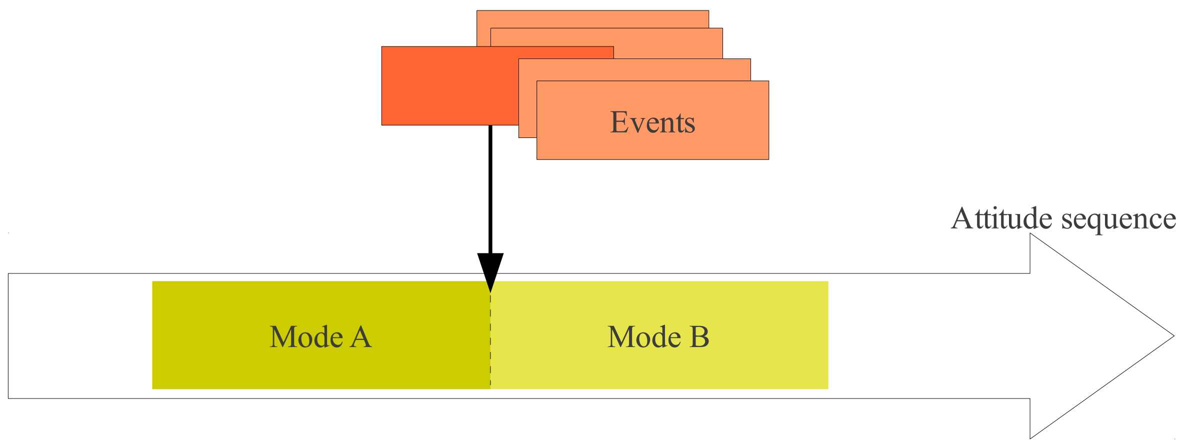
Another frequent need is to simulate a sequence of attitude modes corresponding to different orbit or mission phases. For example, in observation mission, it is usually necessary to have different pointing modes depending if the spacecraft is in an night time or in a daylight phase. During daylight it would typically be Sun pointed, whereas in night time it would be Earth pointed.

Another examples would be that the spacecraft should be pointed towards a target from the moment that target becomes visible from a given field of view, or leave a mode when Sun enters a dazzling zone, etc.

In most attitude tools available, switches between attitude modes must be defined by their date beforehand. This is not always possible, for example when the switch depends on the current state or even on the current spacecraft attitude, for example the visibility status of a target in a field of view. Transitions sometimes need to be defined without knowing in advance their occurrence time.

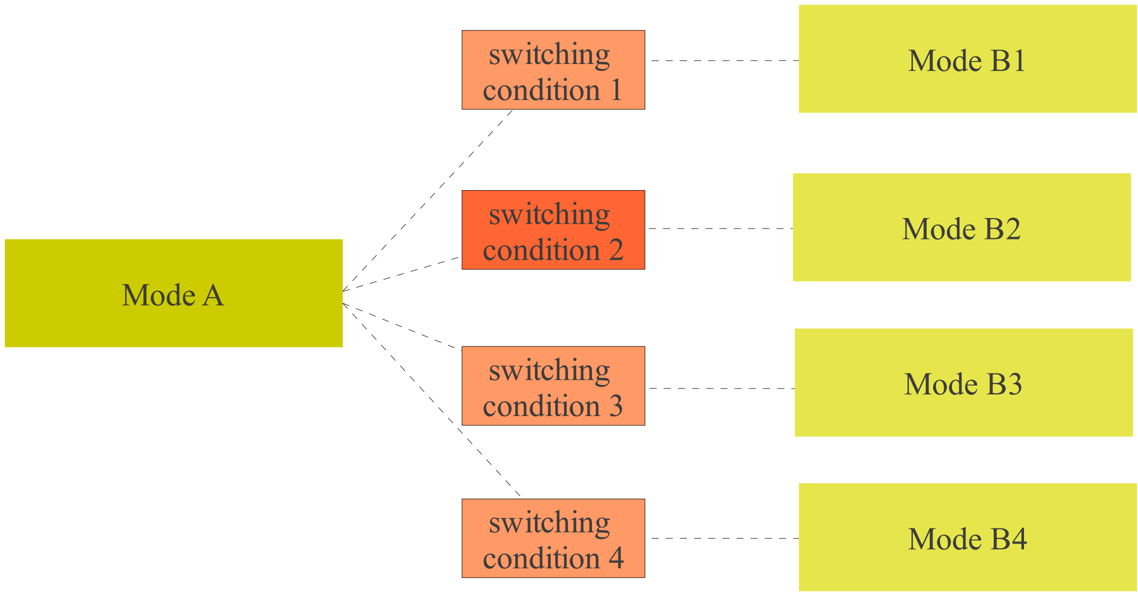
In order to meet such needs, an attitude scheduling mechanism has been set up that allows automatic, events-based switch between several modes. The exact occurrence times of events are not known in advance but they are discovered on the fly during simulation. Transitions between modes are then automatically triggered, allowing to switch to the next mode. These events allow to introduce discrete actions inside continuous propagation and to run long-time simulations even when hundreds of attitude changes occurs.

Transition events can be chosen independently from scheduled modes, so that any event can be used to switch from any mode A to any next mode B, and a switching event can be replaced by another for different simulation.



The sequence can even be a loop sequence, like for daylight / night time succession for example.

To go further, a switching conditions tree can also be defined. Several events can trigger attitude mode change, each one being associated to different possible following modes. Depending on which event occurs first, the effective following mode is then activated.



Most useful transition events are orbital events like apside, node or altitude crossing, ground events like elevation crossing, station events, environmental events like eclipses with different kind of occulting/occulted bodies, target in a plane, attitude events like a target in field of view with different possible field of view shapes, etc.

To ensure a highly accurate attitude computation, even when the user chooses a large computation step, the exact transition time is used to initialize the next attitude mode.

It is even possible to detect multiple switches inside a single step, which can be useful for very transient modes like rallying for example.

This approach has been developed fully in Vasco, the attitude simulation plugin for STK, and partially in OREKIT, the CS-SI owned space flight dynamics Java library.

4 References

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