Attitude Control System Design and Simulation for the SVOM Mission

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Abstract. SVOM is an astronomical satellite used to observe a collection of Gamma Ray Burst and other targets. The general pointing attitude is inertial pointing in J2000 coordinate. As the telescope’s exposure time will be 100s or even longer, the satellite platform should provide severe stability during the exposure period. This article describes the design of Attitude Control System (ACS) for SVOM satellite. First, ACS’ key performance requirements are presented which include the extremely high stability target, 0.8 arcsec/100s along Ys and Zs axes. Second, ACS hardware selected and bus design are described. Then, the ACS modes and transfer logic are introduced. Next, the controller design and simulation results are given. At last, the conclusion is obtained and all the required index are fulfilled by current ACS design.

1. Mission Overview

SVOM mission is a Sino-French cooperation project which will be launched in 2022. SVOM’s aim is to detect GRBs by a collection of instruments in various gamma and X energy bands and in visible wave lengths by a narrow field of view telescope [1, 2]. Scientific target is to detect more than 200 GRBs during the 5 years’ mission. The satellite platform is provided by Chinese side, and two of the payloads are provided by the French side. The CAD sketch of SVOM satellite is shown in Figure 1.

![Figure 1. CAD sketch of SVOM satellite.](image)

The main characteristics of SVOM satellite [3] are shown in Table 1.

| Item        | Parameter          |
|-------------|--------------------|
| Mass        | \~1050kg           |
| Envelop Size| \(\varphi 2458\text{mm} \times 2805\text{mm}\) |
Average Power Consumption | <1000w  
Life Time | 5 years  
Orbit |  
Semimajor Axis | 7013km  
Eccentricity | 0deg  
Inclination | 29deg  
Ascending Node Local Time | No constraint  
Pointing Mode | Inertial Stable Pointing  
Payload [4-7] |  
GRM (Gamma Ray Monitor)  
VT (Visible Telescope)  
ECLAIRs (Gamma Ray Detector)  
MXT (Micro X-ray Telescope)  

### 2. Key Performance Requirements

The Attitude Control System (ACS) is responsible for the attitude determination and attitude control. In order to achieve the observation target, the main performance requirements of ACS are driven from the long exposure time of VT, which is 100 seconds, or even longer. ACS should guarantee extreme high stability during the scientific observation time. The main performance requirements during mission mode are shown in Table 2 [8].

#### Table 2: Main Performance Requirements During Mission Mode.

| Item | Axis | Requirement |
|------|------|-------------|
| Attitude Determine Accuracy | Ys/Zs | ±20 arcsec (3σ) |
| | Xs | ±40 arcsec (3σ) |
| APE | Ys/Zs | ±50 arcsec (3σ) |
| | Xs | ±150 arcsec (3σ) |
| RPE (based on FGS) | Ys/Zs | 0.8 arcsec / 100s |
| | Xs | 12 arcsec / 100s |

The Absolute Performance Error (APE) and Relative Performance Error (RPE) are defined as the European standard in Space engineering Control performance, as shown in Figure 2.

![Figure 2. An example shows the APE and RPE.](image)

\[
APE(t) = e_p(t) 
\]

\[
RPE(t, \Delta t) = e_p(t) - e_p(\Delta t) = e_p(t) - \frac{1}{\Delta t} \int_{t_0}^{t} e_p(t) dt \quad (t \in \Delta t) 
\]
3. Attitude Control System Hardware and Bus Designs

3.1. Hardware Design

Hardware used in SVOM ACS includes Sun Sensors, Magnetometers, Star Trackers, etc. The number and performance of hardware are listed in table below.

| Item               | No. | Performance                                      |
|--------------------|-----|--------------------------------------------------|
| Sun Sensor         | 8   | FOV: ±57°±57°                                    |
|                    |     | Accuracy: 0.5°                                   |
| Magnetometer       | 2   | Measurement range: -60,000nT ~ +60,000nT         |
|                    |     | Accuracy: 0.05%                                  |
| Star Tracker       | 3   | FOV: 20deg circular                              |
|                    |     | Accuracy: [3.5 3.5 28]arcsec                    |
| FGS                | 1   | 2 CCDs                                           |
|                    |     | Accuracy: 0.3arcsec                              |
|                    |     | Frequency: 2Hz                                   |
| Optical Gyro       | 2   | Absolute error≤5×10⁻⁵°/s                         |
|                    |     | Bias <0.2°/h                                     |
|                    |     | Random walk coefficient≤0.0007°/h₁/²              |
| Magnetic Torquer   | 6   | Torque: 100Am²                                   |
| Reaction Wheel     | 5   | Angular Momentum Storage: 15Nms                  |
|                    |     | Typ. Motor Torque up to ±2000 rpm: ±0.215Nm      |
|                    |     | Max. Loss Torque at 2500 rpm: 0.025Nm            |

The FOV of Sun Sensors and Star Trackers are shown in the figure below.

As the common Star Tracker cannot achieve an attitude measurement accuracy of sub-arcsecond level, ACS designs two novel sensors, called FGSs, located above and under VT’s CCD, which share the same focus plane as VT’s CCD, as shown in Figure 4. This design can guarantee that the thermo elastics deformation between the VT and FGS can be neglected. Figure 3 also shows two images obtained by FGSs. According to the current design, there are at least 2 target stars on the one CCD each for more than 98% cases.
The main characteristics of FGSs include:
1) Calibre: ~600mm
2) Focal length: 3600mm
3) FOV: 12.7 arcmin×12.7 arcmin (each CCD)
4) Spectrum range: 400~650nm
5) Optical system efficiency: 0.74
6) Energy concentration: > 80% in 2.36×2.36 pixel²
7) Stay light: <1/9 of background light
8) SNR: >10
9) Accuracy: 0.3 arcsec
10) Mode: Standby Mode, Full Frame Mode, Big Window Mode, Small Window Mode

3.2. Bus design
The signal and power supply for ACS are shown in Figure 5. The standard working power is 30±3V. As there is no ACS computer, the measurement information and control algorithm are delivered and processed in the On Board Computer.

4. Attitude Control System Modes Design
According to the mission process, the ACS operating modes include:
- Acquisition and Safe Mode (ASM)
- Conventional Pointing Mode (CPM)
- Slew Mode (SM)
• High Stabilization Pointing Mode (HSPM)

The ACS modes’ transition logic is shown in Figure 6.

![ACS Modes' Transition Logic](image)

Figure 6. ACS modes’ transition logic.

5. Controller Design and Simulation Results

5.1. Controller design

During the HSPM, the controller we use is classical PD controller. A simplified close loop for one axis is shown in Figure 7. There are two loops in the controller. The inner loop is angular rate loop and the outside loop is angle loop. In order to obtain high accuracy attitude, the FGS information is involved only in High Stability Pointing Mode. Special data fusion method based on FGS, Star Tracker and Optical Gyro is designed in article [9].
5.2. Simulation Results

In order to verify whether the control capability can fulfil the requirements, we put up digital simulation software based on MATLAB and do digital validation in Phase C.

Simulation condition:
- $I_{xyz} = [750, 850, 1250]$ 
- $K_p = [53.3, 60.2, 88.9]$  
- $K_d = [254.5, 287.8, 424.4]$

The simulation results are shown in the Figure 8 to Figure 10.

Figure 7. ACS’s close loop design.

Figure 8. APE curve (APE [30, 16, 7] arcsec).

Figure 9. RPE curve (RPE<[10, 0.6, 0.6] arcsec).

Figure 10. The modes transfer logic of FGS.
According to the simulation results shown in the Figure 8, the APE can reach [30, 16, 7] arcsec. And as shown in Figure 9, the RPE can reach [10, 0.6, 0.6] arcsec in the 100s’ time window. The modes transfer logic of FGS is shown in Figure 10. These results fulfil the pointing accuracy and stability requirements well. The FGS mode can transfer from Standby Mode, to Full Frame Mode, to Big Window Mode, and keep in Small Window Mode.

6. Summary
SVOM’s severe stability requirement is driven by the 100s’ exposure time of the telescope. ACS is the most important system of satellite platform which is responsible to guarantee the extremely high stability. In order to obtain high accuracy attitude information, a novel sensor called FGS is designed. This article focuses on the design of ACS and shows the requirements, hardware and bus design, control modes and controller design. The digital verification result is given at last. According to the simulation result, the APE and RPE performance can fulfil the requirements well. Also, FGS mode transfer is presented.

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