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CloudCT – A Formation of Cooperating Nano-Satellites for Cloud Characterisation by Computed Tomography

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Abstract

As clouds are one of the key sources of uncertainty in global climate models, the CloudCT mission uses a formation of 10 nano-satellites to detect 3D properties of clouds. Computed tomography methods similar to medicine are used for observation of backscattered Sun light by the cameras of 10 satellites from different perspectives, in order to obtain high spatial and temporal resolution for water distribution inside the clouds. With respect to satellite technology requirements, precision attitude control as well as formation flying capabilities are crucial to characterize at the level of nano-satellites the interior of clouds. CloudCT integrates interdisciplinary synergies from nano-satellite system engineering, cloud modelling, and tomographic imaging to enable a sensor network approach to innovative Earth observation. This way improved relevant inputs for climate predictions are generated.

Keywords: nano-satellites, satellite formation, climate prediction, clouds, computed tomography

1. Introduction

Formations of small satellites at the mass level of a few kilograms offer interesting opportunities to realize sensor networks in orbit [1, 2, 3, 7, 9]. Here specifically the characterisation of clouds is addressed in the "CloudCT"-mission, as this is one essential uncertainty for climate predictions. Thus in particular the detected physics of warm convective and stratiform clouds, and the clouds' sensitivity to environmental changes will improve inputs to global-climate models [4]. The CloudCT's innovative sensing approach uses cloud scattering-tomography of incident Sun light to fuse measurement data from a self-organizing formation of ten small satellites. This way an improvement of inputs to climate models is expected, leading to reduced uncertainties through a database of 3D macro- and micro-structure of warm cloud fields.

2. The CloudCT Mission

The inputs are generated by simultaneous imaging of cloud fields from multiple directions with a resolution of 50 m. By the scattering tomography approach [6] the 3D volumetric structure of cloud fields is derived, generating base-to-top profiles of droplets' size and their variance, volumetric distribution of optical extinction and rain indicators.

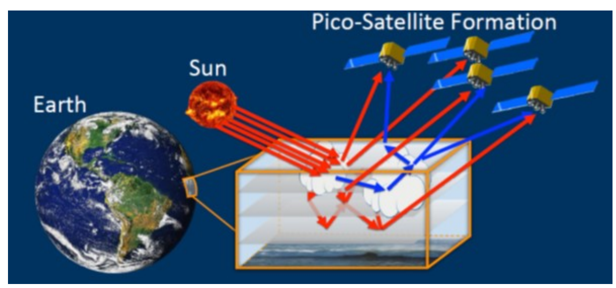

Fig. 1. Observation principle of backscattered Sun-light by the CloudCT small satellite formation.

Optical cameras are placed on 10 nano-satellites [2] in a low-Earth-orbit (LEO) for joint observation of the cloud target area from different perspectives. These observation principles and related data processing were tested in flight experiments by aircrafts [5].

3. The CloudCT Spacecraft

The required coordinated observation by 10 distributed networked spacecraft raises challenging requirements for small satellite attitude and orbit control. On basis of relative navigation methods, orbit corrections of the formation topology for optimal observation conditions are realized by an electric propulsion system.

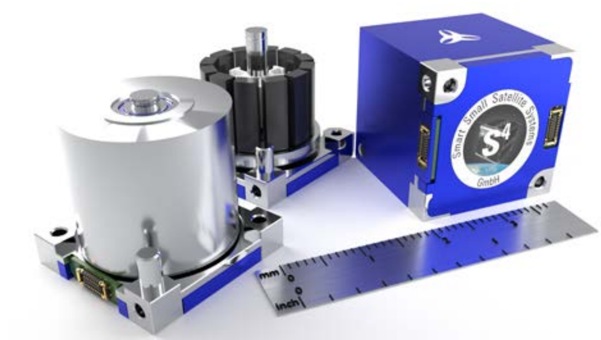

Fig. 2. The integration of the miniature reaction wheel in a 2 cm cube with brushless motor, and rotation mass placed in the sealed housing.

The novel tomography approach [6] requires precision attitude determination and control. For this purpose, energy-efficient miniature reaction wheels provide the required pointing and tracking capabilities at nano-satellite level. Distributed control algorithms enable the formation to appropriately self-organize via the inter-satellite links, without the need of a ground control station contact. Advanced in-orbit autonomy, distributed computing, and networked control are the key features to self-organization capabilities of the formation [7, 8].

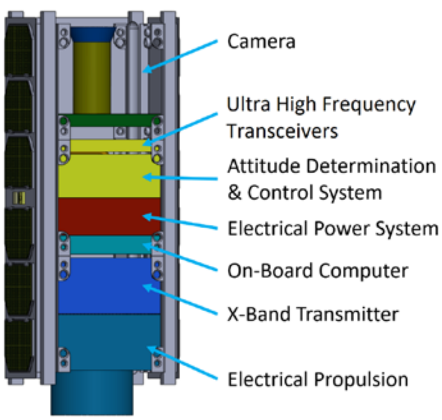

Fig. 3. Basic design of the 30 cm x 10 cm x 10 cm spacecraft with its subsystem accommodation.

In order to test the crucial attitude control of the formation and the computed tomography approach on ground, hardware-in-the-loop simulations use high precision turntables.


Fig. 4. High precision, high dynamics turntables for testing relative attitude motion in the satellite formation for intersatellite links and for joint observations.

4. Conclusions

Combination of synergies from spacecraft engineering, imaging and cloud physics supports innovative Earth observation methods to characterize the clouds‘internal properties in 3 dimensions. The CloudCT mission uses a computed tomography approach of images simultaneously taken from different perspectives to generate 3D-images by sensor data fusion. The main challenge for satellite technology refers to a precision 3-axes attitudes control system composed of miniature reaction wheels to support the required coordinated precision pointing. The aim is to improve by the acquired information the inputs to climate predictions.

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