Space Telescopes based on Satellite Tandem Flights

Rene Hudec* **, Vit Pomahač*, Eva Stanik***, Thorsten Döhring*** Klaus Schilling ****

** Czech Technical University in Prague, Faculty of Electrical Engineering, CZ-16627 Prague 6, Czech Republic*
*** Astronomical Institute, Czech Academy of Sciences, CZ-25165 Ondřejov, Czech Republic*
**** TH Aschaffenburg – University of Applied Sciences, D-63743 Aschaffenburg, Germany*
***** Center for Telematics (ZfT), D-97074 Würzburg, Germany*

mailto:hudecren@fel.cvut.cz

Progress in satellite control engineering enables tandem flight arrangements of mini-satellites in future space missions. Cost effective CubeSat technologies offer an interesting possibility for space-born telescope payloads. Two small satellites will carry the telescope optics and the detector system, respectively. Related formation flight requirements could be transferred from the NetSat-Mission.

1 Introduction

Due to the recent progress in satellite control engineering, tandem flight arrangements of mini-satellites are currently in discussion and under consideration for future space missions [1]. CubeSat technologies offer an interesting possibility for space-born telescope payloads based on this approach [2]. In such scenario, two small satellites will fly at a constant distance of a few meters up to 100 meters. Thereby, the front satellite will carry the telescope optics and the second satellite the detector system. Related formation flight requirements were addressed in the NetSat-Mission, composed of four 3U-CubeSats, launched 2020 [3]. Space technology challenges concern in particular orbit control by an appropriate propulsion system as well as precision attitude pointing towards the joint target. Technology for small satellite formation flights could be adopted from the NetSat-Mission. This will allow space-based telescopes with a long focal length even placed on board small or miniature CubeSat-type satellites. Cost effective Kirkpatrick-Baez type X-ray telescopes represent an important application here as they have longer focal lengths compared to previous astronomical observatories using Wolter I type X-ray mirrors.

2 Formation Flying

There is a broad range of potential formation flying arrangements in space. Firstly, satellite formations can already be found in earth orbit. In such a configuration, satellites use relative navigation, attitude and orbit information. Their flight control is networked via inter-satellite links. For optimum observation self-organization is deployed in orbit. The satellites need to be synchronized so that they overlap well in coverage. Another possible configuration are satellite-trailing formations. These are multiple satellites orbiting on the same orbit.

Finally for a tandem spacecraft carrying optical equipment some specific requirements have to be fulfilled: the necessity of large apertures, virtual antennae or occlusion needs to be considered. Typically, tandem spacecrafts are used for science missions or for earth observation. An example for a possible application is a CubeSat tandem flight for asteroid surveillance [1]. One crucial challenge for the implementation of tandem spacecrafts as space telescopes is a very precise relative positioning. The typical relative distance of the two satellites is quite small, in the range of 10^2 m to 10^3 m [3]. For a telescope payload, however, an even smaller distance of less than 100 meters would be required in such a combination of two CubeSats.

3 Example: SAR Interferometry

Synthetic aperture radar (SAR) interferometry was one of the first applications of formation flying. SAR is a radar system in which the satellites measure differences in the phase of the waves returning to the spacecraft. Two satellites act together as a large single-pass SAR interferometer. This enables the acquisition of cross-track and along-track interferograms (see figure 1).

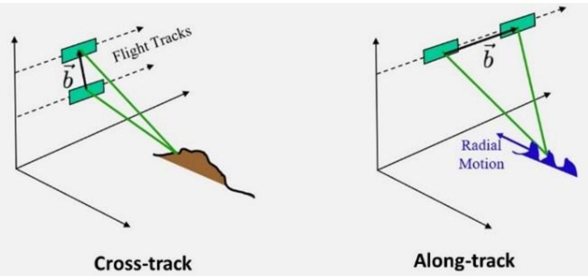

Fig. 1 *Two tandem flight track options*

The first formation flying bistatic SAR interferometer was constructed by extending the TerraSAR-X mission by a second similar satellite TanDEM-X [4].

The resulting bistatic SAR interferometer is one of the few tandem flight systems with formation flight heritage in orbit.

4 Example: NetSat

The objective of the Pico-Satellite Distributed System Control (NetSat), which is in orbit since 2020, was the technology demonstration for small satellite formation flights. This could be proved at the level of four nano-satellites in three-dimensional configurations (see figure 2). Crucial formation technologies in operations software for distributed systems, in networked control as well as in attitude and orbit control hardware, were addressed in preparation of the NetSat mission. Partially they have already been demonstrated in orbit. Current application missions in telecommunication, Earth and space weather observations are in implementation [3].

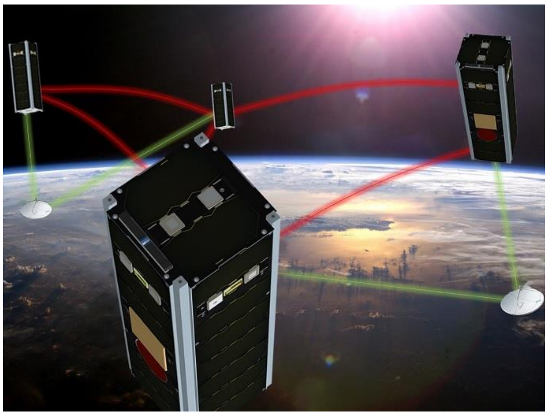

Fig. 2 *NetSat (Source: Center for Telematics)*

5 Kirkpatrick-Baez X-ray Space Telescopes

Kirkpatrick-Baez (KB) optics require long focal distances (see figure 3), which could be accommodated by two formation flying CubeSats. Thereby one CubeSat carries the KB module and the other one is equipped with a suitable detector. The CubeSats are expected to be separated by a distance of 1-10 meters in this application.

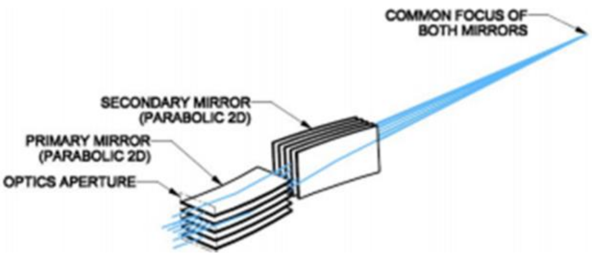

Fig. 3 *Kirkpatrick-Baez X-ray Optics*

6 Enabling Technologies

The enabling technologies for space telescopes based on satellite tandem flights comprise various fields like propulsion, navigation and communication. Concerning the propulsion and micro-propulsion there are essentially two options: Chemical propulsion with the disadvantage of a short lifetime, and electrical propulsion, which is a promising candidate. Relating to navigation GNSS based systems are limited to satellites positioned in Earth orbit. Star sensors can be used for a precise attitude determination. The relative position and attitude are identified by RF, laser, time-of-flight cameras or visual based systems which are actually in research status. Deep Space Communication also is a field that is only starting to evolve and is still in its beginnings.

7 Conclusions

Satellite tandem flights are a technology that offers several advantages for space telescopes, such as increasing the size of the effective aperture for optical payloads and reducing the overall size of spacecraft. However, it also imposes significant demands on autonomy, navigation, attitude and orbit control precision. Progress in miniaturization as well as in software technology is the basis for improved functional capabilities of small satellites. An increasing number of multi-satellite systems are in orbit. Formation flying allows significant baseline distances for virtual distributed observation systems. Supporting technologies related to autonomy, navigation, attitude and orbit control become available at nano-satellite level. Data pre-processing and reduction supports the downlink of payload information even at a limited communication bandwidth. CubeSats offer a cost-efficient implementation approach due to standardized interfaces.

Acknowledgments

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