Technologies, challenges and opportunities for optical CubeSat payloads

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This contribution describes optical payloads of CubeSat nanosatellites and their limiting factors. Some prominent examples are presented, and performance characteristics are discussed in the context of different commercial and scientific applications. Furthermore, the optical payload market has been evaluated and identified suppliers of commercial-of-the-shelf products are listed.

1 Preface

Within the degree program "International Technical Sales" at Aschaffenburg University of Applied Sciences future sales engineers are trained for the global market [1]. This study on optical payloads for CubeSat satellites was part of a corresponding Bachelor's thesis [2] and exemplifies the inter-disciplinary training in this modern educational course at the interface of market and technology. Thereby this work is embedded into international research cooperations on satellite instrumentation.

2 Introduction to CubeSat technology

The term "CubeSat" describes a class of satellites that use a standardized size and form. The basic CubeSat size is "one unit" or "1U", measuring 10x10x10 cm, also scalable to multiple units. An 1U-CubeSat has a volume of one litre. In most cases, CubeSats have a mass of one to ten kilogram and can therefore be classified as nanosatellites. For scientific and commercial applications, CubeSats enable cost-effective missions and significantly reduce the time between mission concept and launch compared to classical large satellites. Since 2000, there has been an accelerating increase in CubeSat launches, which in turn is expected to drive up the demand for dedicated optical instruments, especially in commercially relevant areas like high-resolution optics for earth observation.

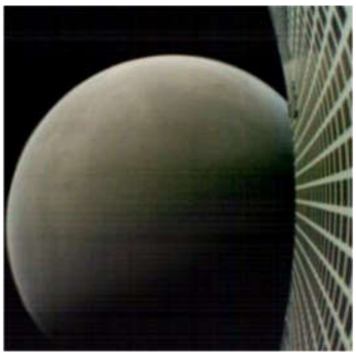

***Fig. 1** Picture of planet Mars by the MarCO-B mission* [3]

The initial CubeSat concept was developed in 1999. Nearly two decades later, the first interplanetary CubeSat mission took nearby photos of Mars (figure 1). The 6U nanosatellite “ASTERIA” even observed an exoplanet transit in 2018, achieving a first for the CubeSat platform. Opportunities in the form of new applications can trigger the process of innovative and challenging technological solutions for such nanosatellites.

3 Physical size and data processing challenge

A CubeSat is a very restrictive platform, considering all critical aspects of space, weight, and power (SWaP). Physical dimensions and effective aperture are the determining factors for achievable signal-to-noise ratios of a given optical instrument. Innovative solutions arise from these limitations like collapsible telescope assemblies (see figure 2) or rectangular mirrors in folded optical paths (e.g. CUTE CubeSat). This indicates that traditional, opto-mechanical technology is reaching its physical limits for such nanosatellites.

***Fig. 2** NASA’s Collapsible Space Telescope* [4]

Detector and processing systems are also limited by the size of the CubeSat platform. With more advanced detectors, higher resolution data can be captured in an increasing number of spectral bands. This in return increases the quantity of captured data and the required data transmission bandwidth. For example, the volume of data acquired by multispectral and hyperspectral imaging carries

DGaO-Proceedings 2020– *https://www.dgao-proceedings.de* – ISSN: 1614-8436 – urn:nbn:de:0287-2020-P030-0

eingegangen: 17.06.2020 veröffentlicht: 07.08.2020

much more information in its data sets. These data are increasingly hard to pre-process in situ without potential data loss and so require new algorithms to reduce the amount of transmitted data for the available bandwidth. The computing power and data storage required for such data are again limited on CubeSats by the available power and space. As the rate of innovation is high for semiconductor technology, we can expect more capable on-board data selection, reduction, and compression in the future.

Remote sensing is an area of great commercial relevance for the space up- and downstream industry. For earth observation in the visible spectral range, ground sample distances (GSDs) of 3 to 5 m are already achieved, e.g. by the “Dove”-constellation of 3U crafts by Planet Labs. Thermal infrared cameras are of lower GSD, e.g. NASA’s CUMULOS CubeSat has an LWIR instrument with ~400 m GSD.

4 CubeSat-based astronomical X-ray imaging

CubeSat-based X-ray science is an area of active development. The miniaturization of instruments is a big challenge here. Czech Aerospace Research Centre‘s 2U VZLUSAT-1 integrates a “Lobster Eye” wide-field instrument using a 256 x 256 pixel TimePix detector, capable of capturing the photon energy range between 3 keV and 30 keV [5]. Thereby, the collected X-rays are focused by plano grazing-incident mirrors at total reflection. The instrument flown on the VZLUSAT-1 is a 1D module with a focal length of 250 mm, consisting of 56 reflective gold-plated foils with a thickness of 145 microns (see figure 3). Angular resolution is specified to 2 arcminutes [5]. This design enables the detection and positioning of fast X-ray transients. The technology demonstrator was successfully launched in June 2017 as one of fifty CubeSats of the international QB50 mission.

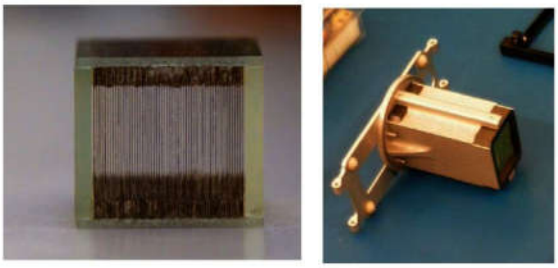

Fig. 3 *1D LE module of the VZLUSAT–1 nanosatellite* [5]

5 Commercial-of-the-shelf products (COTS)

The situation of the optical payload market has been evaluated from the perspective of the COTS payload availability as in early 2020. The question to be answered is which systems are offered by what supplier. A general finding is that, most often, products were small 1U form factor wide-angle RGB cameras. In a few instances, these instruments operating in the visible light spectrum (VIS) can be optioned to offer multispectral (MS) or hyperspectral (HS) capability. Two available products are infrared cameras (IR), while Thoth Technology offers a variety of IR spectrometers. Gathering information about the active organizations in the relatively new CubeSat payload market, it became evident that the number of suppliers was quite limited. The range of supplier company size was very wide, from small enterprises specialized in CubeSat subsystems to international corporations in the sector of aerospace and defence.

Company	Country	Instrument Type
cosine measurement systems	Netherlands	HS
Crystalspace	Estonia	VIS
GomSpace	Denmark	VIS
Hyperion Technologies	Netherlands	VIS
Headwall	United States	HS
Malin Space Science Systems	United States	VIS, IR, MS, HS
SatByul	South Korea	VIS
Simera Sense	South Africa	VIS, MS
SCS Aerospace Group	South Africa	VIS, MS, HS
Space Advisory Company	South Africa	VIS, MS, HS
Thoth Technology	Canada	IR, IR Spectrometer
XCAM	United Kingdom	VIS

Table 1 *COTS supplier and instrument type category*

6 Conclusion

The CubeSat concept is a unique opportunity to realize innovative projects economically. This requires the challenging adaption of existing technology into the restrictive satellite platform. Existing physical and electronics limitations are overcome by new innovations, mostly in the field of detectors and processing technology. In a relatively short time, CubeSats with their high temporal and sufficient spatial resolution have become a valuable and versatile tool for both commercial and research exploitation. In the future, we can expect innovative companies and scientists to take the CubeSat concept further, literally.

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eingegangen: 17.06.2020 veröffentlicht: 07.08.2020