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Initial Results from the TechnoSat in-Orbit Demonstration Mission

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ABSTRACT

Until now, Technische Universität Berlin successfully developed, built and operated sixteen satellites ranging from several single unit CubeSats to a 56 kg Earth observation mission. The recently launched TechnoSat mission has the primary objective to demonstrate and test novel small satellite technologies and components in Low Earth Orbit. To this end, the 20 kg spacecraft carries seven payloads. One payload, for example, is the fluid-dynamic actuator developed by Technische Universität Berlin. This novel attitude control actuator is based on momentum storage via a liquid metal that is accelerated using an electromagnetic pump. The secondary mission objective of TechnoSat is the in-orbit verification of the newly developed satellite platform TUBiX20 of Technische Universität Berlin. This platform bases on a modular systems design and provides scalability regarding selected performance parameters, which allows for tailoring of the platform towards individual mission requirements. TechnoSat was launched into a 600 km Sun-synchronous orbit on the 14th of July, 2017. Since then, experiments are successfully conducted regularly with all payloads and the analysis of the collected data is in progress. This paper presents first orbit results of the TechnoSat mission focusing on selected technology demonstration payloads.

INTRODUCTION

Before application, newly developed satellite technology is comprehensively tested to ensure flawless functioning in orbit. However, the space environment cannot be completely reproduced on the ground and thus in-orbit demonstration (IOD) is of very high significance for such technology. This results in a large demand for frequent and cost-effective IOD capabilities.

Among various other approaches that have been applied or proposed to provide such IOD capabilities, small satellites with a payload mass of approximately 10 kg that can carry several payloads have been found to be especially suited for this task [1].

TechnoSat is a 20 kg IOD mission that is developed, built and operated by Technische Universität Berlin. The TechnoSat spacecraft carries seven technology demonstration payloads and has been launched to a 600 km Sun-synchronous orbit in July 2017.

THE TUBIX20 PLATFORM

TechnoSat is the first mission to implement the TUBiX20 satellite platform of Technische Universität Berlin. TUBiX20 was developed to support future science, Earth observation and IOD missions of the university [2].

The TUBiX20 architecture bases on a distributed network of computational nodes, which provide computing power for the different subsystems' tasks and further act as interfaces to connect devices such as sensors or actuators to the central power and data bus system of the platform. These nodes are realized as plug-in cards housed in a central electronics box with a backplane that provides a standardized connector interface.

The software running on these nodes is implemented as building blocks that communicate using a publish-subscribe pattern. All nodes share a common set of hard- and software components that cover basic tasks, such as communication on the central data bus, time synchronization or software upload.

Due to this architecture, the TUBiX20 platform can be easily scaled to suit the performance needs of the individual subsystems for a specific mission.

The fundamental platform tasks are divided between four nodes, which are therefore called the primary nodes. Here, the electrical power system (EPS) node switches and supervises all other nodes including their redundancies and the data bus system. To this end, the EPS node is implemented in warm redundancy, while all other nodes are implemented cold redundantly. Furthermore, the EPS node is the time-master that distributes time messages on the central data bus. The communications (COM) node receives telecommands from ground and transmits telemetry. To this end, it implements a four channel UHF transceiver system. Here, two transceivers are connected to each redundant side of the node and are operated in hot redundancy. The onboard-computer (OBC) node is assigned with different system-level tasks, such as telemetry storage and satellite mode management. The attitude determination and control (ADCS) node hosts the high-level attitude determination and control algorithms.

The first mission to implement the TUBiX20 platform is TechnoSat. TUBIN will be the second TUBiX20 spacecraft and will demonstrate wildfire detection from space using two microbolometers and a camera that is sensitive in the visible spectrum [3].

THE TECHNOSAT MISSION

The TechnoSat mission has the objective to demonstrate different newly developed satellite technologies in orbit [4]. To this end, the spacecraft carries seven different payloads. Furthermore, the TUBiX20 platform itself is tested for the first time within the TechnoSat mission.

Figure 1 shows a rendering of the CAD model of the TechnoSat spacecraft in flight configuration.

Figure 1: Rendering of the TechnoSat Spacecraft

In the following, the payloads of the TechnoSat Mission are listed and briefly described.

1. **Fluid-dynamic actuator (FDA)**

   The fluid-dynamic actuator (FDA) is a novel attitude control actuator that is based on liquid metal that is moved within a circular tube using an electromagnetic pump [5, 6].

2. **Laser ranging retro reflectors**

   TechnoSat carries fourteen commercial 10 mm laser retro reflectors that are distributed over the outer faces of the satellite and allow for highly precise range measurements from ground [7, 8]. The experiment is a joint effort between Technische Universität Berlin, the Helmholtz Centre Potsdam - GFZ German Research Centre for Geosciences, the German Space Operations Center (DLR/GSOC) and the Austrian Academy of Sciences (ÖAW).

3. **S band transmitter HiSPiCO**

   HiSPiCO is an S band transmitter that has been developed by Technische Universität Berlin and the Berlin based company IQ wireless GmbH [9].

4. **Reaction wheels system**

   TechnoSat carries a reaction wheel system that comprises four wheels which allow for accurate pointing of the spacecraft. The reaction wheels were developed at Technische Universität Berlin.

5. **CMOS camera**

   A simple CMOS camera that is carried by the spacecraft allows to generate data to be downloaded by the S band transmitter and used as outreach material. Furthermore, the pictures are used to assess the pointing accuracy achieved by the ADCS. Also, a candidate lens for the successor mission TUBIN is tested in orbit.

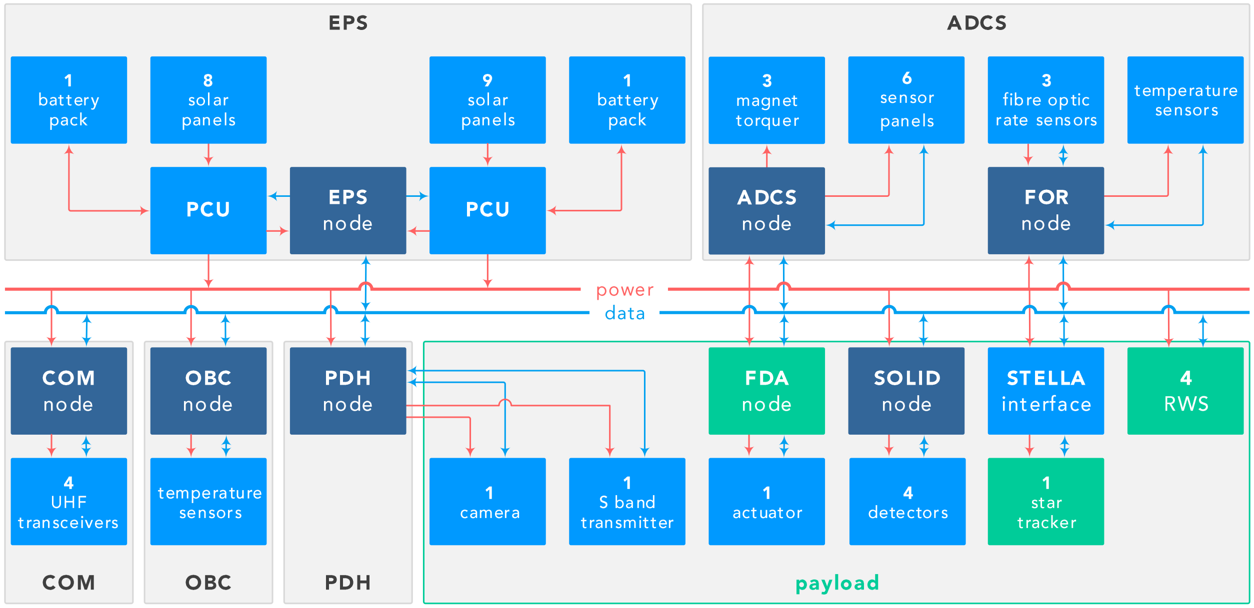

Figure 2: Overview over the System Design of the TechnoSat Spacecraft (modified from [4])

6. Particle detector SOLID

The Institute of space systems of the German Aerospace Center (DLR) developed SOLID, a method for the detection of Space Debris and Micrometeoroids [10, 11]. TechnoSat integrates SOLID detectors inside four of its 17 solar panels.

7. Star tracker STELLA

STELLA is a star tracker suitable for pico- and nanosatellites that was developed by the University of Würzburg in Germany [12].

The main parameters of the TechnoSat mission are listed in Table 1.

Table 1: Main Parameters of the TechnoSat Mission

Parameter	Value
Payload	Seven IOD payloads
Orbit	600 km SSO
Launch date	July 14^{th}, 2017
Launcher	Soyuz with Fregat upper stage
Design lifetime	1 year
Spacecraft mass	20 kg
Spacecraft volume	465 x 465 x 305 mm^3
TM/TC link	Four UHF transceivers
Attitude sensors	IC magnetometers, Sun sensors, MEMS gyroscopes, fiber optic rate sensors
Attitude actuators	Torque rods

Figure 2 gives an overview over the systems design of the TechnoSat spacecraft. Here, the central power (red) and data (blue) bus system is shown in the middle. The dark blue boxes represent TUBiX20 nodes, while the green boxes mark the payloads that are directly connected to the TUBiX20 power and data interface, but do not implement standardized TUBiX20 hard- and software elements. Light blue boxes represent the individual components of subsystems and payloads, which are indicated by light grey boxes.

The electrical power system (EPS) generates and stores electrical energy in two separated strings, each comprises several solar panels, a battery pack and a power conditioning unit (PCU) that manages battery charging and feeds the central power bus. The electrical power system is controlled by the EPS node, that also manages the redundancy of the central data bus and all other nodes in the system.

The communication system (COM) comprises the COM node that controls four UHF transceivers. Here, two hot redundant transceivers are connected to each cold redundant microcontroller of the node.

The on-board computer (OBC) is also a TUBiX20 node. It performs systems level tasks such as the satellite mode management and reads several temperature sensors that monitor the satellites primary structure.

The attitude determination and control system (ADCS) consists of two TUBiX20 nodes. The ADCS node hosts the core application of the subsystem and connects to the sensor panels, which host Sun sensors, magnetometers and gyroscopes, as well as to the magnet torquers. The fiber optic rate sensor (FOR) node reads three highly precise FORs and provides the filtered rate values.

The payload data handling (PDH) is also represented by a TUBiX20 node, which connects to the CMOS camera and the S band transmitter and further runs interface software for the star tracker and the fluid-dynamic actuator (FDA). The FDA comprises the actuator itself and the FDA node that is, however, not implementing standardized TUBiX20 hard- or software elements. SOLID uses a TUBiX20 node that is identical to the OBC as experiment computer to read the four detectors. STELLA is directly connected to the central power and data interface but requires a passive hardware interface board. All four reaction wheels are directly connected to the central power and data bus system.

PAYLOAD FLIGHT RESULTS

The first four weeks of the TechnoSat mission were mainly used for commissioning of the platform. Subsequently, all payloads were powered one after another, and first telemetry was received to confirm their correct functioning. This was followed by nominal operations, where experiments are conducted regularly. Table 1 gives an overview over the TechnoSat mission operations as of April 2018.

Table 2: Mission Operations (as of June 2018)

Parameter	Value
Orbits	> 4800
Ground stations used	2
Passes with active operations	> 1500
Experiments performed	> 130
Telemetry downloaded	32.9 MiB
Payload data downloaded	77.3 MiB

In the following sections, initial results from selected payloads of the TechnoSat mission are presented.

Fluid-Dynamic Actuator (FDA)

The fluid-dynamic actuator (FDA) is a novel attitude control device suitable for small satellites. In the scope of the TechnoSat mission, an FDA is tested under space conditions for the first time. An FDA comprises a closed ring structure that contains liquid metal, an electromagnetic pump, and respective control electronics. Here, the bi-directional DC-conduction pump uses the Lorentz force to accelerate the liquid metal in the ring and hence to store angular momentum. Due to its straightforward design, which does not include any moving parts, FDAs offer strong shock resistance and low abrasion. Furthermore, the electromagnetic pump allows for generating large torques at comparatively low electric power consumption. At Technische Universität Berlin, the theoretical foundations of the FDA have been developed and the first flight model was implemented for the TechnoSat mission [5, 6].

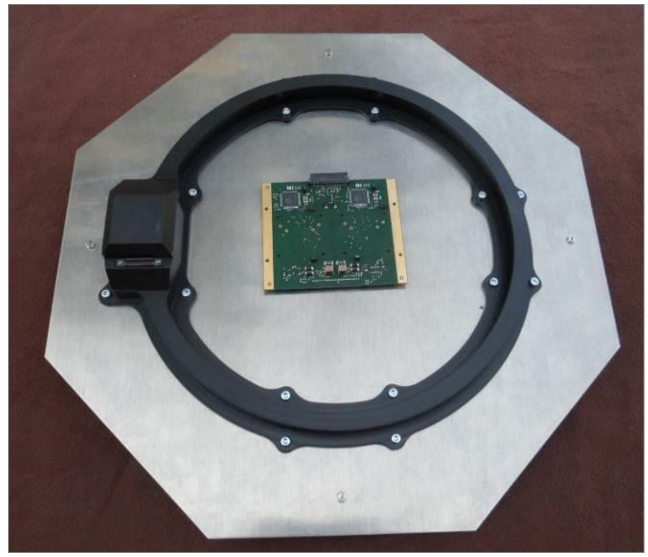

Figure 3: FDA-A6 EQM and FDA Node

Figure 3 shows the FDA-A6 and its controller board (the FDA node), which drives the electromagnetic pump and acts as interface between the actuator unit and the satellite platform. It includes two microcontrollers, operated in cold redundancy, each connected to the satellite's power and data bus system. The octagonal shaped aluminum platform matches the cross-section area of the TechnoSat spacecraft and served as platform for air bearing experiments to assess the characteristics of the actuator.

Table 3 shows the main characteristics of the FDA-A6, the model which is demonstrated in orbit within the TechnoSat mission, as determined under laboratory conditions.

Table 3: Characteristics of the FDA-A6

Parameter	Value
Angular momentum capacity (at 12 V)	0.035 Nms
Max. torque (at 12 V)	0.100 Nm
Max. power consumption (at 12 V)	5 W
Working medium	Ga-In-Sn
Loop diameter	300 mm
Total mass	1085 g
Data interface	CAN 2.0 (1 Mbit/s)

The FDA's software allows to command arbitrary angle and rotation rate maneuvers. Here, the controller uses a MEMS gyroscope to determine the satellite's angular velocity. P- and I-parameters of the controller can be adjusted via telecommands. In addition to the control loop which is directly implemented on the FDA node, the actuator can be controlled by the ADCS of the satellite. Here, data of the highly precise fiber optic rate sensors of the platform are used for satellite rate control.

The FDA can be operated in a nominal mode at 5 V and in a high-power mode at 12 V. Figure 4 depicts a ten-step acceleration maneuver in nominal mode performed in orbit on 2017/11/09. In this mode, the maximum power consumption of the FDA is 0.75 W. Here, rate data are provided by the platform's fiber optic rate sensors at 2 Hz. As shown, the FDA accelerates the satellite around its yaw-axis by more than 2.3 deg/s in one second (cf. the step in the middle section of the graph). This corresponds to a torque of around 40 mNm.

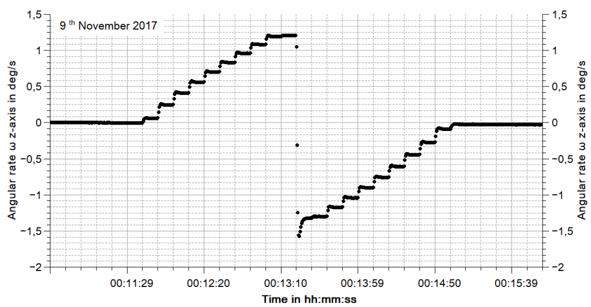

Figure 4: Ten-step Satellite Acceleration Maneuver

To date, a number of different experiments have been conducted successfully with the FDA. As a next step it is planned to include the FDA in the attitude control loop of the satellite. Furthermore, it is planned to analyze the jitter characteristics of the FDA and compare them to reaction wheels.

Reaction Wheel System

The reaction wheel system that is tested for the first time in orbit within the TechnoSat mission comprises four wheels in tetrahedron configuration. Each single unit has overall dimensions of 65 x 65 x 55 mm^3 and a weight of 315 g. Table 4 gives an overview over the specifications of the reaction wheels.

The wheel has two mechanical interfaces for flexible integration and one power and data interface unified in a single connector. Up to five different control modes can be selected, e.g. traditional ones like the motor rate mode and the motor ramp (torque) mode or (due to an integrated gyroscope) some special modes like the satellite rate mode.

The housing is sealed and pressurized for improving the thermal behavior and using COTS lubricants for the motor's ball bearings.

Table 4: Reaction Wheel Specifications

Parameter	Value	Unit
Mass (depending on configuration)	280…320	g
Dimensions	65 x 65 x 55	mm^3
Radiation tolerance	10	krad (Si)
Vibration	20	g RMS
Shock	1500	g
Operation temperature range	-20…+50	°C
Angular momentum (6000 rpm)	up to 45	mNm s
Max. rotation speed (steady state)	6000	rpm
Nominal torque (ramp mode)	0.1	mNm
Moment of inertia (rot. mass)	up to 730	gcm^2
Nominal voltage (1)	12	V
Standby power	220	mW
Power at max. rotation speed	1.35	W
Max. power (2)	< 20	W
Data interface	UART, CAN	
(1) unregulated (2) can be limited by the software		

The main part of the electromechanics is a commercial-off-the-shelf brushless motor with three integrated Hall sensors which are used for trapezoidal control. A dedicated logical circuit for commutation designed from discrete logic components leads to negligible commutation delays and reduces requirements on processor clock frequency. All electronic components are integrated into the wheel's housing and are protected against radiation through an aluminum shield with a thickness of at least 1 mm. However, the shielding can be increased to approximately 3 mm to meet customer lifetime requirements regarding radiation dose.

The dynamic vibration and shock loads of the launch introduced via the mechanical interface are decoupled from the motor's ball bearing by a miniaturized interface that uses springs and centering elements and was designed for this purpose. Here, the spring force is adjusted for a particular rotating mass, as moment of inertia and weight can be customized to meet individual customer requirements.

The housing of the wheel accommodates the motor and the electronics and is sealed and pressurized. The sealing is realized using three kinds of epoxy adhesives with different viscosities. A sensor measures the barometric pressure inside the wheel (cf. Figure 5).

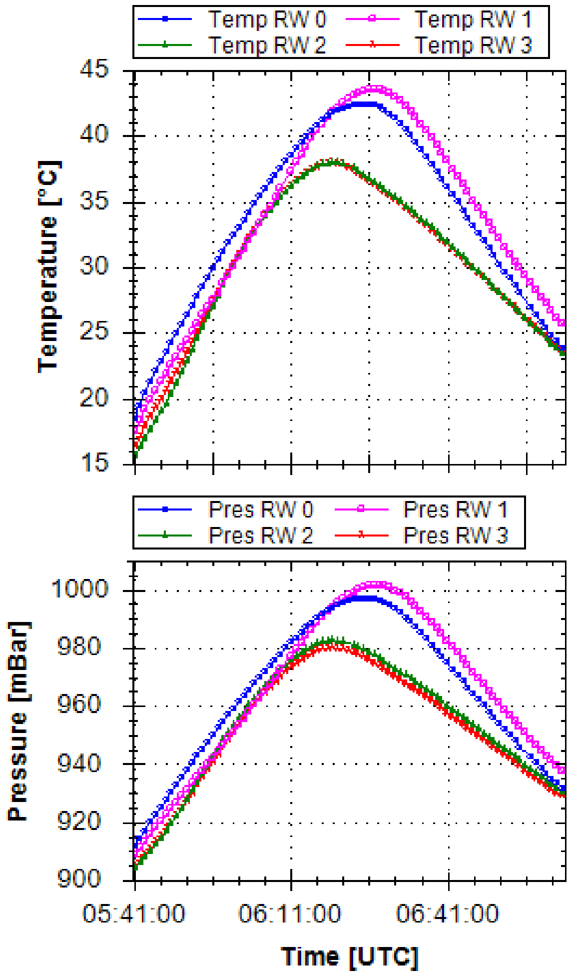

Figure 5: Reaction Wheel Temperature and Pressure of one Orbit (recorded 2018/05/30)

Figure 6 shows a reaction wheel unit in flight configuration.

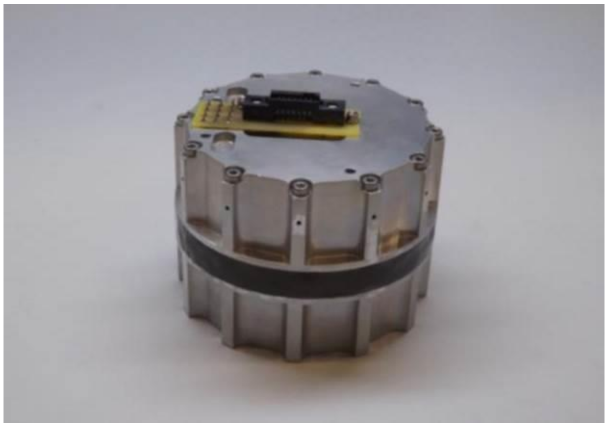

Figure 6: Reaction Wheel Assembly

Three types of sensors are used in the wheel's control loops: first, three square-wave signal Hall sensors being integrated into the brushless motor, second, a shunt to measure the electrical current through the coils and last, a gyroscope for angular rate measurement along the rotational axis of the wheel. Using these sensors five control loops are realized in wheel's software.

Motor Speed Control uses the rotational period as set value being captured from the Hall sensors. Here, eight state changes per full rotor rotation are available. The controller measures the time between sensor pulses and averages the value allowing for precise speed measurements with low jitter. Figure 7 shows a step response example of this control mode.

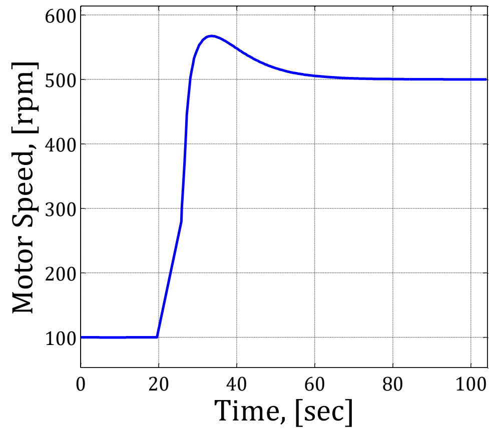

Figure 7: Motor Speed Mode Step Response

Motor Torque Control uses the change of the rotational period from one control cycle to the next actually being the discrete representation of the derivative. This value suffers greatly from the phase noise of the Hall sensors square-wave signals but is smoothened using averaging. The torque control performs very well up to 3000 rpm with decreasing accuracy above this value. A rotational encoder could improve the performance on higher rpm numbers but, on the other side, would enlarge dimensions and power consumption of the wheel.

Both, *Satellite Speed Control* and *Satellite Angle Control*, use a MEMS chip gyroscope that is integrated into the wheel. The satellite angle mode integrates the value of the angular rate. These modes perform very well without loss of accuracy up to 6000 rpm and even higher rpm values.

Motor Current Control can be used in place of torque control. It works up to 6000 rpm without performance loss. One precondition for that is that the external control loop implemented in the ADCS controller of the satellite must have an integral term. Figure 8 shows a step response example of this control mode.

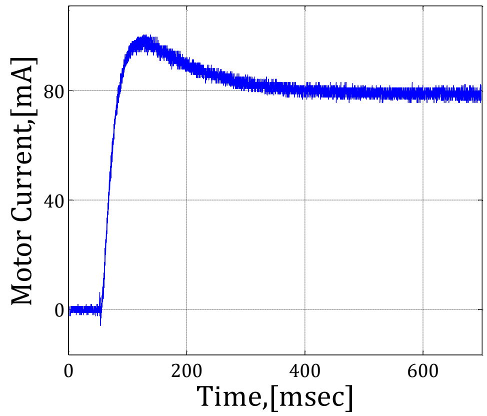

Figure 8: Motor Current Mode Step Response

The motor current loop, which closes every 5 milliseconds, is the fastest of all control loops and is used as internal loop (cascade). All other control loops are being closed every 50 milliseconds.

Figure 9 shows the angular momentum of Technosat's four reaction wheels while the satellite is performing nadir pointing.

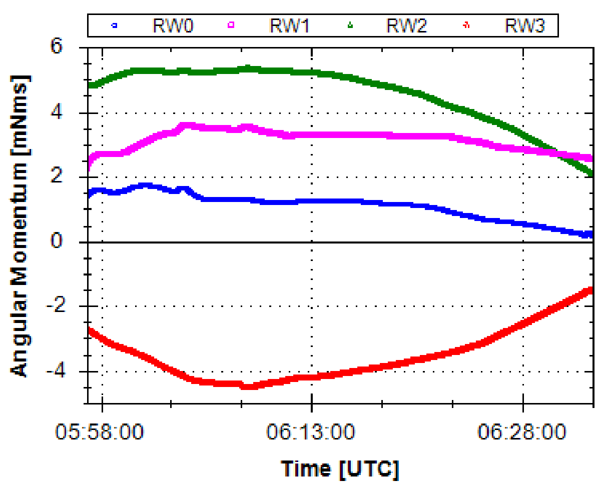

Figure 9: Angular Momentum of the four reaction wheels while performing nadir pointing (recorded 2018/05/30)

The reaction wheels were commissioned one by one between 2017/09/18 and 2018/09/27. Due to the very good commissioning results, it was decided to also test the wheels in the ADCS loop straight away, although this was originally planned to be performed much later in the mission.

As the camera was also commissioned successfully in the meantime, it could be used to assess the accuracy while performing attitude control using the reaction wheel system as actuators. Figure 10 shows the Austrian Alps with the town Spittal an der Drau captured by TechnoSat 2017/11/27 during such an experiment. Here, the overall attitude alignment error was estimated to be approximately three degrees [13].

Figure 10: Spittal an der Drau, Austria (captured 2017/11/27 09:53:30) [13]

In the future, the overall attitude control performance shall be improved by avoiding zero crossing of the wheels during fine pointing. Furthermore, different attitude control algorithms shall be tested in orbit and new pointing modes shall be added.

S Band Transmitter HiSPiCO

HiSPiCO is an S band transmitter, that was developed in a joint effort of Technische Universität Berlin and the Berlin-based company IQ wireless GmbH. An overview over the specifications of the S band transmitter and the antenna is given in Table 5.

Table 5: Specifications of the S Band Transmitter

Parameter	Value	Unit
Frequency	2.263	MHz
Data rate (nominal)	1.02	Mbps
Data rate (extended)	0.68 and 1.39	Mbps
RF Power Output	+27	dBm
Power consumption	5	W
Antenna type	patch	-
Antenna gain	6	dBi
Antenna opening angle	85	degree

The S band transceiver uses a patch antenna located on the nadir face of the spacecraft (cf. Figure 1). The flight model of HiSPiCO, along with its mount is shown in Figure 11.

The S band transmitter was powered for the first time in orbit on 2017/08/01. Since then, many experiments have been conducted with the transmitter and hundreds of pictures have been downloaded.

Figure 11: Flight Model of the S Band Transmitter

Currently, a software upload is being performed, which will simplify the assessment of the link quality throughout the pass. Once the new software has been commissioned a new series of tests will be performed to assess the performance of the transmitter for different elevation angles and data rates.

Laser Ranging Retroreflectors

Satellite laser ranging (SLR) in the kHz range is not only one of the most accurate technique for precise orbit determination (POD) of a spacecraft [14], but also a precise method to determine attitude and attitude motion of a satellite during its lifetime or even after decommissioning [15].

Table 6: Distribution of the 14 CCRs on TechnoSat

Face of the satellite	Number of reflectors
Positive x face (+*x*)	3
Negative x face (+*x*)	4
Positive y face (+*y*)	2
Negative y face (-*y*)	1
Positive z face (+*z*)	2
Negative z face (-z)	2

The structure of TechnoSat allows a maximum of 24 corner cube reflectors (CCR) to be mounted on the 6 faces of the spacecraft (up to 4 CCRs on each face). However, for a clear identification of the attitude, number and arrangement of the CCRs have to be optimized. After simulating the responses from different CCR arrangements, an optimized distribution using 14 CCRs has been selected (cf. Table 6). The CCRs are commercial-off-the-shelf (COTS) products with a diameter of 10 mm and have been tested and verified by the Helmholtz Centre Potsdam - GFZ German Research Centre for Geosciences in Potsdam, Germany [8].

Figure 12 shows a comercial 10 mm corner cube retro reflector with a Euro coin to show a comparison of size.

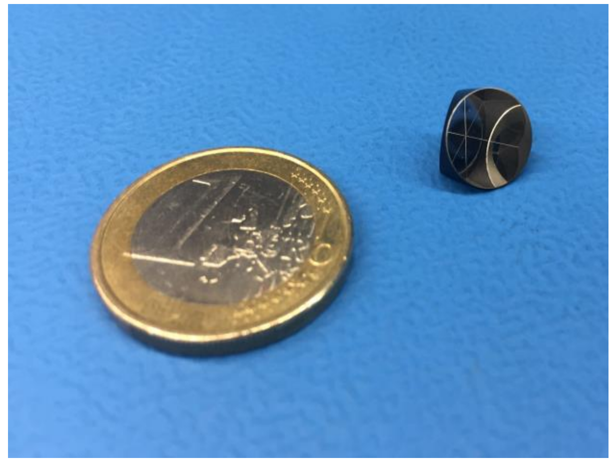

Figure 12: Corner Cube Reflector with Euro Coin

Figure 13 represents a simulation which applies the selected distribution of CCRs and assumes that TechnoSat stays at a fixed elevation angle of 45 degrees while spinning with a period of approximately 22.5 s. Distance variations to each visible CCR show unique patterns, thus allowing not only straightforward identification of each surface, but also determination of spinning rate and attitude angle with a precision better than one degree.

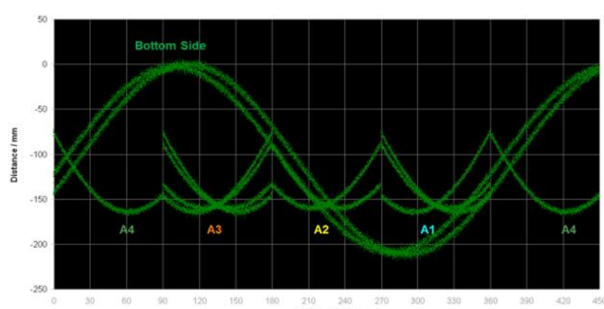

Figure 13: SLR Simulation with fixed Elevation Angle

To verify the simulations, a geometry model of TechnoSat was placed on a small mountain about 32 km southwest to the SLR station in Graz, Austria on a tripod, and rotated by stepper motors. The distance to the individual reflectors was measured using a 2 kHz SLR system.

TechnoSat is tracked by the International Laser Ranging Service (ILRS) [16] and the Flight Dynamics department of DLR's German Space Operations Center (GSOC) is conducting the orbit determination for the mission. After the launch on 2017/07/14 of course no SLR data of the ILRS was available, yet, since the

ILRS stations need accurate orbit predictions beforehand. As TechnoSat does not implement a GPS receiver two-line elements (TLEs) as provided by Spacetrack had to be used for the first orbit determination attempts. Since TechnoSat was released along with four other satellites in a similar altitude, an explicit identification of TechnoSat was not to be expected during the first days.

On 2017/07/20 Spacetrack was able to designate TechnoSat to one of the launched satellites. Since the prediction accuracy of one single TLE is varying - depending on the quality and number of processed observations - a smoothing process was applied here. This means, all available TLEs of three to five days were retrieved (on average 2 TLEs per day) and a smoothed orbit over this period was determined. This way outliers could be identified and disregarded. Furthermore, a more accurate propagation model was applied compared to the common SGP4-model. The resulting prediction was provided to the ILRS in the CPF format on 2017/07/24 for the first time. TechnoSat was tracked for the first time by the SLR station in Yarragadee, Australia on 2017/07/30. On 2017/08/09, sufficient SLR data was available for orbit determination. Since then the SLR data is retrieved and the orbit is determined based on the laser ranging information. Using SLR data of cause improved the prediction accuracy which in turn resulted in more observations. Today, SLR data downloading, orbit determination, CPF generation, and upload are fully automated at GSOC.

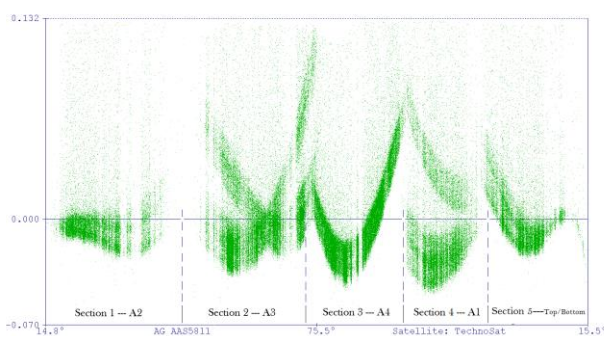

Figure 14: Five Faces of TechnoSat Tracked in Graz on 2018/03/22

Figure 14 shows the residuals (Observed Minus Calculated, O-C) of a successful pass tracked by the SLR Station in Graz, during which TechnoSat was tumbling free. From this O-C plot one can see that section 2 includes four traces from four different CCRs, which indicates that it corresponds to the *-x* face of the satellite; section 3 corresponds to the *-y* face due to its single traces and less RMS; section 4 corresponds to the *+x* face due to its three traces; from section 4 to 5 a small vertical step of about 35 mm in one-way distance indicates that section 5 corresponds to the top (+*z*) or bottom (-*z*) face.

As a conclusion, it can be said, that the 10 mm commercial CCRs that are applied on the TechnoSat mission can be used successfully for POD, but also for attitude and attitude motion determination independently of the operational status of the satellite. As a next step, it is attempted to achieve a higher resolution attitude analysis based on O-C values, the cutoff and transition from different faces and a comparison to sensor data of TechnoSat to verify our method.

CMOS Camera

TechnoSat carries a commercial CMOS camera for outreach purposes. Furthermore, the camera generates data for downlink using the S band transmitter and is used to assess the attitude control performance of the platform. Another objective is the orbit demonstration of the camera's lens, that will also be used within the next TUBiX20 mission that is currently under development (cf. section: The TUBiX20 Platform). The main specifications of the camera are given in Table 7.

Table 7: Specifications of the CMOS Camera

Parameter	Value	Unit
Focal length	22.9	mm
Resolution	640 x 480	pixel
Ground sample distance (GSD)	147	m
Swath width	94	km

The first picture from orbit was taken on 2017/08/23. Figure 15 shows a selection of enhanced versions of pictures that were captured in March 2018:

a. Part of Lake Nasser, Egypt, near Abu Simbel
2018/03/10 at 08:48:17 UTC

b. Faiyum Oasis, Egypt
2018/03/10 at 08:50:06 UTC

c. Turkish coastline near Marmaris
2018/03/10 at 08:52:06 UTC

d. Libyen coastline near Labraq
2018/03/13 at 09:20:28 UTC

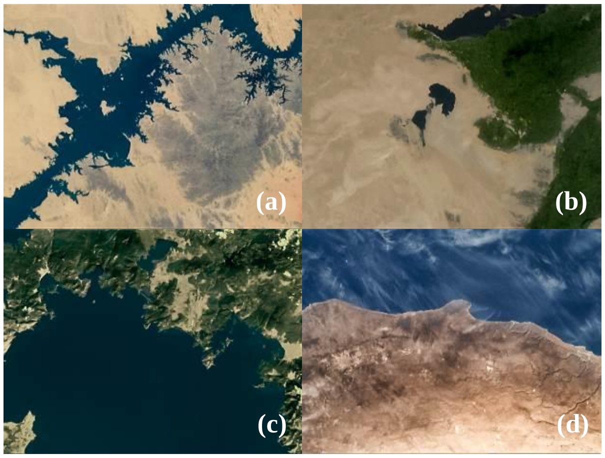

Figure 15: Images Captured by the CMOS Camera

As a next step, the number of pictures that can be stored is greatly increased, while the minimal time between two taken images is reduced significantly by means of a software upload of the PDH node.

CONCLUSIONS

TechnoSat is a 20 kg in-orbit demonstration (IOD) mission of Technische Universität Berlin that carries seven technology demonstration payloads. Furthermore, it is the first mission to use the newly developed TUBiX20 platform of the university.

Since the launch in July 2017, regular experiments are conducted with all payloads successfully and the data are handed over to the experiment providers. Furthermore, platform experiments are conducted on a regular basis to assess its performance.

While experiments with platform and payloads are continued, the TechnoSat spacecraft is also used to test new software features for future TUBiX20 missions, such as TUBIN, in orbit.

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