EventSat: A CubeSat Mission for Neuromorphic Vision-Based Space Object Detection

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Abstract

EventSat is a student-driven mission aimed at demonstrating space-based detection, classification, and identification of objects by leveraging neuromorphic vision. The mission consists of a 6U CubeSat with commercial-grade subsystems and a payload comprising an event camera and a commercial-off-the-shelf embedded AI computer. As part of the mission, algorithms are developed for event compression and object detection, taking into account the camera's very low latency and the specific characteristics of event data. The data may inform space objects catalogues for Space Situational Awareness (SSA). The EventSat mission serves as a platform for both academic and educational activities, allowing for the research and development of novel vision technologies and algorithms for their application in space, as well as providing training opportunities for students through hands-on learning with real space hardware. In this paper, we provide insights into the student-based structure of the team and the educational projects associated with it, with a focus on the impact on student learning through their involvement in the mission.

Keywords

Event camera, CubeSat, satellite mission, educational mission

1. Introduction

EventSat is a 6U CubeSat technology demonstration mission to validate the use of event-based cameras for space-based observation of stars, satellites, and space debris. It offers a platform for both research on novel spacecraft perception technologies that may inform Space Situational Awareness (SSA) [1], as well as for education in space engineering.

The EventSat platform is primarily built of commercial-off-the-shelf, flight-proven CubeSat subsystems procured from the EnduroSat and CubeSpace companies. Most subsystems come from the former, while the Attitude Determination and Control System (ADCS) is procured from the latter. EventSat's Electrical Power System (EPS) includes EnduroSat's "EPS Type II" components (two battery packs and a power distribution module), two 6U body-mounted solar panels, and two 3U body-mounted solar panels. For sensing, the ADCS integrates three Sun sensors (two high-accuracy, one coarse), an Earth sensor, and two three-axis magnetometers (one compact and one deployable). Actuation is provided by four reaction wheels arranged in a pyramidal configuration and a three-axis magnetorquer. Communication is supported in both the commercial S-Band (2025–2290 MHz) with data rates up to 125 kbps and the amateur UHF band (435–438 MHz) with data rates up to 20 kbps, with each band comprising a dedicated transceiver and antenna sourced from EnduroSat. The onboard computing is handled by EnduroSat's "On-Board Computer Type I," which features an STM32H7 microcontroller (ARM Cortex-M7 architecture, up to 480 MHz),

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2 MB of Flash memory, 1 MB SRAM, external FRAM, and an SD card socket. All platform modules are compatible thanks to the EnduroSat hardware and software environment and are stackable via standardized PC104 headers. The structure, also procured from EnduroSat, includes internal rails for subsystem placement. Payload processing is supported by a NVIDIA Jetson Orin Nano, a compact computer equipped with a GPU, operating in the low-power 7 W mode. Observations are recorded using a Sony IMX 636/EVK4 Event Camera from Prophesee [2] connected to a commercial-off-the-shelf optics and a custom-made baffle for stray light rejection. Figure 1 shows a notional image of the CubeSat.

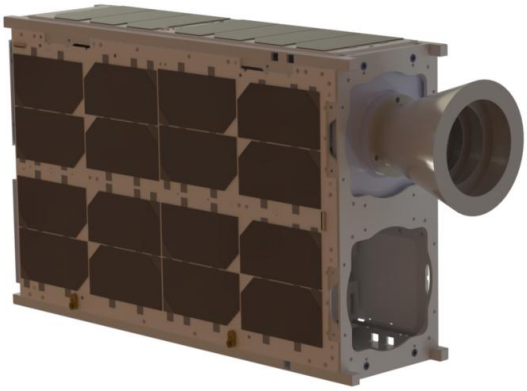


Figure 1: Current external view of EventSat.

In earlier publications, we presented the EventSat mission, first through a comprehensive mission architecture study [1], and subsequently through a detailed analysis and design of the satellite's event-based camera payload [3]. We kindly direct the reader to these publications for more information on these aspects of the mission design. The novel contribution of this paper lies in its focus on the educational framework surrounding the project.

Unlike most university CubeSat initiatives, the EventSat development is hosted within a single laboratory group, TUM's Chair of Spacecraft Systems (SPS). This structure allows formal courses to complement hands-on CubeSat development, serving both as preparatory training and as a recruiting tool. Students can receive structured classroom instruction on relevant topics before contributing to the project, while the CubeSat itself provides a platform to reinforce and deepen that knowledge in practice.

This paper describes the educational structure of the EventSat program, including the supporting courses, laboratory and test infrastructure, and experiential learning environment. Using survey-based assessments, we evaluate student learning outcomes, professional development, and career impact. The results offer insight into how university CubeSat programs can enhance formal coursework and serve as a platform for authentic systems engineering education.

The remainder of the paper is organized as follows: Section 2 provides a brief overview of the courses offered by the chair; Section 3 describes the demographic survey used to evaluate student learning outcomes; Section 4 presents high-level survey results; Section 5 highlights opportunities for improvement and outlines next steps for satellite development, and Section 6 provides a summary.

2. Courses Offered at the SPS Chair

The TUM Chair of Spacecraft Systems (SPS) conducts teaching for the Bachelor of Science and Master of Science in Aerospace, as well as for the Earth Oriented Space Science and Technology and the Mechanical Engineering programmes, among others. Table 1 shows a complete table of the course offerings, and their typical degree level of the attending audience.

Table 1: TUM SPS Courses' Overview.

Course Title	Degree
Introduction to Spaceflight	BS
Spacecraft Design – Fundamentals	MS & BS
Space Mission Design	MS & BS
Systems Engineering – Fundamentals	MS & BS
Systems Engineering – Advanced	MS & BS
Spacecraft Operations	MS & BS
Spacecraft Electronics	MS & BS
Spacecraft Computers, Software, and Data	MS & BS

Introduction to Spaceflight is an undergraduate/introductory lecture and exercise course that provides a broad overview of spaceflight engineering. Topics likely include the space environment, orbital mechanics, spacecraft subsystems, launch vehicles, and mission lifecycle considerations.

Spacecraft Design - Fundamentals is a lecture-and-exercise course covering the principles and processes of spacecraft subsystems. The course covers the functions, interfaces, and performance metrics of various subsystems, providing insights into their roles and interdependencies. Emphasis is placed on

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evaluating subsystem trade-offs within the context of mission requirements, guiding students through the process of selecting an optimal design solution that meets system constraints.

Space Mission Design is a project-based course that equips students with the conceptual knowledge and tools to design complete space missions. This includes defining mission goals, selecting orbits, performing link budget and mass budget analyses, and synthesizing mission concepts into feasible spacecraft solutions. Students practice mission analysis, system sizing, and early design decision processes.

Systems Engineering - Fundamentals is an introductory course on systems engineering with integrated exercises. Students learn foundational methods and frameworks for designing, analyzing, and managing complex multidisciplinary engineering systems, with emphasis on holistic thinking, requirement decomposition, functional allocation, trade studies, design documentation, and verification/validation planning. Topics include system lifecycle models, interface definition, risk and configuration management, and model-based systems engineering principles relevant to space systems.

Systems Engineering - Advanced is a project-based course that serves as an advanced continuation of foundational systems engineering concepts. Students are tasked to demonstrate their systems engineering knowledge through team-based building of a high-altitude balloon payload.

Spacecraft Operations is a laboratory course covering the functional structure of mission control, with an emphasis on satellite overpass, mission lifetime, and mission scheduling algorithms.

Spacecraft Electronics is a laboratory course emphasizing electronic systems relevant to spacecraft. Students gain hands-on experience with circuit design, electrical measurement tools, analog and digital electronics, and microcontrollers.

Spacecraft Computers, Software, and Data is a laboratory course focused on onboard computing, software engineering for space systems, internal data handling, and wireless communication. Students learn about embedded systems, flight software architecture, real-time operating environments, fault-tolerant design, data acquisition and storage, communication with ground systems, and software verification and validation methods in resource-constrained spacecraft environments.

The courses offered by the Chair of Spacecraft Systems are intentionally aligned to provide complementary perspectives and a scaffolded learning progression. For example, in Systems Engineering – Fundamentals, students are introduced to the concept of operations (ConOps) from a holistic, systems-level perspective. Here, ConOps is treated as a general systems engineering artifact embedded within the system lifecycle, rather than being spacecraft specific. Instruction emphasizes model-based thinking, stakeholder analysis, requirements derivation and traceability, functional decomposition, and formal technical communication. Students apply these principles in a hands-on exercise by developing a ConOps for a household item, providing a low-complexity context to strengthen structured thinking and abstraction skills.

In Spacecraft Operations, the ConOps concept is contextualized within the full mission lifecycle of a space system. As a laboratory-based course with small instructional groups, it emphasizes active learning, collaborative problem-solving, and peer instruction. Students engage in hardware labs, operational simulations, and scenario-based exercises. The course functions as a transition layer, deepening prior systems engineering knowledge while introducing authentic space-specific context.

Finally, in Space Mission Design, ConOps development is elevated to an advanced, integrative level. Students are tasked with designing a complete mission concept by the end of the semester, requiring the synthesis of technical, operational, programmatic, and stakeholder considerations. This capstone-style experience reflects a constructivist and project-based pedagogy: students define mission objectives, select payloads, develop architectures, and articulate a comprehensive ConOps that ensures coherence between mission goals, system design, and operational strategy.

Besides course teaching, the Chair supervises Master's theses (30 ECTS) and smaller Research practices (11 ECTS) for the M.Sc., as well as Bachelor's theses (12 ECTS) and smaller Engineering projects (6 ECTS) for the B.Sc. programmes. These academic projects

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are an additional way to involve students in specific tasks of EventSat's development within the frame of graded academic work.

In EventSat, students select a subsystem of interest and get a small project to perform that contributes to its development or simulation efforts. They get guidance and support from the subsystem's leader (typically a PhD student), as well as the necessary resources, and an opportunity to work with space hardware. A weekly meeting assembles all EventSat members for an update on the team's work.

3. Survey Description

Satellites are inherently complex systems, and as such, it is difficult to ensure uniform learning outcomes for all students, since their expertise and experience can vary depending on the specific projects they undertake. Nevertheless, the courses offered by the Chair of Spacecraft Systems are designed with clear, specific, and measurable learning objectives that are topic focused.

As instructors within the department, we were particularly interested in exploring how student engagement with the EventSat project influences their understanding of the space industry, their self-directed learning, and their professional self-conception. We were also interested in assessing the extent to which the lecture-based courses supported their hands-on project experience.

To gather feedback, we surveyed 15 students actively involved in EventSat. Table 2 summarizes their degree level and nationality. While a larger number of students (n = 48) have participated in the project over its entire lifetime, this subset is representative of the broader participant population. Within the survey, students were asked:

1. How have the courses offered by the Chair contributed to your work on EventSat?
2. How has your understanding of satellite development evolved since joining the project?
3. How have your career goals or aspirations changed as a result of your participation in the project?

This approach allowed us to capture both the impact of formal instruction and the experiential learning opportunities provided by direct project engagement, providing insight into the effectiveness of an integrated educational framework in spacecraft systems engineering.

Table 2: Demographic Information for Survey Participants.

Category	Subgroup	Number
Region	EU	6
	Non-EU	9
Degree Level	Bachelors	9
	Masters	6
Total		15

4. Survey Responses

4.1. High Level Takeaways

The majority of students participating in the project (93%) have completed at least one course offered by the Chair, highlighting how the structured, course-based curriculum serves as an effective platform for both technical training and talent recruitment within the spacecraft systems program.

4.2. Key Themes from RQ1

Students highlighted Introduction to Spaceflight and Spacecraft Design as foundational courses that provided a comprehensive overview of satellite systems. They reported that these courses established the necessary conceptual fluency to engage effectively with project activities, enabling them to interpret subsystem interactions, understand design trade-offs, and contribute meaningfully to the engineering and integration tasks within EventSat. They also highlighted the importance of requirements engineering, traceability, risk analysis, and interface definition, and how the SE courses improved the understanding of subsystem interdependence.

4.3. Key Themes from RQ2

A common theme in student responses to RQ2 was that joining the CubeSat program made them realize much more about the inherent ambiguity in real-world space systems engineering. Unlike traditional classroom problems that often have well-defined solution paths, working on the satellite required students to navigate ill-structured problem spaces, interpret incomplete documentation, engage in iterative problem solving, and make design decisions in the absence of clear, predetermined answers. Indeed, an additional common theme was that integration of subsystems, and their interfaces, are the harder part compared to isolated subsystem work, and that real documentation and configuration

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documents are messier and more incomplete than documentation examples seen in classroom. This experience reflects one of the key educational benefits of project-based learning in engineering: confronting authentic, open-ended challenges that mirror professional practice and require students to apply theoretical knowledge in contexts with inherent uncertainty and complexity. This feedback reflects the larger body of literature in engineering education, that has shown that project-based learning enhances students' technical competencies and fosters development of professional skills such as teamwork, oral and written communication, and complex problem-solving-abilities [4].

4.4. Key Themes from RQ3

Students mentioned they appreciated that the work they got to do within the CubeSat gave them practical engineering experience. Students reported skill improvements in topics as varied as CAD and tolerances, manufacturability, understanding of thermal control devices, GNSS signal evaluation, orbital analysis with GMAT, risk analysis, or mission operation dashboards, among others. Several students noted that taking responsibility for a design component provided deeper insight into the engineering process, including performing advanced design analyses, defining system requirements, conducting load and stress evaluations, and developing or selecting parts for manufacturing.

4.5. Survey Limitations

This survey has several limitations that affect the interpretation of the results.

First, as with many self-reported surveys in educational research, there is a potential response bias. Students may feel hesitant to provide fully candid feedback, particularly when evaluating courses, instructors, or project experiences in which they are actively engaged.

Second, the survey represents a single time point. A longitudinal study tracking students' perspectives before, during, and after participation in the CubeSat program would provide more robust insights into how experiential learning influences technical skills development, systems engineering understanding, and professional growth over time.

5. Protoflight Model and FlatSat

As EventSat is based on TRL-9 COTS platform components, it follows a protoflight model (PFM) approach for development and testing, to conserve resources for future research missions. This approach allows us to gain experience directly on the flight hardware but necessitates additional care to ensure that software configurations are always reverted to flight configuration from tests.

As an interim step before an integrated flight model, we set up the satellite modules in a FlatSat configuration that we can extend successively. Here we follow a philosophy of starting with a core component (the OBC) and extending the configuration by an additional component.

For each extension we identify basic functions that the extended system needs to provide. The initial FlatSat configuration consists of the OBC, EPS and payload computer board. The EPS can be configured to power the FlatSat off the battery power, so that meaningful EPS telemetry is generated during FlatSat tests.

The FlatSat is connected to a development PC which interfaces with it via RS-485 and two USRP 2290 Software-Defined Radios (SDR). For development-flashing the OBC, a JTAG programmer is connected as well. Commanding is done using a Python backend that translates command strings into bytecode, which are sent via the RS-485 bus or SDRs.

On a hardware level, the remaining modules except ADCS and solar panels can be connected. Functional integration is done successively in a four-stage model:

1. **FlatSat I** (current): Explore basic functionality of the platform bus and create the necessary development tools for further expansion.

   Functions: Command EPS, One-Way Command Payload.

2. **FlatSat II**: Develop telemetry mechanism and study payload communications, test mission control System (MCS) prototype.

   Functions: Onboard gathering of telemetry, simple commands via RF.

3. **FlatSat III**: Develop ADCS software interface for flight software development and ADCS acceptance testing, development of operations.

   Functions: Executing command stacks via MCS, Telemetry beacon and file download from platform and payload.

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4. **FlatSat IV**: Explore behavior of fully integrated system, identify and address operational edge cases.

   Functions: Full mission simulation, MCS-based commanding (“Test as you fly”).

The FlatSat development process will allow us to identify and integrate missing interfaces that are not included in the current COTS architecture. Using the PFM approach, we are then able to ensure that these interfaces work with the flight hardware.

One downside of a PFM approach without additional engineering model (EM) hardware is an added challenge to reproduce anomalous behavior on ground once the mission is in orbit. To mitigate this, we are implementing a hardware-in-the-loop (HIL) setup that will replicate component behavior during satellite development.

As the de-/encoding backend is based on Python, we utilize the Basilisk Astrodynamics Framework [5] as the main software architecture for the HIL setup. Basilisk can be compiled both on Desktop as well as embedded devices (such as a Raspberry Pi 5). The embedded device is then able to directly interface with the hardware components that are integrated into the HIL simulation.

As we are limited to one set of flight hardware, we use stand-ins for the flight hardware for exploring environmental testing. At this stage, we are using thermal vacuum tests $(\vartheta = -60\,°C \dots 150\,°C, p \leq 10^{-5} Pa)$ for payload characterization (optics suitability, sensor thermal noise, Jetson thermal dissipation) and vibration tests for assessing the general suitability of mechanical solutions (Jetson housing) and electronic interfaces (Forecr carrier board interfaces). Both tests are performed in house with equipment from the research group or the University. vibration tests are conducted on an IMV i210 vibration test system [6].

6. Conclusion

In this paper, we have introduced the EventSat mission currently in development at the TUM Chair of Spacecraft Systems, describing its high-level architecture, design, and current status of FlatSat and AIT activities.

As a University project, EventSat contributes both to the Chair’s research and development activities, but also to its educational mission. The incorporation of students from the early Bachelor’s to the late Master’s into the different subsystems, both in the framework of curricular projects as well as in a voluntary capacity, offers an opportunity to translate classroom’s theory into practice on a real space mission setting.

As the project continues into achieving full integration and launch readiness, and eventually into satellite operations, more educational opportunities and capabilities are expected to be opened by the EventSat.

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References

[1] L. Schuberth *et al.*, “Leveraging event-based cameras for enhanced space situational awareness: A nanosatellite mission architecture study,” in *75th International Astronautical Congress (IAC)*, 2024.

[2] “Event-based sensor IMX636 Prophesee Sony,” PROPHESEE. Accessed: Feb. 09, 2026. [Online]. Available: https://www.prophesee.ai/event-based-sensor-imx636-sony-prophesee/

[3] S. Dolan *et al.*, “Design and Analysis of an Event Camera Payload for Space-Based Object Detection on the EventSat 6U CubeSat Mission.,” in *15th IAA Symposium for Small Satellites for Earth System Observation*, 2025.

[4] L. Das, A. Naiksatam, and M. Shama, “Project Based Learning: Effective Tool for a Course on Electronic Product Design,” *Journal of Engineering Education Transformations*, pp. 257–259, Jan. 2020, doi: 10.16920/jeet/2020/v33i0/150157.

[5] P. W. Kenneally, S. Piggott, and H. Schaub, “Basilisk: A Flexible, Scalable and Modular Astrodynamics Simulation Framework,” *Journal of Aerospace Information Systems*, vol. 17, no. 9, pp. 496–507, Sep. 2020, doi: 10.2514/1.I010762.

[6] “Baureihe i,” IMV CORPORATION. Accessed: Feb. 23, 2026. [Online]. Available: https://we-are-imv.com/de/business/products/item/vibrationtest-iseries/