Improving communication between can-sized satellite and ground control station for accuracy of data acquisition

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ABSTRACT

The can-sized satellite, ScoreSAT satellite is a small communications satellite. ScoreSAT helps to develop a platform for finding directions and the exact spot where a lack of communications signal occurs, as well as a real-time visual feed for analysis of communication during and after landing. The project focuses on the design of ScoreSAT and provides a real-time system for capturing real-time data during descent. The objective of the real-time system is to improve the accuracy and location of ScoreSAT data collection, which can provide pressure, humidity, temperature, altitude, latitude, and longitude readings. The main components of this platform are the hardware design that comprises the flight controller, GPS module, and telemetry kit, the software design, which are Mission Planner, and the real-time system (RTS). Based on the entire research, the compact design of the ScoreSAT and ground station was developed to provide alternative meteorological parameter monitoring to complement primary meteorology ground observation such as weather station and radiosonde and to enhance the reliability of the remote sensing observation for environmental studies concerning the factors determining the environment and atmospheric.

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1. INTRODUCTION

The SiswaSAT platform is a modern educational concept used to simulate a satellite mission by designing, building, testing, and analyzing a miniaturized can-sized satellite. For this purpose, ScoreSAT (signal communications by orbiting relay) is named to honor the world’s first purpose-built communications satellite. The ScoreSAT is proposed to mimic a real satellite that integrates all the major subsystems such as power, sensors, and a communication system, into the can-sized volume to carry out the scientific mission and achieve a safe landing back to the ground station.

ScoreSAT is a nano-scale satellite model that fits into a 325 ml standard soda can, which aims to perform various scientific experiments. In this project, it describes how subsystem specifications were derived from top-level requirements and how each subsystem will be designed to meet subsystem specifications. It also shows how the concept of operations is implemented by the spacecraft. The central concept of the proposed design lies in the small, rapid, low-cost, and risk-tolerant engineering approaches while trying their best to achieve minimal mission requirements [1]. The obejective of designing the ScoreSAT system is to mimics the real satellite system at a small scale to acquire knowledge of space engineering and to face the engineering challenges in building a satellite.

The ScoreSAT's primary mission is to measure various vertical profiles of tropospheric meteorological parameters such as temperature, humidity, altitude, and pressure, then send the information to their ground station for data analysis. Such a mission was proposed to enhance the capability of remote sensing and earth obersation, with the aim of monitoring its environment. This mission is an essential element in providing long-term and cost-effective monitoring of the earth's resources. Its primary objectives are to provide alternative meteorological parameter monitoring (temperature, humidity, pressure, and altitude) to complement primary meteorology ground observation such as weather stations and radiosonde and to enhance the reliability of the remote sensing observation for environmental studies concerning the factors determining the environment and atmospheric [2].

In addition to the primary mission, ScoreSAT is also aiming to perform ground landscape imaging as a secondary mission to compliment the primary mission and objectives and to reflect various aspects of real-world missions. The above missions and objectives of ScoreSAT should be carried out with a low-cost financial budget, which inexpensively gathers key engineering and scientific data utilizing small, rapid, low-cost, and risk-tolerant engineering approaches [3]. The objective of the ScoreSAT project structural system is to provide a simple, solid structure that able to survive loads launching. At the same time, it provides an easily accessible data and power bus for components debugging and assembly [4]. The ScoreSAT design process is based on philosophy of maximizing interior space, while minimizing the cost of the design. This is because of the size constraints of the ScoreSAT and small allocated budget. The shape of ScoreSAT is essentially a can, with outer dimensions of 11×6.6 cm, with some space clearance above each side of the can. Every side of the can is mounted wtih the exterior components such as antenna, data link, and battery. The maximum allowable mass of ScoreSAT is 350 g.

Ground system (GS) is one of the crucial segments in the ScoreSAT as all the data transmitted from the spacecraft should be collected, display, and analyses spacecraft telemetry state of health by GS in real-time. In this proposed design, as the mission requirement does not require two-way communication between payloads and GS, for the sake of keeping minimum system complexity, the GS will design in such a way of only receiving data from payloads subsystem and process those received data set which consists of altitude, locations (latitude, longitude), temperature, humidity, and pressure accordingly [5]. These also include ground images captured by an imaging camera on satellite during the descent phase [6].

2. METHOD

ScoreSAT uses a parachute as a principal unit. This includes at least the following essential components: a lightweight parachute, various sensors, a radio receiver, a flight controller, a telemetry kit, software for ground positioning system (GPS), and ground station (Mission Planner) [7]. Telemetry and ground station system will be illustrated in this section. This section will also address the block diagram and flowchart, and the purpose of each component, why it is needed, and what considerations to make when selecting that component.

There are a few steps that need to be carried out to complete this research. This project is divided into three sections which are the hardware design, the software design, and the development of a real-time system. Primarily, the system design process begins with the hardware design of a ScoreSAT payload and assembling of the parachute with ScoreSAT [8]. Secondly, the development of ground control station (GCS) to communicate and monitor ScoreSAT [9]. After the connection between ScoreSAT and GCS have been established, all the telemetry data are being transferred from the ScoreSAT to GCS.

ScoreSAT collects the telemetry data such as latitude, longitude, pressure, and other parameters in real-time. This process is within a 1-second interval or less [10]. The data will be analyzed. Lastly, the project focus on the design of ScoreSAT after the real-time system has been accomplished. The functioning process of real-time system (RTS) will be discussed in the next section.

2.1. Software development

The operating software is required to run the hardware. This research started with a study on GCS and its applications or platforms used to communicate with ScoreSAT [11]. As the Raspberry Pi is used, Python programming will be the programming language of this subsystem. Raspberry Pi Foundation recommends Python as a language for learners. Python is an interpreted, high-level, general-purpose programming language. The development environment will be IDLE. IDLE is Python's integrated development and learning environment. IDLE platform has been with Raspbian for generations as the default editor. For the software development, the raw data from ScoreSAT is extracted from GCS. As all ScoreSAT information is included in the raw data, it is necessary to filter important data such as pressure, latitude, and longitude.

2.1.1. Software component and design

Mission Planner is software selected for this research at the ground station. Mission Planner for the ArduPilot APM 2.8 GCS application is a detailed and best-suited navigation control. It can save and load autonomous missions into ScoreSAT with a simple click at way-point entry on Google maps. The GCS can access and evaluate mission records generated by ScoreSAT in real-time application [12]. The flight controller for this project is ArduPilot APM 2.8 which works in conjunction with Mission Planner and is suitable for graphical user interface (GUI). Mission Planner is considered as the software for ground stations because of its various features [13].

ArduPilot has a desktop GCS for mission planning, calibration, and vehicle setup. As shown in Figure 1, the flight data screen of Mission Planner shows a Google satellite map indicating the location of ScoreSAT and overall status information of the transponder. This is also including a detailed head-up display. This features allow the user to turn any fixed, rotary-wing, or multirotor vehicle into a fully autonomous vehicle and also capable of performing programmed GPS missions with waypoints. It includes a 3-axis gyro, accelerometer and a high-performance barometer. The ground station can download and analyze mission logs in real-time applications. Finally, as previously stated in the 3DR 915 MHz Radio Telemetry Kit, users can also track the vehicle's status during operation and record the telemetry logs via wireless telemetry communication.

Figure 1. Mission Planner in GUI

The use of the Raspberry Pi application as another user interface is to view ScoreSAT's real-time data system when it is launched from an altitude of 200 meters. The data comes from Mission Planner when MAVLink transferred ScoreSAT data to the ground station [14]. The Raspberry Pi application has been selected because it has VNC viewer, which allows the ground station to display the data collected by ScoreSAT in a better way.

2.2. Hardware development

The signal transmitted from the spacecraft at the ground station will be received by two radio communication receiver stations and the meteorological data, consisting of longitude, latitude, acceleration, temperature, humidity, and pressure will be received in real-time while descending [15]. The 3DR radio telemetry RF receiver operating at the 915 MHz frequency can operate to collect telemetry data and captured image files. The hardware design of ScoreSAT is involved in designing the compartment to locate ScoreSAT components to match the specification dimension [16]. The initial step is to measure the dimension of each sensor and its weight [17]. The distance of the telemetry kit needs to be a measure to ensure the communication distance between ScoreSAT and the GCS is still linked. The real-time system (RTS) is the key component throughout this research to enhance the system's precision and location speed for data collection [18]. First, connect the ScoreSAT to the ground station software Mission Planner [19]. Once the MAVLink IP message is connected, the real-time system transmits online data to GCS.

ScoreSAT flight operation sequences are divided into several phases to achieve the above-mentioned mission objectives. At first, ScoreSAT is carrying by a drone to an altitude of 200 m. When the drone and ScoreSAT reach the mission height, the ScoreSAT will be released from the drone. The parachute will be deployed to control the descent process to ensure the spacecraft is safely land on the ground. During the descent process, telemetry and payload data from the sensors on-board will be transmitted to the ground terminal [20]. Such data includes temperature, humidity, altitude, and pressure as well as ground image data will be acquired and transmit real-time at the interval of less than 1 sec (1 Hz transmission rate) as per the mission requirement. Figure 2 illustrates the general view of flight sequence operation, and explains the details of the operation of each stage.

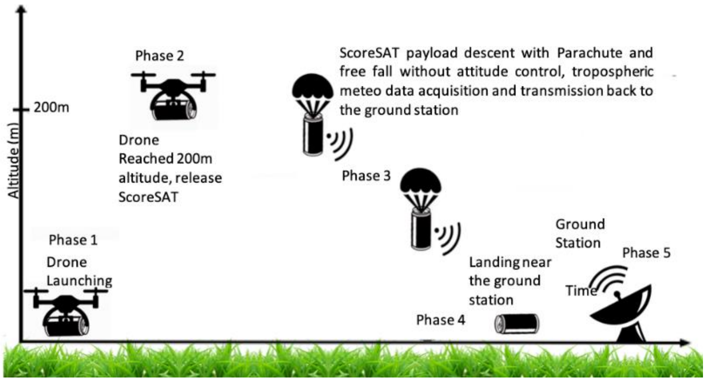

Figure 2. Flight operation sequence of ScoreSAT

3. RESULTS AND DISCUSSION

The design of the ScoreSAT body and components placement was standardized after testing a couple of types of prototypes. In order to take a precise reading in the direction of localization, the compass analysis was performed. Therefore, all the observations obtained will be dealt separately in the following subchapter.

3.1. Project overview and design

Four components, which are telemetry data (temperature, pressure, and location), 3DR radio telemetry kit (air and ground module), and GCS, primarily involved in the ScoreSAT project overview. First, switch on the ScoreSAT that is already connected to the Gaoneng GNB 2S 7.4V 550 mAH Li-Po battery and PKCELL Ultra Alkaline 9V 500 mAH battery with a 5 V power supply. During the descent to the GCS using the MAV link protocol, telemetry data including altitude, latitude, longitude, temperature, and pressure are transmitted in real-time after ScoreSAT is released [21]. The 915 MHz frequency is used for wirelessly linking both ScoreSAT and GCS.

3.2. ScoreSAT and components position design

In this research, for carrying devices such as flight controller, Raspberry Pi Zero WH, GPS unit, 3DR radio telemetry package, and other parts, a can-sized body that is 6.6 cm in diameter and 11 cm in height cylindrical shell is required [22]. The positioning of the components of the other part must be taken into account to maximize the ScoreSAT design so that there is no waste of space on the body. A complete of ScoreSAT prototype with all attached parts, as shown in Figure 3.

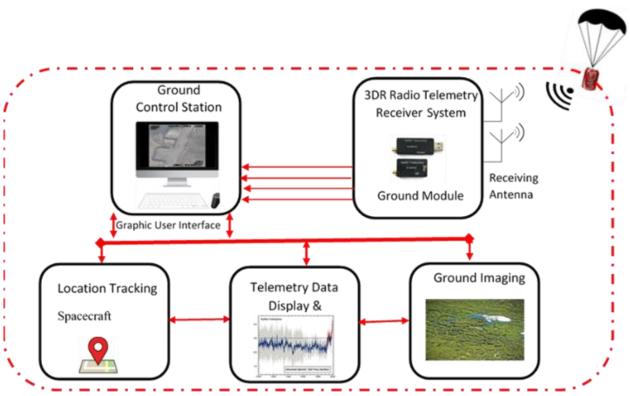

Figure 3. Generic ground station block diagram

The Figure 4 shows the layout of the internal structure of ScoreSAT Spacecraft. In order to ensure and protect the position of the components that do not move at launch and rover to the target stage, the first cover was layered with transparent tape. In general, the shape of ScoreSAT is a can with external dimensions of 11×6.6 cm and some space over each face of the can for mounting external components such as the antenna, the data link, and the battery [23].

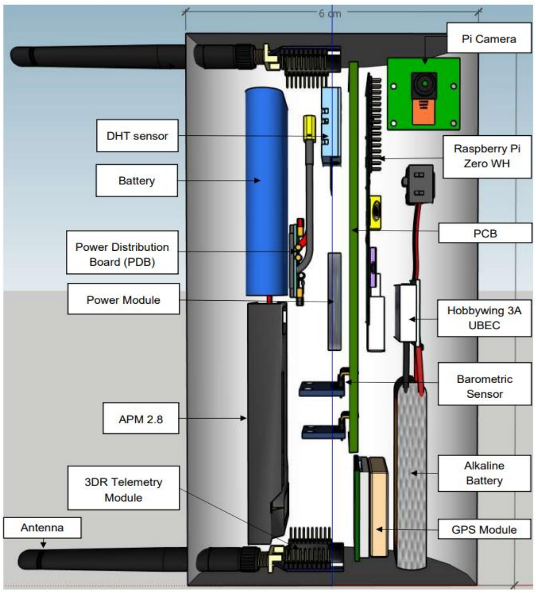

Figure 4. The layout of the internal structure of ScoreSAT spacecraft

3.3. Data received of APM 2.8

The position of the spacecraft is read successfully by attaching the GPS module to APM 2.8 and the effectiveness of the ground station in obtaining the spacecraft's position and health status by APM 2.8 [24]. Finally, when it is launched and was flying by a drone when the altitude reached 200 meters and released, the real mission is to gather telemetry data from ScoreSAT. The relation between ScoreSAT and the GCS is shown in Figure 5 to measure whether the accuracy of data collected is accurate or not [25].

During payload assembly, the system testing is being performed at the ground station. Firstly, with a baud rate of 57 600 and a USB cable rate of 115 200, the Mission Planner is successfully linked to the ArduPilot APM 2.8. Figure 5 shows the Mission Planner which is installed and connected with the 3DR telemetry ground module and running in the ground segment laptop. The altitude and the spacecraft position of the APM 2.8 can be retrieved at the Mission Planner interface. As it plots the point of the way on the Google Map as shown in Figure 6, the GPS module works correctly to locate ScoreSAT.

Figure 5. The reading of telemetry data displayed on Mission Planner software

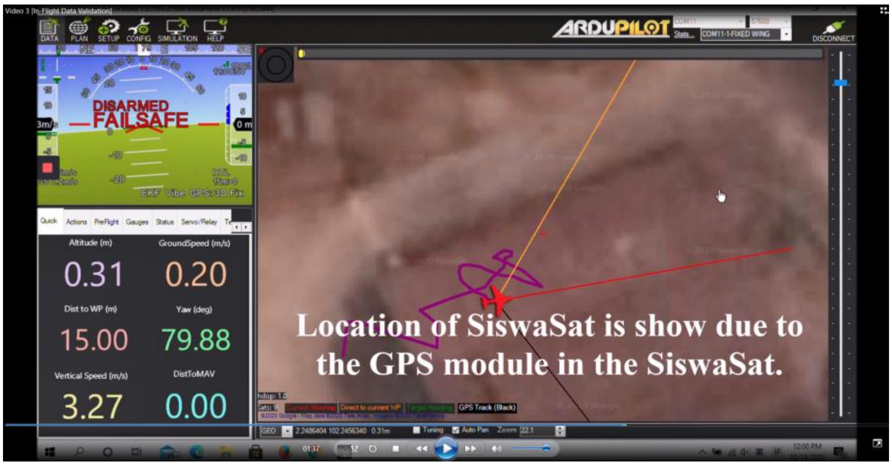

Figure 6. The reading of telemetry data displayed on Mission Planner software

3.4. Data analysis

The final aspect of the overall mission is data review, where the telemetry data from the ScoreSAT spacecraft will be extracted from the memory storage card and compared to the data obtained from the ground station for final confirmation of the accuracy of the telemetry data. Data are compared side by side from several sensors with the same parameter and statistical analysis will also be carried out. The example of the telemetry data from BMP180 compared with the data displayed on the user interface data is shown in Figure 7.

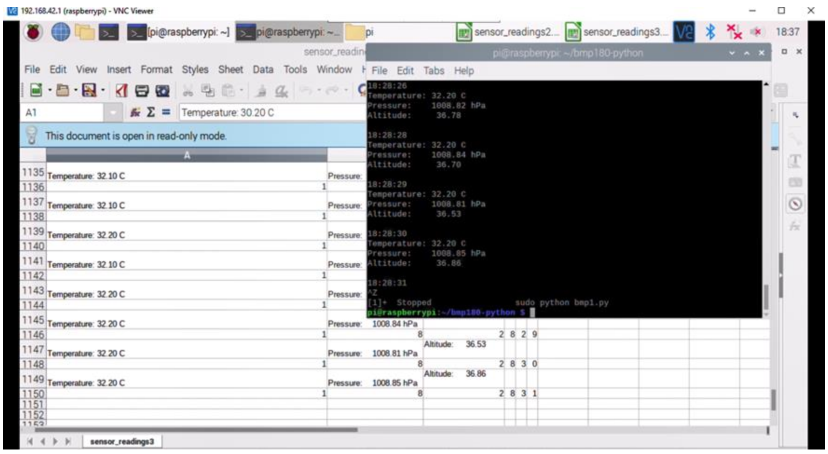

Figure 7. The telemetry data from BMP180

4. CONCLUSION

The ScoreSAT and GCS configuration on this can-sized satellite was successfully developed at the end of this research and accomplished all the goals. The electrical power subsystem (EPS) will support the power demand of camera operation for image capture and image storage in spacecraft memory, based on the secondary mission of ScoreSAT. The real-time data from the project would reduce the issue of contact signals. The real-time system of ScoreSAT will locate ScoreSAT's real-time location and transmit information such as telemetry pressure.

Besides, ScoreSAT's real-time data was obtained and stored in the CSV file format for analysis purposes. The data obtained can be analyzed to determine the precise location where there is a lack of a contact signal. In addition, accurate data was provided by all sensors and the GPS provided ScoreSAT with a reliable and secure position. The nature of the GCS is to help the user track ScoreSAT when the user understands the actions of ScoreSAT when it moves. Last but not least, the communication between ScoreSAT and GCS has been improved by the changing of components and software used in the system.

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REFERENCES

[1] M. E. Aydemir, R. C. Dursun, and M. Pehlevan, "Ground station design procedures for CANSAT," in *RAST 2013 - Proceedings of 6th International Conference on Recent Advances in Space Technologies*, Jun. 2013, pp. 909–912, doi: 10.1109/RAST.2013.6581343.

[2] P. H. D. Nehme, R. A. Borges, C. Cappelletti, and S. Battistini, "Development of a meteorology and remote sensing experimental platform: The LAICAnSat-1," in *IEEE Aerospace Conference Proceedings*, Mar. 2014, pp. 1–7, doi: 10.1109/AERO.2014.6836250.

[3] S. Paudel, R. C. Prajapati, J. Thapa, and S. Shrestha, "Development of CanSat ground-station using LabVIEW," *MARS Summit*, no. November, pp. 24–26, 2017.

[4] A. Spiridonov, V. Baranova, D. Ushakov, V. Saetchnikov, and V. Cherny, "Orbital parameters pre-launch calculation methods for a piggyback launched university small satellite," in *2022 IEEE 9th International Workshop on Metrology for AeroSpace, MetroAeroSpace 2022 - Proceedings*, Jun. 2022, pp. 486–490, doi: 10.1109/MetroAeroSpace54187.2022.9856203.

[5] D. Y. Lee, H. Park, S. Sarma, and J. W. Cutler, "Small satellite communication system design and optimization," *AIAA Aerospace Sciences Meeting*, Jan. 2018, doi: 10.2514/6.2018-1940.

[6] K. Murthy, M. Shearn, B. D. Smiley, A. H. Chau, J. Levine, and D. Robinson, "SkySat-1: very high-resolution imagery from a small satellite," in *Sensors, Systems, and Next-Generation Satellites XVIII*, Oct. 2014, vol. 9241, p. 92411E, doi: 10.1117/12.2074163.

[7] S. Sajin *et al.*, "A miniaturised low-cost telemetry system for small satellite launch vehicles," in *RASSE 2023 - IEEE International Conference on Recent Advances in Systems Science and Engineering, Proceedings*, Nov. 2023, pp. 1–6, doi: 10.1109/RASSE60029.2023.10363529.

[8] M. Schmidt, J. Bolvansky, and K. Schilling, "Satellite operation improvement through efficient data combination in ground station networks," *IFAC Proceedings Volumes (IFAC-PapersOnline)*, vol. 18, no. PART 1, pp. 524–529, 2010, doi: 10.3182/20100906-5-jp-2022.00089.

[9] Y. Nakamura and S. Nakasuka, "Ground station network to improve operation efficiency of small satellites and its qperation scheduling method," *AIAA 57th International Astronautical Congress, IAC 2006*, vol. 7, pp. 4533–4543, 2006, doi: 10.2514/6.iac-06-c1.6.10.

[10] G. Shirville and B. Klofas, "Genso: a global ground station network," *AMSAT Symposium*, 2007, [Online]. Available: https://www.ksat.no/ground-network-services/the-ksat-global-ground-station-network/.

[11] C. Sachdeva and M. Gupta, "A nano-satellite system for atmospheric monitoring and ground imaging," Jan. 2017, doi: 10.2514/6.2017-0617.

[12] C. Iacopino, S. Harrison, and A. Brewer, "Mission planning systems for commercial small-sat earth observation constellations," *2015 International Workshop on Planning & Scheduling for Space (IWPSS) of the International Joint Conferences on Artificial Intelligence*, p. IJCAI-15, 2015, [Online]. Available: http://www.academia.edu/15483513/Mission_Planning_Systems_for_Commercial_Small-Sat_Earth_Observation_Constellations.

[13] R. Tsubouchi, K. Nakahira, K. Shimomura, S. Ueta, N. Hirakoso, and T. Takada, "Mission planning variation of CanSat student group education: development, course design and practice," *Journal of JSEE*, vol. 66, no. 2, pp. 2_79-2_84, 2018, doi: 10.4307/jsee.66.2_79.

[14] A. Freimann, A. Kleinschrodt, M. Schmidt, and K. Schilling, "Advanced autonomy for low cost ground stations," *IFAC Proceedings Volumes (IFAC-PapersOnline)*, vol. 19, no. PART 1, pp. 388–392, 2013, doi: 10.3182/20130902-5-de-2040.00054.

[15] M. Abo-Arais *et al.*, "Approaching a nano-satellite using CAN-SAT systems," in *RAST 2015 - Proceedings of 7th International Conference on Recent Advances in Space Technologies*, Jun. 2015, pp. 813–817, doi: 10.1109/RAST.2015.7208452.

[16] S. N. Bulut *et al.*, "Model satellite design for CanSat competition," in *RAST 2013 - Proceedings of 6th International Conference on Recent Advances in Space Technologies*, Jun. 2013, pp. 913–917, doi: 10.1109/RAST.2013.6581344.

[17] M. H. Zohari, and M. F. Johari, "Weather monitoring system using Blynk application," *International Journal of Innovative Technology and Exploring Engineering*, vol. 9, issue. 1, pp. 1315–1319, Nov. 2019, doi: 10.35940/ijitee.L3666.119119

[18] W. Edmonson *et al.*, "Systems engineering of inter-satellite communications for distributed systems of small satellites," in *9th Annual IEEE International Systems Conference, SysCon 2015 - Proceedings*, Apr. 2015, pp. 705–710, doi: 10.1109/SYSCON.2015.7116833.

[19] J. L. Tresvig, T. A. Bekkeng, and T. Lindem, "CubeSTAR - a nanosatellite for space weather monitoring," *1st IAA Conference on University Satellite Missions and CubeSat Workshop*, 2011.

[20] D. Fathurrochman, P. Musa, D. D. Wimananda, and O. B. Lestari, "Remote sensing system of odometry and telemetry data in real- time," in *Proceedings of the 3rd International Conference on Informatics and Computing, ICIC 2018*, Oct. 2018, pp. 1–6, doi: 10.1109/IAC.2018.8780484.

[21] N. H. Crisp, K. Smith, and P. Hollingsworth, "Launch and deployment of distributed small satellite systems," *Acta Astronautica*, vol. 114, pp. 65–78, Sep. 2015, doi: 10.1016/j.actaastro.2015.04.015.

[22] B. Chandra P *et al.*, "Low-cost Raspberry Pi star sensor for small satellites," *Journal of Astronomical Telescopes, Instruments, and Systems*, vol. 8, no. 03, Jul. 2022, doi: 10.1117/1.jatis.8.3.036002.

[23] S. Gao, Y. Rahmat-Samii, R. E. Hodges, and X. X. Yang, "Advanced antennas for small satellites," *Proceedings of the IEEE*, vol. 106, no. 3, pp. 391–403, Mar. 2018, doi: 10.1109/JPROC.2018.2804664.

[24] S. Narayana, R. V. Prasad, V. S. Rao, L. Mottola, and T. V. Prabhakar, "Hummingbird: an energy-efficient GPS receiver for small satellites," *Communications of the ACM*, vol. 65, no. 11, pp. 133–140, Nov. 2022, doi: 10.1145/3559770.

[25] M. Schmidt and K. Schilling, "Internet-based ground stations networks for pico satellites," *SpaceOps 2008 Conference*, 2008, doi: 10.2514/6.2008-3205.

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