Penerbit Akademia Baru

Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage: www.akademiabaru.com/araset.html
ISSN: 2462-1943

A brief review of the cubic star on structural design, applications, and future perspective

Quanjin Ma[1,2,3,*], M. R. M. Rejab[1,2], Bo Sun[1], M. N. M. Merzuk[1]

[1] Structural Performance Materials Engineering (SUPREME) Focus Group, Faculty of Mechanical & Automotive Engineering Technology, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia
[2] School of Mechanical Engineering, Ningxia University, 750021 Yinchuan, China
[3] EHang Intelligent Equipment (Guangzhou) Co., Ltd, Guangzhou, China

ABSTRACT

With the increasing diversification of space missions, the cube star, as a standard module-based miniature spacecraft, has gradually become increasing research interest and development in the field of aviation based on its low cost, high integration, and short development cycle. This paper briefly reviews the design, application, and prospect of the cubic star, analysing the standardised structural design, attitude system, power system, communication measurement, and control design. It focuses on the application areas of cube star in demodulation of satellite signals, space exploration, discovery technology verification, earth observation, communication interruption, etc. Finally, the development trend of future cube star technology is analysed.

Keywords:
cubic star, structural design, application, future perspective

Received: 7 September 2021 **Revised: 3 October 2021** **Accepted: 3 October 2021** **Published: 7 October 2021**

1. Introduction

Cubesat, a 1 kg mass, 10 cm × 10 cm × 10 cm Cubesat, as defined by the California Institute of Technology and Stanford University in 1999, established the design and manufacturing standards for this type of satellite [1]. This type of nanosatellite is easy to achieve modularity, low cost, and short development cycle. It has become a research hotspot in recent years with typical CubeSat specifications, such as 1U, 2U, 3U, 6U, and 12U [2]. One of the top ten scientific breakthroughs of the year announced by Science magazine in 2014 was CubeSat technology in May 2015. NASA began to implement the "In May 2015, the NASA Innovative Advanced Concepts (NIAC) program also included planetary exploration using CubeSats as one of the important research directions. As of January 2019, more than 900 cubesats have been launched into orbits, such as the EU-led QB50 project, India's 104 satellites in one arrow, and Northwestern Polytechnic University's Soaring Star [3]. Moreover, Several commercial companies offer services to launch typical (1U–3U) CubeSats, and Boeing, Interorbital

* *Corresponding author.*
E-mail address: neromaquanjin@gmail.com

https://doi.org/10.37934/araset.24.1.1017

Systems, Lockheed Martin, SpaceX, and Virgin Galactic have announced to lower this price to anywhere in the range of $10,000 and $85,000 by 2020 [4].

The emergence of Cubesats has brought new research content to satellite and arrow separation technology, satellite payload technology, satellite networking, and space science exploration and research [5]. One of the outstanding features of Cubesats is their flexible and straightforward loading mode, which can be easily docked to the rocket through a standardised launcher (P-POD) [6]. It is installed as an additional payload next to a large satellite, which significantly simplifies the launch's coordination and greatly reduces the launch cost of spacecraft by using a one-arrow and multi-star launch mode. As micromechanics (MEMS) technology continues to evolve, Cubesats improve their capabilities, including faster processing speeds, more significant data communication capacity, and increasing attitude control accuracy [7]. A growing number of research institutions are experimented with multiple Cubesats to achieve global coverage. Typical satellite networking missions include the EU 7th Framework Flagship QB50 Project and NASA's PLOCK space networking mission. The satellite ground station is part of the satellite communication system, and its role is to send uplink control commands to the satellite, which receives satellite telemetry signals and transmitted data.

The Cubesat ground station system has the functions of satellite orbit prediction, automatic satellite tracking, and the characteristics of wideband coverage, strong anti-interference ability, and high reception sensitivity [8]. "Hope 1", SWISSCUBE, QB50P1, QB50P2, and other satellite signals. The related research summarises the experience of ground station construction at home and abroad, which introduces the ground station composition and working principle. It proposes a ground station scheme with AFSK modulation and BPSK demodulation mode applied to Cubesat satellite-to-ground communication [9].

2. Cubestar Design

2.1 Design of System Layout

The distribution of subsystems in a Cubesat is highly dependent on the requirements for diverse missions. In general, an example of SE01 Cubesat, in addition to the antennas, solar panels and other external appendages, the common configuration of a Cubesat should also include at least one payload, an attitude determination, an electric power supply, a data concentrator, an on-board computer, a transceiver, and control system [10].

2.2 Design of Standardised Structure

It is up to 48% in the early failure rate of (university-led) Cubesats [11]. One main reason for such low reliability is the correspondingly poor-quality standards applied during the manufacturing, assembly, integration and validation phases in the design of the Cubesat structure. Hence the international standard structure form of cubic star adopts the combination of structure frame plus crossbeam, which divides the cubic star into multiple 1U combination structure forms. It is convenient to form shelf products for users to select. The external envelope has a standard structural spectrum, which facilitates the standardised design of the corresponding cubic star deployer. Meanwhile, the structural material is made of high-strength aluminium alloy, grade 7075-T651. In parallel, austenitic stainless steel material should also be adopted with excellent specific strength.

The Stanford/Cal Poly CubeSat and Poly-Picosatellite Orbital Dispenser (PPOD) standards have standardised small satellite mechanical systems. For example, NASA has recognised this as evident by their Educational Launch of Nanosatellites (ELaNa) program, which recently selected 17 CubeSats for the ELaNa-4 launch in 2012 [12]. The external standard cube star structure and satellite exit crosssection dimensions are shown in Figure 1 [3]. The internal dimensions allow the standardisation of the internal part components of the Cubesat by defining a standard CSKB (CubeSat Kit Bus) board. The board can be installed with any Cubesat structure, and the CSKB board is designed with an asymmetric structure with an anti-insertion function.

Fig. 1. Standardised cubic star structural design [3]

The term ‘microsatellite’ was very probably coined by members of the AMSAT-NA (North America) community. There are many different ways to classify artificial satellites by function, type of orbit, cost, size, performance, etc. However, a classification by mass turns out to be quite useful because it directly bears the launch cost of a spacecraft. Subsequently, two more classes (pico- and Femto-) were added to Sweeting's original proposal [13]. The latest satellite classification by mass criterion is summarised in Table 1. Within this classification, the term ‘small satellite’ class covers all spacecraft within a launch mass of less than 1,000 kg [14].

Table 1
Small cubic star satellite classification by mass criterion [14]

Satellite class	Class type	Mass
Large satellite (observatory, etc)	Large satellite class	＞1,000 kg
Minisatellite		100-1,000 kg
Microsatellite	Small satellite class (or	10-100 kg
Nanosatellite	LightSats)	1-10 kg
Picosatellite		0.1-1 kg
Femtosatellite	Satellite-on-a-chip	1-100 g

2.3 Design of Control System

The Cubesat attitude control system's main tasks include eliminating the initial angular velocity of entry into orbit and maintaining the attitude required during the operation of the payload. The sensitisers used mainly include gyroscopes, magnetometers, solar sensitisers, GPS receivers. The actuators used mainly include magnetic moments and flywheels [15]. The satellite control includes the main control modes, such as initial detection, declination, coarse attitude, orientation to the Earth, safety wait, and charge recovery [16]. Since the resources and energy for cube star control are limited, ensuring the satellite attitude stability and coordinating the control system and payload are working modes. It has become the focus in the design of the cube star autonomous operation. For example, a satellite attitude control system was designed using low-cost hardware and software for a 1U CubeSat. It was obtained through a two-stage approach involving coarse and fine control modes [1].

2.4 Design of Power System

The power system of the cube star mainly depends on the power supply, which can help the satellite collect, convert, store and distribute energy [17]. It has a critical role in completing the satellite mission. Because of the small size of Cubesat, the power system could be a much smaller, more efficient, more versatile interface, more intelligent, and lower cost. Therefore, it is significant differences in topology and design ideas from traditional satellites.

A power budget analysis is necessary to study the mission's feasibility and size of the components in the power supply chain. Hence it is required to gather the power consumption by every subsystem. Additionally, the required peak load is relevant to sizing the capacitors that fulfil exceptional power demands during transitions. The key technologies of the cube star power system are mainly reflected in the power controller [18]. Several main functions are (1) high-efficiency energy conversion topology implementation technology used MPPT technology. (2) highly integrated power controller implementation technology integrates energy conversion, charge and discharge management, secondary voltage conversion, power distribution and protection, and even battery in a single board structure. (3) standardised and modular design. (4) standardised modular design methods and power dexterity expansion and configuration technology. (5) COT device based on the implementation of highly reliable systems and intelligent fault-tolerant control technology.

2.5 Design of Communication, Measurement, and Control

Cubesat's communication and measurement and control system mainly includes the on-board communication system and the ground station system. The on-board communication system includes UHF/VHF RF transceivers and deployable antennas. The on-board computer controls the RF transceiver to send and receive data. The VHF band is used for command uplink, and the UHF band is used to downlink telemetry data. The ground station is mainly based on the VHF/UHF band for satellite measurement and control, respectively 144–146 MHz and 435–438 MHz for the amateur region 1. It is noted that the Cubesat missions require a wider bandwidth to download science data, which operates between 2.40 and 2.45 GHz [19]. Typically, though the telecommunication frequency requests from the International Telecommunication Union, many Cubesats tend to operate with radio amateur frequencies due to accessibility and free of charge [20].

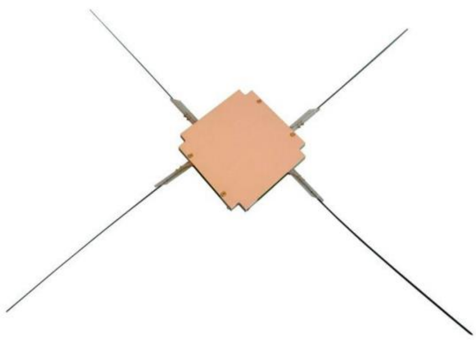

Fig. 2. Image of the deployable antenna [2]

In China, the Soaring Series Cubestar ground station named Northwestern Polytechnic University was independently fully completed in April 2016. It is realised satellite measurement and control based on UHF/VHF bands [21]. Figure 2 shows the physical diagram of the deployable antenna. In addition, the problem of cube satellite attitude control through magnetic torque rod is considered. Therefore, the use of predictive model control (MPC) as magnetic control is designed by considering both the actuator saturation and the Earth's magnetic field constraints [22].

3 CubeStar Application Areas

3.1 Space Field

Cubesats play a unique role in space science missions. In the space weather experiment CubeStar Explorer I discovered the existence of the Earth's radiation belts. The Mars Insight CubeStar companion, Mars CubeStar I, and Insight carried out many communication and flight navigation experiments in a miniaturised deep space communication equipment test mission. The Planetary Science Division (PSD) has also made significant strides toward accommodating CubeSats for astrophysics research and exploration of the solar system. The QB50 project has completed the largest low-cost, long-duration, multi-point in situ exploration of the Earth's lower thermosphere based on CubeStar. The data obtained can further improve the Earth's atmospheric model, which is of great scientific value. Figure 3 represents the mission concept diagram of CubeStar's work in the field of space area [23]. Furthermore, the cube-satellite propulsion system is further investigated, which is the primary mobility device to a spacecraft. It is used to assist orbit modifications and attitude control [24].

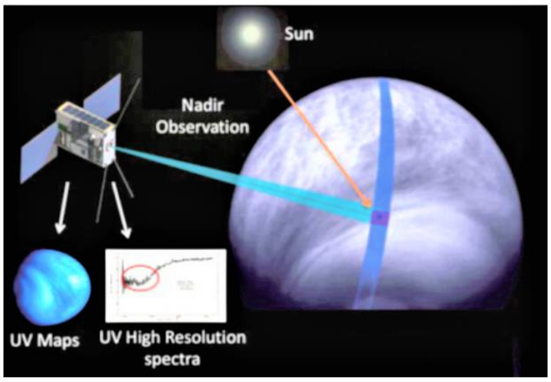

Fig. 3. Conceptual diagram of the CubeStar mission in space area [23]

3.2 Environmental and Air Pollution Detection

The majority of Cubesats today are devoted to Earth observation. Xi'an-1 A/B [25], the Shaanxi-1 low-orbit remote sensing constellation pilot star, is a 16U and 20U CubeSat platform for environmental and atmospheric pollution detection. 72 CubeSats are launched in the first phase of the Shaanxi-1 constellation. It can achieve comprehensive coverage and detection of Shaanxi and countries along the Belt and Road. Additionally, Planet Labs has put more than 330 satellites in orbit since 2013. These small Cubesats work on obtaining high-quality images of our planet and provide accurate and up-to-date maps of the entire planet. In addition, Cubesats have also adopted the fight against ocean pollution and the detection of oil spills and spills. There are many important parameters involved, such as monitoring marine life, the control of desertification, the study of the progress of melting ice, or the protection of areas of special environmental importance.

In recent years, the emerging Earth-Observation micro/nanosatellite technique has provided new data sources for polar region observations, named TW-1A. It is a 3U CubeSat of 2.9 kg with the size of 30×10×10 cm. It was confirmed that the satellite data could meet the demand of glacier and sea ice observation [26]. Satellite image time series (SITS) data has been widely used in resource investigations and environmental monitoring. ST-cube is introduced to reduce the spectral heterogeneity in spatial and temporal domains, contributing to a wider range of applications and analysis of SITS [27].

3.3 Magnetic Anomaly Detection

The "Macau Science 1" satellite project is a 48U flexible design modular assembly microsatellite jointly developed by Northwestern Polytechnic University and Macau University of Science and Technology. Firstly, it is used as an equatorial orbit low orbit satellite to detect the magnetic anomaly in the South Atlantic Ocean, which plays to the low cost of CubeSat, short development cycle, and rapid testing launch. The characteristics of low cost, short development period, rapid testing, and flexible launch of CubeSats are utilised to achieve 5-year long-life geomagnetic measurements with high accuracy using 70 to 80kg microsatellites [28].

3.4 Security, Defence Programmes

In crises, such as earthquakes, hurricanes or tsunamis, Cubesats immediately know the extent of the damage (even in isolated areas) and manage relief and rescue teams to act quickly [29]. For example, a system of sensors and buoys in the ocean can detect by Cubesats in advance the arrival of a tsunami, or a sensor in a reservoir can automatically generate a warning message if the water reaches a dangerous level [30]. Moreover, with the support of nanosatellites, the information and data could be gathered from certain areas of the planet, which allow the planning of humanitarian aid.

4. Future Perspective

The ongoing domestic and international application projects include the One Arrow Multi-Star Deployer and the Cubestar Deep Space Exploration Program. CubeStar adopts the international standard cassette separation mechanism, with the simple interface between the CubeStar body and rocket adapter [31]. It is the easiest to realise the standardisation and serialisation of multi-star separation. The functional components of the separation mechanism are developed to form a standardised and modularised CubeStar separation mechanism. The quality of the separation mechanism can be significantly reduced, thus lowering the launch cost, and it can realise the common use of the components to achieve mass production. Deep space exploration has become an interesting topic for the research study. Internationally, the United States, Japan, and Europe have launched a series of microsatellite-based deep space exploration missions, including the Lunar Polar Zone Hydrogen Mapping SkyFir Cubesat Mission (SkyFir) Asteroid Origins Satellite AOSAT and other projects [32].

There are plans by the Northwestern Polytechnic University to launch the Cubesat deep space exploration program with six to eight 6U ~ 12U Cubesat on the trip to the Moon [33]. 12U cubic stars, in the various stages of the asteroids mission, separate the deployment, form a constellation, and carry out international deep space exploration and asteroid detection missions. Besides, promoting multi-point detection and supplementary detection is also an important project in the future, which is vital for CubeSat to obtain diversified data and improve detection resolution in many aspects [34].

Moreover, as advanced technologies have emerged as the main trends in the earth observatory sector, artificial intelligence plays a crucial role in effectively analysing satellite data [34]. The key players leverage the capability of AI to allow systems to derive insights and make the right decisions using raw data sets with the negligible human contribution. For instance, the European Satellite Association (ESA) plans to launch a CubeSat, which is equipped with on-board artificial intelligence to improve the efficiency of sending Earth observation data back to Earth [35].

5. Conclusion

CubeSat is a modular development and production of micro-nano-satellite. Its development cycle is short, low cost. The network approach can supplement the shortcomings of large satellites in remote sensing, communications, education, and other applications, network mobility, and flexibility with multi-tasking capabilities. The key target gaze time, revisit time, revisit frequency, and large satellites can not be compared. However, CubeStar still needs to be improved in structure scale, control accuracy, working life, data transmission capability, orbit control capability, etc. In the future, CubeStar will play a more significant role in promoting and facilitating the industrialisation of spaceflight and spaceflight innovation education through rapid applications, such as verification, deep space exploration, environmental monitoring, disaster assessment, urban construction.

References

[1] J. Li, M. Post, T. Wright, and R. Lee, "Design of attitude control systems for CubeSat-class nanosatellite," *Journal of Control Science and Engineering,* vol. 2013, 2013.

[2] M. Wei *et al.*, "Design and flight results of the VHF/UHF communication system of Longjiang lunar microsatellites," *Nature Communications,* vol. 11, no. 1, pp. 1-10, 2020.

[3] K. Woellert, P. Ehrenfreund, A. J. Ricco, and H. Hertzfeld, "Cubesats: Cost-effective science and technology platforms for emerging and developing nations," *Advances in Space Research,* vol. 47, no. 4, pp. 663-684, 2011.

[4] A. K. Nervold, J. Berk, J. Straub, and D. Whalen, "A pathway to small satellite market growth," *Advances in Aerospace Science and Technology,* vol. 1, no. 1, pp. 14-20, 2016.

[5] V. Lappas and V. Kostopoulos, "A Survey on Small Satellite Technologies and Space Missions for Geodetic Applications," in *Satellites Missions and Technologies for Geosciences*: IntechOpen, 2020.

[6] A. Farhat, J. Ivase, Y. Lu, and A. Snapp, "Attitude Determination and Control System for CubeSat," *Worcester Polytechnic University: Worcester, UK,* 2013.

[7] S. Janson, "Micro/nanotechnology for micro/nano/picosatellites," in *AIAA Space 2003 Conference & Exposition*, 2003, p. 6269.

[8] A. Wang, P. Wang, X. Miao, X. Li, N. Ye, and Y. Liu, "A review on non-terrestrial wireless technologies for Smart City Internet of Things," *International Journal of Distributed Sensor Networks,* vol. 16, no. 6, p. 1550147720936824, 2020.

[9] J. Mevada, J. Samuel, S. Bhadane, A. K. Gulati, and R. D. Koilpillai, "Design and implementation of a robust downlink communication system for nanosatellites," in *2015 International Conference on Space Science and Communication (IconSpace)*, 2015: IEEE, pp. 164-169.

[10] S. Song, H. Kim, and Y.-K. Chang, "Design and implementation of 3U CubeSat platform architecture," *International Journal of Aerospace Engineering,* vol. 2018, 2018.

[11] M. Swartwout, "The first one hundred cubesats: A statistical look," *Journal of Small Satellites,* vol. 2, no. 2, pp. 213-233, 2013.

[12] C. J. Kief, B. Zufelt, S. R. Cannon, J. Lyke, and J. K. Mee, "The advent of the PnP Cube satellite," in *2012 IEEE Aerospace Conference*, 2012: IEEE, pp. 1-5.

[13] S.-Y. Tan, "Remote Sensing Applications and Innovations via Small Satellite Constellations," *Handbook of Small Satellites: Technology, Design, Manufacture, Applications, Economics and Regulation,* pp. 767-797, 2020.

[14] H. J. Kramer and A. P. Cracknell, "An overview of small satellites in remote sensing," *International Journal of Remote Sensing,* vol. 29, no. 15, pp. 4285-4337, 2008.

[15] H. Huang and J. Zhou, "Solar sailing CubeSat attitude control method with satellite as moving mass," *Acta Astronautica,* vol. 159, pp. 331-341, 2019.

[16] F. Sansone *et al.*, "LaserCube optical communication terminal for nano and micro satellites," *Acta Astronautica,* vol. 173, pp. 310-319, 2020.

[17] M. Quanjin, Z. Zhenggang, M. Rejab, M. Idris, B. Zhang, and M. Abdullah, "Design and fabrication of the portable artwork preservative device (PAPD)," *Journal of Modern Manufacturing Systems and Technology,* vol. 3, pp. 31-38, 2019.

[18] I. Iakubivskyi *et al.*, "Coulomb drag propulsion experiments of ESTCube-2 and FORESAIL-1," *Acta Astronautica,* 2019.

[19] C. Nieto-Peroy and M. R. Emami, "CubeSat mission: From design to operation," *Applied Sciences,* vol. 9, no. 15, p. 3110, 2019.

[20] R. S. Jakhu and J. N. Pelton, "Small Satellites and Large Commercial Satellite Constellations," in *Global Space Governance: An International Study*: Springer, 2017, pp. 357-378.

[21] A. Tokovinin, "Ten years of speckle interferometry at SOAR," *Publications of the Astronomical Society of the Pacific,* vol. 130, no. 985, p. 035002, 2018.

[22] X. Chen and X. Wu, "Model predictive control of cube satellite with magneto-torquers," in *The 2010 IEEE International Conference on Information and Automation*, 2010: IEEE, pp. 997-1002.

[23] Cottini, V., Aslam, S., D'Aversa, E., Glaze, L., Gorius, N., Hewagama, T., ... & Piccioni, G. (2017, September). CUVE-Cubesat UV Experiment: Unveil Venus' UV Absorber with Cubesat UV Mapping Spectrometer. In European Planetary Science Congress 2017, Abstract# EPSC2017-771.

[24] A. R. Tummala and A. Dutta, "An overview of cube-satellite propulsion technologies and trends," *Aerospace,* vol. 4, no. 4, p. 58, 2017.

[25] A. Tokovinin, M. E. Everett, E. P. Horch, G. Torres, and D. W. Latham, "Speckle observations and orbits of multiple stars," *The Astronomical Journal,* vol. 158, no. 4, p. 167, 2019.

[26] S. Wu, T. Zhao, Y. Gao, and X. Cheng, "Design and implementation of a Cube satellite mission for Antarctic glacier and sea ice observation," *Acta Astronautica,* vol. 139, pp. 313-320, 2017.

[27] W. Xi, S. Du, Y.-C. Wang, and X. Zhang, "A spatiotemporal cube model for analysing satellite image time series: Application to land-cover mapping and change detection," *Remote Sensing of Environment,* vol. 231, p. 111212, 2019.

[28] M. Costa *et al.*, "A low cost, safe, disposable, rapid and self-sustainable paper-based platform for diagnostic testing: lab-on-paper," *Nanotechnology,* vol. 25, no. 9, p. 094006, 2014.

[29] H. de Boissezon and A. Eddy, "Satellite EO for Disasters, Risk, and Security: An Evolving Landscape," *Handbook of Space Security: Policies, Applications and Programs,* pp. 733-757, 2020.

[30] I. F. Akyildiz and A. Kak, "The Internet of Space Things/CubeSats: A ubiquitous cyber-physical system for the connected world," *Computer Networks,* vol. 150, pp. 134-149, 2019.

[31] A. O. Erlank, "Development of CubeStar: a CubeSat-compatible star tracker," Stellenbosch: Stellenbosch University, 2013.

[32] N. Ahmed, *Design Options For Low Cost, Low Power Microsatellite Based SAR*. University of Surrey (United Kingdom), 2012.

[33] A. Poghosyan and A. Golkar, "CubeSat evolution: Analyzing CubeSat capabilities for conducting science missions," *Progress in Aerospace Sciences,* vol. 88, pp. 59-83, 2017.

[34] R. Sandau, "Small satellite missions," in *Advances in Photogrammetry, remote sensing and spatial information sciences: 2008 ISPRS congress book*, 2008: CRC Press, pp. 119-134.

[35] M. Pastena *et al.*, "Overview of ESA's Earth Observation upcoming small satellites missions," 2020.