The Design for a Space Station's Foldable, Adhesive Crawling CubeSat with Fixed-point Operations

Instructor Name	Title and Position	Detailed Information
Jinxiu Zhang	*Professor*	*School of Aeronautics and Astronautics, Sun Yat-sen University, Guangzhou, Guangdong. Email: zhangjinxiu@mail.sysu.edu.cn*
Jianing Wu	*Associate Professor*	*School of Advanced Manufacturing, Sun Yat-Sen University, Guangzhou, Guangdong. Email: wujn27@mail.sysu.edu.cn*

Team Name	StarStriders Engineers	
Team members	*Siyuan Zhang, Undergraduate student, Sun Yat-sen University, China, +86-13099542851, Shenzhen Campus of Sun Yat-sen University, Shenzhen, Guangdong Province, zhangsy75@mail2.sysu.edu.cn*	
	Junhao Shi , Undergraduate student, Sun Yat-sen University, China, +86-15220242289, Shenzhen Campus of Sun Yat-sen University, Shenzhen, Guangdong Province, shijh25@mail2.sysu.edu.cn	
	Shishuai Wen, Undergraduate student, Sun Yat-sen University, China, +86-15807629598 , Shenzhen Campus of Sun Yat-sen University, Shenzhen, Guangdong Province, wenshsh7@mail2.sysu.edu.cn	
	Zhongjun Peng,Undergraduate student, Sun Yat-sen University, China, +86-14748186104, Shenzhen Campus of Sun Yat-sen University, Shenzhen, Guangdong Province, pengzhj5@mail2.sysu.edu.cn	
	Yuhang Zhang, Undergraduate student, Sun Yat-sen University, China, +86-15314310507, Shenzhen Campus of Sun Yat-sen University, Shenzhen, Guangdong Province, zhangyh378@mail2.sysu.edu.cn	
	Yuquan Zheng, Undergraduate student, Sun Yat-sen University, China, +86-18306690711, Shenzhen Campus of Sun Yat-sen University, Shenzhen, Guangdong Province, zhengyq67@mail2.sysu.edu.cn	
Main Contact info	*Siyuan Zhang*	*+86-13099542851*
	zhangsy75@mail2.sysu.edu.cn	

1. Detail of the projects（Including detail of the design content, key technologies, innovations, etc.）

1.1 Design Motivation

1.1.1 Task Background

The space station is a large-scale manned spacecraft that works in low-earth orbit for a long time. Astronauts live and work in the space station, and conduct various space science experiments. These works have brought many new technologies to mankind, such as the development of space resources. However, due to the harsh space environment, the damage to the space station is huge, so the on-orbit space station must be inspected and repaired for a long time, and its equipment must be replaced to ensure the safety and life of the on-orbit space station. There are currently two space stations in orbit, the International Space Station and the Chinese Space Station(See Fig.1). The International Space Station (ISS - International Space Station) is a modular space station (habitable satellite) located in low Earth orbit, assembled in 1984. This is a multi-national cooperation project, the participating agencies are: NASA (USA), Roscosmos (Russia), Japan Aerospace Exploration Agency (Japan), ESA (Europe) and CASA (Canada). The Chinese space station is also a modular space station in low-Earth orbit and have already been fully assembled in December 2022. Astronauts can perform corresponding space science tasks in the cabin, carry out extravehicular activities, and carry out a series of operations such as necessary extravehicular maintenance, equipment replacement, scientific application payload inspection, and extravehicular space science experiments, so that the space station can It operates normally and reliably in orbit, and carries out high-quality space missions. Both the ISS and the Chinese Space Station play crucial roles in advancing our knowledge of space and enabling the development of technologies for future space exploration. They serve as important stepping stones for humanity's ambitions to explore beyond Earth and establish a sustainable presence in space.

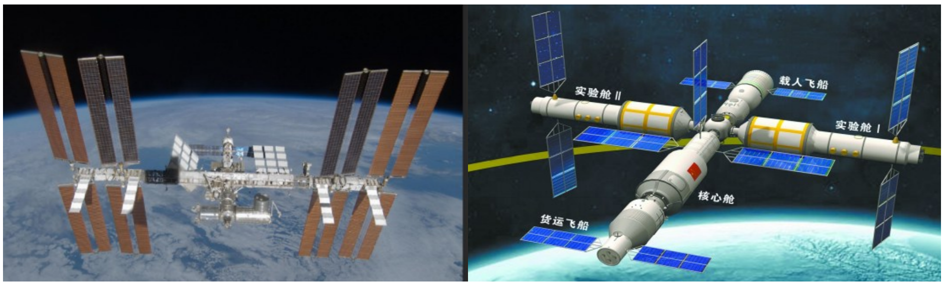


Fig.1 International Space Station(left) and Chinese Space Station(right)

The harsh space environment outside the cabin has caused adverse effects on the space station that has been operating in orbit for a long time. The atmosphere, electromagnetic radiation, low pressure, thermal vacuum, charged particles, and space debris all inevitably cause damage to the surfaces of space stations and facilities. Therefore, it is necessary to monitor and check the status of the external surface and all space science equipment in real time, and to repair and replace the malfunctioning equipment. In order to perform these tasks, the use of robotic arms is necessary. The robotic arm can perform extravehicular status monitoring, assist astronauts in extravehicular activities, check the surface status of the space station, transfer experimental modules, replace parts, monitor and capture visiting spacecraft, and maintain the outer surface of the space station and the equipment on each module. normal state. Robotic arms can also be utilized to remove or reposition space debris that poses a risk to the station. By capturing and manipulating debris, they can help prevent collisions and protect the integrity of the space station.

However, the convex rigid manipulator cannot access every corner of the outer orbital environment of the space station, which limits the efficiency of health inspection and maintenance of related facilities. Based on the high mobility of CubeSats in space, we may be able to find a novel solution to this problem. By equipping CubeSat with multifunctional robotic arms and corresponding equipment, we can build modules for various purposes to meet specific needs in space. Such a design will improve the inspection and maintenance efficiency of all corners of the space station to ensure the normal operation of extravehicular facilities.

A CubeSat is a small satellite used for space science research, consisting of several cube modules with a size of 10cm x 10cm x 10cm. For the record, 1,200 of the 1,350 CubeSats launched have been placed in orbit for various missions. Professor Jordi Puig-Suari from Caltech and Professor Bob Twiggs from Stanford University designed the cubesat paradigm, aiming to enable undergraduates to design, manufacture, test and operate constellation spacecraft by themselves. The first CubeSat was launched in June 2003 by Russia's Eurockot Launch Services. By 2012, about 75 CubeSats of various sizes were in orbit. NASA sponsored the CubeSat Mission Challenge and launched 13 CubeSats from different design teams during 2020-2021. Most of them carry one or two scientific instruments as the main space payload for specific space missions. Launched on September 25, 2015, the STU-2 CubeSat became China's first CubeSat to perform space missions, including tasks such as automatic identification of information exchange between stars. Next, Soaring Star is the world's first 12U CubeSat manufactured and launched by Northwestern Polytechnical University. It conducted the first polarized navigation test in the outer atmosphere and verified the 12U CubeSat deployer for electromagnetic unlocking for the first time(See Fig.2).

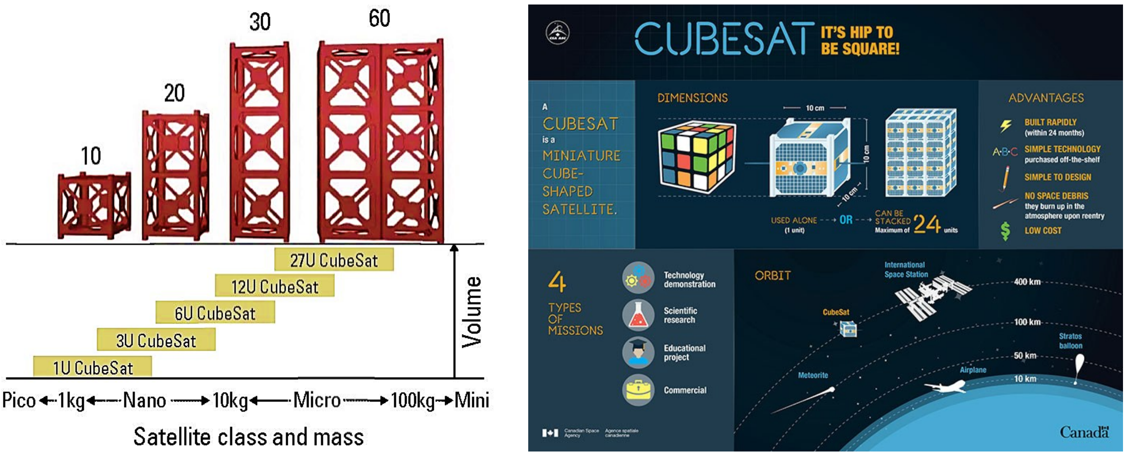


Fig.2 CubeSat Specifications and Scientific Purposes.

1.1.2 Current odstacles

These subsystems work together to enable CubeSats to perform a variety of tasks, operate and transmit data in space. It is worth noting that specific satellite designs may vary, and different missions and applications may require different subsystem configurations and capabilities.

1) However, conventional CubeSats cannot meet specific requirements for outboard inspection and maintenance due to the following reasons:

2) The current CubeSat is extremely compact geometrically, and it only ensures the realization of some basic functions, such as communication or Earth observation[4] in different orbits. This compact design limits the space inside the satellite to accommodate modules for extravehicle operations, such as robotic arms. Traditional CubeSats are more focused on the execution of basic tasks, while extravehicular operations often require greater size and mobility.

3) Some CubeSats may have a collapsible mechanism for tasks such as unfolding when needed or collecting space debris. However, these mechanisms are usually designed and fabricated as rigid structures that lack flexibility. This rigidity limits the satellite's ability to move, making complex extravehicular inspections and operations impossible for CubeSats. More flexible, adjustable and deformable mechanisms are needed to realize the free movement of satellites in the extravehicular environment.

4) Combining soft robots and CubeSats is a feasible way to accomplish complex tasks outside the cabin. However, there are still some challenges in terms of design theory, fabrication methods, and control strategies. The design of soft robots needs to consider how to achieve sufficient maneuverability and flexibility in a limited space to meet the needs of extravehicular operations. Manufacturing and deploying soft robots also requires consideration of how to achieve reliability and durability in the space environment. In addition, the cooperative control and manipulation strategies of soft robots and CubeSats need further research and development to ensure that they can effectively complete complex tasks.

Overall, although CubeSats currently have some limitations, the combination of biomimetic technology and soft robotics technology can provide new solutions for extravehicular inspection and operation. Further research and development will help to overcome existing technological limitations and achieve more flexible and operationally capable CubeSat systems. To overcome the above obstacles, we propose a new design idea that combines biologically inspired design, computer-based control algorithms and multibody dynamics(See Fig.3).

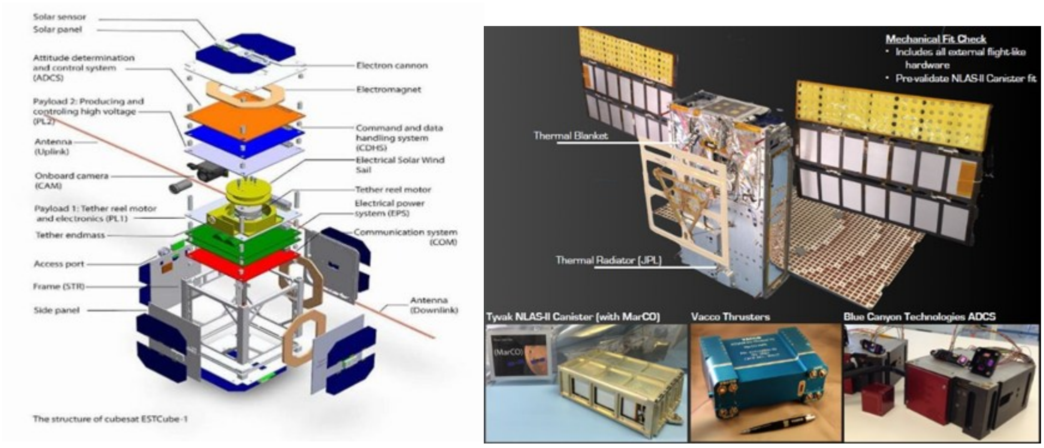


Fig.3 Structure and Configuration of a Common CubeSat

1.1.3 Biomimetic design

In recent years, scientists have been inspired by the structure and behavior of biological limbs, and proposed a variety of new robot design ideas. Against this background, we propose a three-layer framework for the conceptual design of CubeSats. First, the first level involves the anatomical study of the behavior of biological structures, with the aim of gaining a deep understanding of how they work. Second, the second tier includes the development of mathematical and physical models to build accurate simulation and forecasting tools. Finally, the third layer is based on bio-inspired cubesat structures, translating these research results into practical robot designs. With this fluid framework, we are better able to apply biological principles to robotics and enable innovative CubeSat designs.

As bionic technology becomes more and more widely used, on-orbit cube satellites based on bionic technology will have more practical advantages in space, and the limb structure and behavior of specific organisms can provide powerful structural or technical support for specific tasks . According to the special environment and specific tasks outside the space station, combined with the research progress and application fields of cube satellites at home and abroad, we propose the general concept of micro-nano cube satellites for multi-functional space stations outside the space station based on bionic mechanical legs.

In the special environment outside the space station, multifunctional CubeSats outside the space station based on bionic mechanical legs can have practical advantages. By borrowing the structure and behavior of biological limbs, such satellites can be adapted to different mission requirements, such as moving, manipulating and sampling complex surfaces, and interacting with other space devices. This multifunctional satellite concept can be realized at the micro-nano scale, further improving the application and performance of robotics in space.

1.2 Conceptual design

We propose a design concept for a cubesat that combines bionics and mechanical design across disciplines. This design aims to meet a series of on-orbit operation requirements such as stable and orderly operation of the space station in the space environment, onboard maintenance, equipment replacement, scientific application load detection and airborne scientific experiments. In order to achieve these complex tasks, the cubesat needs to have stable and flexible mobility. At the same time, in order to ensure reliable work on the surface of the space station, it needs to have a large contact area with the outer shell of the space station.

Based on the above requirements, we designed the schematic diagram of the cubesat based on the spider's mimic foldable structure. It consists of a foldable mechanical claw, four foldable mechanical legs, a detection device and a main body. This 10U cubesat has multiple sub-modules, which can realize multiple tasks such as stable movement on the surface of the space station, surface detection and removal of space debris on the shell of the cabin, and repair of damaged parts.

According to the complexity of the space environment and extravehicular tasks, we have completed the modular design of the main structure and motion mechanism, mechanical claw operation module, detection module and basic service module according to the design principle diagram(See Fig.4).

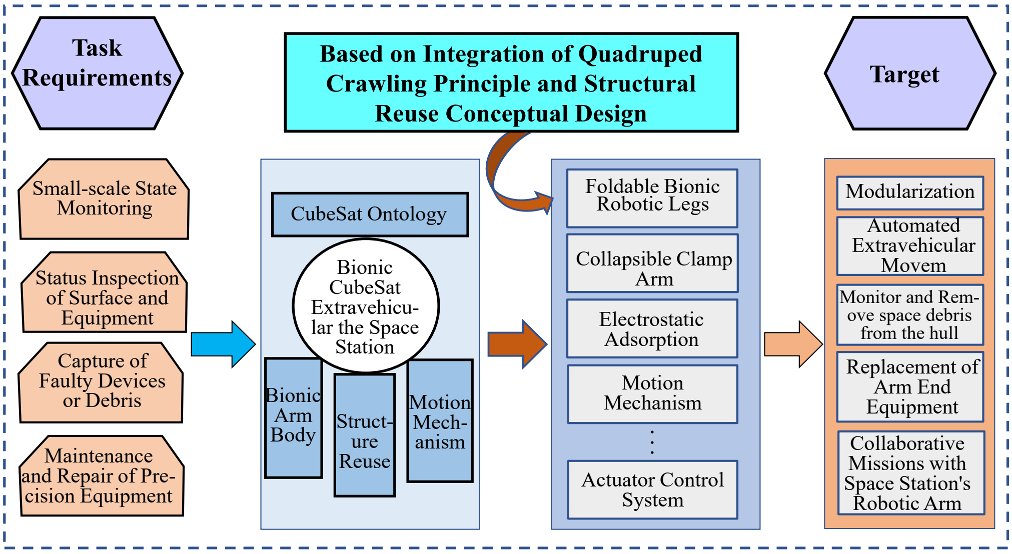


Fig.4 Chart of design principles

In addition, the entire CubeSat can be folded and expanded. The folded state adopts the idea of structural reuse to ensure the stability of the structure; the unfolded state adopts a four-legged smooth round bottom structure, and uses electrostatic adsorption technology to closely connect with the outer surface of the space station to efficiently and reliably perform the established tasks.

We listed the key technologies in our CubeSat design as:

1) Integration technology of CubeSat body and payload

Due to the environmental complexity of space station extravehicular missions, extremely high requirements are placed on the structure and payload of CubeSats. Conventional satellites usually use a common satellite streamlined platform combined with different payloads to meet various space mission requirements. However, this design method will make the design of the payload and the operating system mechanism more complicated, and the overall integrated mass will be relatively large, which is not suitable for the overall design of the miniature CubeSat.

Therefore, our CubeSat adopts the design concept of integrating the main body, load and motion structure. The folding design is realized by combining the kinematic mechanism (mechanical claw and mechanical leg) with the main structure. This integrated design not only makes the overall structure simpler and saves space, but also ensures the stability of the entire structure.

This design approach provides multiple advantages for CubeSats. First, by fusing the kinematic mechanism with the main structure, the interfaces and connections between modules are reduced, reducing the risk of failure and damage. Secondly, the folding design makes the CubeSat more convenient during transportation and deployment, and takes up less space. In addition, the integrated design also improves the overall structural strength and stability, enabling the CubeSat to perform tasks reliably in complex extravehicular environments.

To sum up, our CubeSat design adopts the design idea of integrating the main body, load and motion structure, and realizes a simple, space-saving and stable overall design by combining the folding motion mechanism with the main structure. This design approach provides a solution to complex extravehicular mission requirements.

2) Electrostatic attachement techniques

The electrostatic adsorption structure enables the CubeSat to adhere firmly on surfaces with varying shapes and roughnesses by increasing the electrostatically controlled adhesion(See Fig.5). Typically, an electrode plate consists of at least two sets of independent electrodes with different potentials. When the positive charge on the adjacent electrode is switched to negative charge, the electric field generates an opposite charge on the outer surface of the cabin, thereby achieving electrostatic adhesion between the electrode plate and the outer surface of the cabin. Crawling robots based on electrostatic adhesion properties can adapt to various surfaces and have a high degree of adaptability.[1]

Therefore, when the CubeSat is attached to the outer surface of the cabin, electrostatic adsorption can ensure the safety of the CubeSat and enable slow movement on the outer surface of the cabin, while maintaining stability in the folded state. The electrostatic adsorption structure enables the CubeSat to overcome the irregular shape and roughness of the outer surface and provide sufficient adhesion. This design allows the cubesat to perform its mission stably and to fold and unfold when needed.

In summary, the electrostatic adsorption structure enables the CubeSat to be safely attached to the outer surface of the cabin through electrostatically controlled adhesion, and to maintain stability in the moving and folding states. This design provides significant functionality and adaptability for the CubeSat to operate in an extravehicular environment.

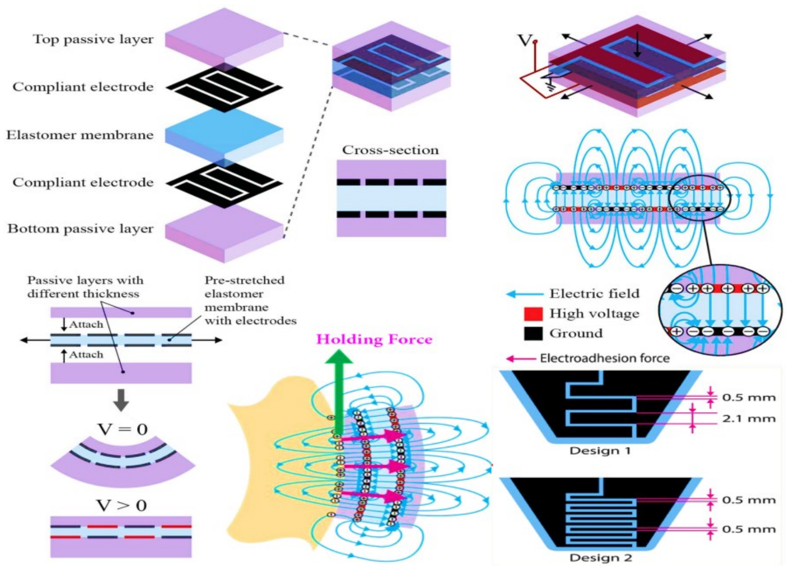


Fig.5 Principle of Electrostatic Adsorption

3) Patrol and Inspection Technology

In space, the most common problem encountered is the inspection problem. So far, the inspections have been completed by astronauts. Including the repair of damaged parts and the replacement of parts, for astronauts, every mission tests physical strength and willpower. At the same time, the life safety of astronauts is not fully guaranteed, and the radiation that can be seen everywhere is one of the impacts. But some of the tasks are necessary but the amount of work is relatively small. For these tasks, they can be completed by the inspection robot of the space station.

The inspection robot can adopt two task modes: inside the cabin-outside the cabin and outside the cabin-outside the cabin.

a) Inboard - outboard:

Astronauts replace the ends with different functions and put them on the outer surface of the space station to perform tasks with different functions. The CubeSat needs to be taken back into the cabin from the hatch every time.

b) Out of the cabin - out of the cabin:

For the execution of a specific function in the inspection, the function is single, but it does not need to be retrieved into the cabin to replace the end. It can be placed outside the cabin.

The biggest advantage of patrol inspection is to minimize the harm caused by space debris. When no astronauts are involved, it is cheap, safe and effective to only use the inspection system robot to perform early warning, removal and repair after the discovery of space debris. Combined with a mature visual perception system, it can accurately find the location of space debris and provide strong technical support for the inspection function.

4) Dexterous Manipulative Technique

CubeSat needs to complete many complex tasks on the surface of the outer module of the space station, including simultaneously moving and checking the status of the outer module surface and equipment, capturing faulty equipment, and removing space junk. Therefore, the coordinated operation of the detection device, the mechanical claw and the motion mechanism is crucial, which can ensure the real-time monitoring and inspection of the entire area by the CubeSat, thereby ensuring the safety of the space station and the accurate and stable operation of the mission.

Through the detection device, CubeSat can collect relevant data on the surface of the outer cabin and equipment, such as temperature, pressure, vibration, etc. This data can provide critical information for assessing the condition of the external environment and the health of the equipment. At the same time, as an operating tool, the mechanical claw can capture malfunctioning equipment or space junk for repair or cleanup.

The function of the motion mechanism is to enable the CubeSat to move flexibly on the outer surface of the cabin and locate it to the position that needs to be inspected or operated. Through the precise control of the motion mechanism, the CubeSat can achieve highly precise positioning and movement on the outer surface of the cabin to meet various mission requirements.

The coordinated operation of the three ensures the versatility and adaptability of the CubeSat. CubeSat can instantly obtain information, locate targets and execute tasks to ensure the safety of the space station and achieve accurate and stable operation of tasks.

In short, the CubeSat can monitor, inspect and operate in real time on the surface of the outer cabin of the space station through the coordinated operation of the detection device, mechanical claws and motion mechanisms. This collaborative work ensures that the CubeSat monitors and maintains the entire area, thus ensuring the safety of the space station and the smooth execution of tasks.

5) Intelligent detection technology

The space environment in which the space station is located is extremely harsh and dangerous. CubeSat can monitor the status of external surfaces and equipment in real time on a small scale, and compare the captured external surface conditions with the local data details of each position on the space station, so that it can monitor the conditions of each position of the space station more quickly.

In order to achieve this goal, we built a model library, learned and trained with machine learning algorithms, and obtained images and state data of normal state data outside the cabin. The monitoring organization transmits the monitoring data to the database for comparison in real time, and feeds back the corresponding status information at any time, so as to ensure that the problems of small-area equipment outside the cabin can be discovered and dealt with in time, and the safety of the surface and equipment outside the cabin can be ensured.

Through this mechanism, we can form a situational awareness of surveillance awareness, and conduct real-time comparative learning and rapid prediction of problems found on the outer surface of the space capsule. Using smart technology, we are able to lead the scientific study of the space station's orbital safety, ensuring that timely measures are taken to solve problems that may arise.[3]

To sum up, CubeSat can quickly monitor the status of each position of the space station through small-scale real-time monitoring of the status of the outer surface and equipment, and compare and learn with the data in the model library. This monitoring mechanism uses intelligent technology to provide timely feedback and predictions, thereby ensuring the safety of scientific research on the space station in orbit.

1.3 Design Paradiam

1.3.1 Overall Design and Layout

As the cornerstone of space exploration, the space station's safety and equipment integrity are of paramount importance. In order to explore in the complex and harsh external environment, it is an excellent choice to design an external cube satellite with a multifunctional bionic arm. This type of CubeSat is capable of performing multiple tasks such as moving on the outer surface of the vehicle, monitoring complex small-scale conditions, inspecting the condition of surfaces and equipment, and capturing malfunctioning equipment and space junk. The following is a schematic diagram of the overall structure of a CubeSat(See Fig.6)

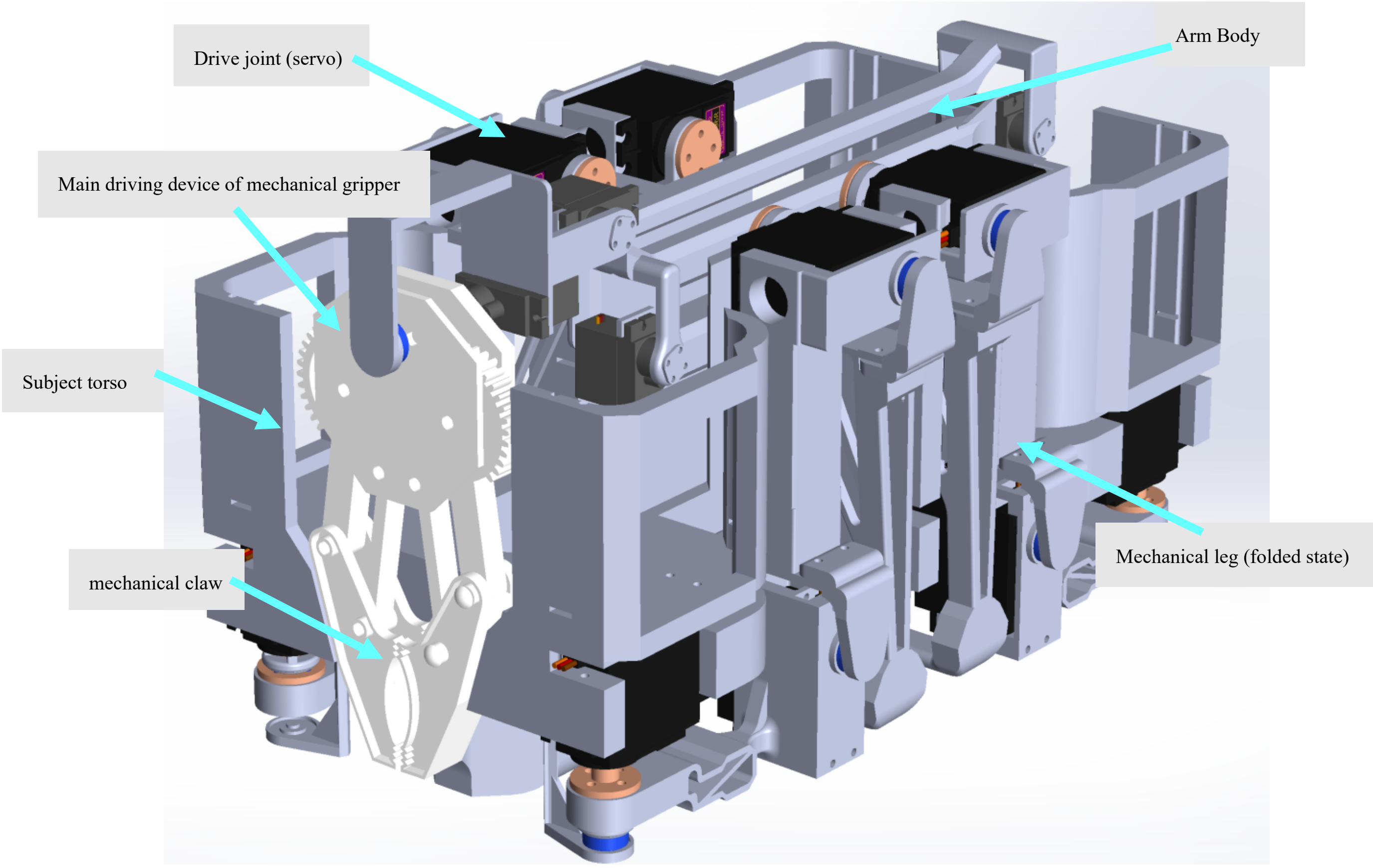


Fig.6 The overall structure in the folded state, including the retraction of the gripper and arm and the legs

The design incorporates a multifunctional robotic arm with flexible locomotion and multiple functions. There are many forms of the clamping mechanism at the front end of the mechanical arm, each corresponding to a different operating environment. When you need to hold objects, use the jaw end; when you need to drill holes and remove bolts and nuts, you will use the drill multi-function end. It is sufficient to replace a specific end for a specific scene. Consider specific circumstances. Through this robotic arm, the CubeSat can move freely on the outer surface of the cabin and reach the position that needs to be inspected or operated. At the same time, it can also monitor complex and small-scale conditions, including the inspection of surface conditions and equipment conditions. In addition, this robotic arm also has the ability to capture malfunctioning equipment and space junk for repair or clean-up work. This extravehicular CubeSat design with a multifunctional robotic arm provides highly flexible and diverse operational capabilities that can be adapted to different mission requirements.

Through such a design, CubeSat can perform tasks in complex external environments, ensure the safety of the space station and its equipment, and provide important support for space exploration.

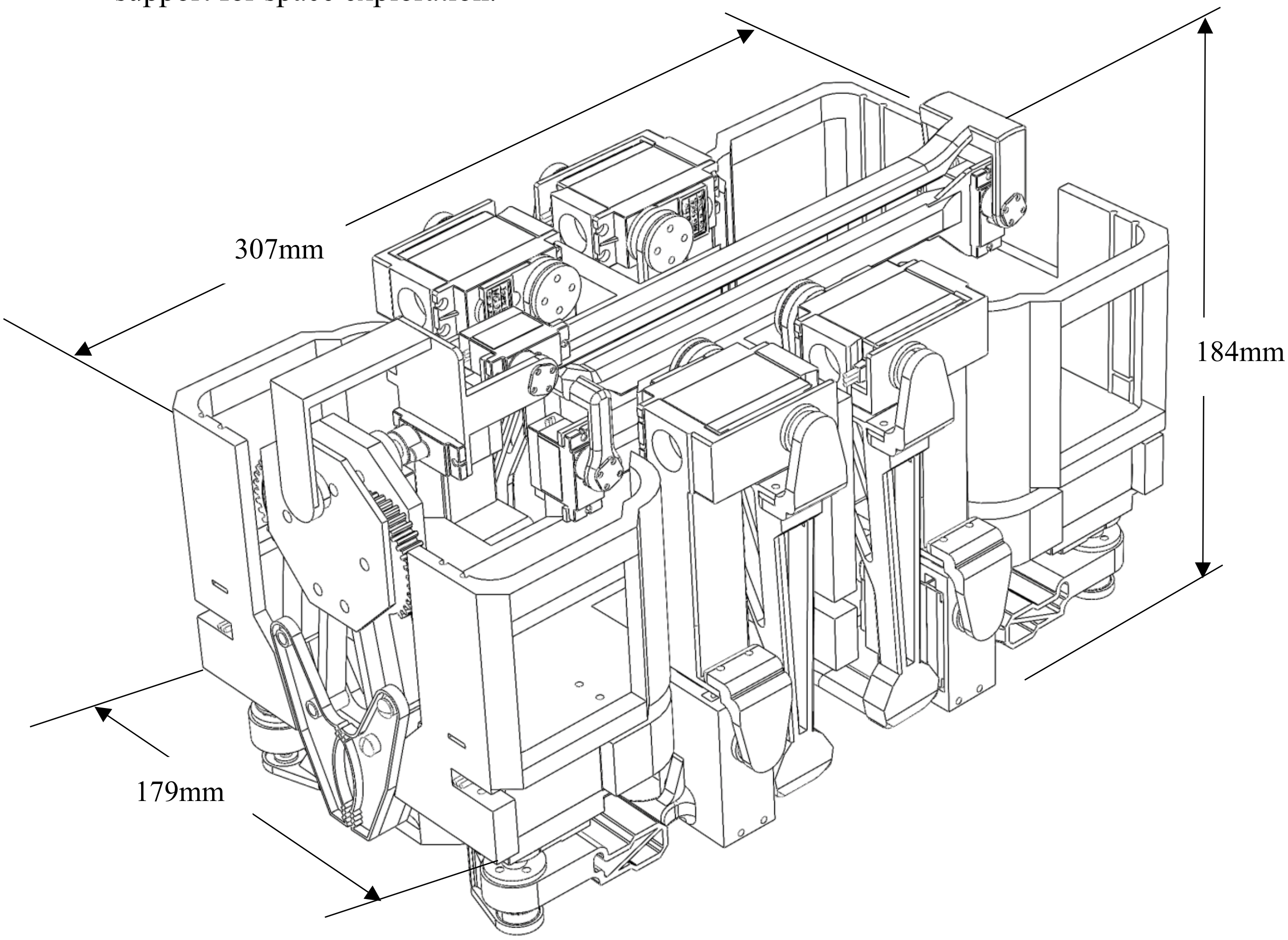


Fig.7 The Size of CubeSat

The schematics of design for the CubeSat are shown in Fig. 7 (units： mm).

1.3.2 Main Functions and Index

As a spacecraft, the outer cabin CubeSat has a number of main functions, not only can it move on the outer surface of the space capsule, but also can perform fine and small-scale status monitoring. It is able to inspect the condition of surfaces and equipment, and also has the ability to capture malfunctioning equipment. In addition, this CubeSat also has the ability to repair delicate equipment. The mobility of CubeSats is especially important when performing exoplanet activities. Its own design allows it to move stably across surfaces in a zero-gravity environment, allowing it to remain efficient while performing tasks. Its fine and small-scale status monitoring function is also particularly important, which allows us to obtain a large amount of real-time data to evaluate and control its performance.

CubeSats can also perform detailed inspections of the condition of external surfaces and equipment, as well as capture malfunctioning equipment. These features enable CubeSat to identify and deal with potential problems in a timely manner, thereby improving the reliability of mission execution.

CubeSats also have the ability to repair delicate equipment, which is critical to maintaining and extending the life of the spacecraft.

These are the main functions of CubeSat, and more specific performance indicators are shown in Table 1. These metrics play a key role in understanding the capabilities and performance of CubeSats.

<table>
<tr><th>Name</th><th colspan="2">Index Parameter</th></tr>
<tr><td>Mass of CubeSat</td><td colspan="2">20kg</td></tr>
<tr><td>Structural Components</td><td colspan="2">The Multifunctional Bionic Robotic Arm, The Mechanical Claw, The Spider-inspired Mimetic Folding Body, Integrated Design of Body, Payload and Motion Structure, The Mechanical Legs, Electrostatic Adsorption Movement Mechanism、Actuator Control System、Mobile Mechanism Control System、CubeSat Signal Panel、Battery Pack、Power Panel and Power System、Solar Panels、Instruction and Data Acquisition System、CubeSat Framework</td></tr>
<tr><td>Size of CubeSat</td><td>Size of the Body</td><td>Length :307mm
Width :179mm
Height :184mm</td></tr>
<tr><td>Life Span</td><td colspan="2">3 year</td></tr>
</table>

Table.1 Main Indicators of The CubeSat

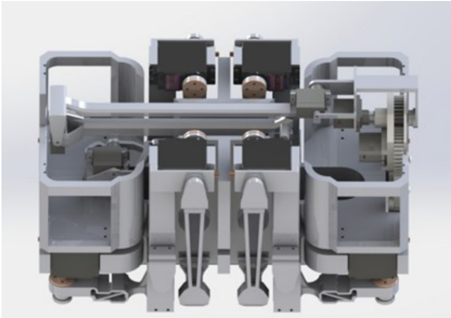
1.3.3 Structure and Movement Mechanism Module

The grabbing and moving mechanism module mainly includes the gripper mechanism of the manipulator and the quadruped mechanism. It adopts the integration of the body and the load and the electrostatic adsorption technology to ensure the stability of the CubeSat in the folded state and the unfolded state. The combination of the gripper mechanism of the robotic arm and the main body can not only complete the grabbing task, but also serve as a bearing mechanism to ensure the overall stability of the cubesat.

In the folded state, the four mechanical legs can be connected to the main body and itself through electrostatic adsorption, preventing the internal load from being affected by the external environment. This design ensures the stability and reliability of the CubeSat in the folded state. When the cubesat is switched to the unfolded state, the motor-driven folding mechanical leg structure gradually unfolds, and the feet are strongly adsorbed on the outer surface of the cabin to ensure that the cubesat will not break away from the outer surface of the cabin during the working process.

When the CubeSat is performing missions outside the cabin, it can detect the surrounding environment and move to a designated location to check the condition of the surface. At the same time, when encountering space junk, the robotic arm can be quickly deployed to remove the trash. In this way, the CubeSat can perform different tasks in different states, increasing its functionality and flexibility.

In general, the grasping and moving mechanism module adopts the gripper mechanism of the manipulator and the quadruped mechanism, which combines the integrated design of the body and load and electrostatic adsorption technology to ensure the stability of the cubesat in the folded and unfolded state. This design enables the cubesat to perform a variety of tasks outside the cabin, and has the ability to detect the environment, move the location and remove space junk. The functionality of the CubeSat has thus been enhanced.



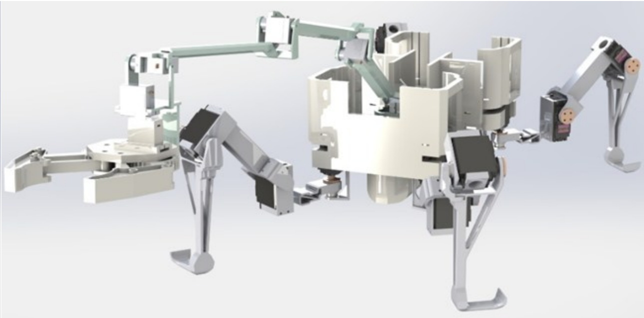


Fig.8 Folded State

Fig.9 Unfolded State

In the folded state(See Fig.8) and unfolded(See Fig.9), the quadruped mechanism and the mechanical claw mechanism are fixed by electrostatic force, so that the various parts of the CubeSat are closely connected and maintain the electrostatic strength during adsorption. This design ensures that when the CubeSat is on the outer surface of the cabin, whether it is folded or unfolded, it can maintain the stability of the structure and maintain the adsorption to the outer surface of the cabin.

Specifically, the various parts of the quadruped mechanism and the gripper mechanism are tightly connected by electrostatic force in the folded state. This means that they are close together and in turn maintain the necessary electrostatic strength for adsorption. Such a design enables the CubeSat to remain stable in the folded state, and will not be detached from the outer surface of the cabin due to the influence of the external environment.

The solar panels come into play when the CubeSat module is on the outer surface of the space station. Solar panels will provide the power needed to conserve energy from the CubeSat's internal battery pack. This ensures that the CubeSat has sufficient electrostatic forces in both folded and unfolded states to maintain the stability of the structure and maintain its attachment to the outer surface of the cabin.

Through such a design, the CubeSat can remain stable in the external environment and can perform tasks in different states. The application of electrostatic force ensures the tight connection between the CubeSat and the outer surface of the cabin, while the operation of the solar panels provides the required power to ensure the long-lasting stability of the CubeSat.

Traditional veneer adhesion methods mainly use pneumatic or magnetic principles. Pneumatic pressure is a common method, but it can cause the adhesion mechanism to fail for any void location in a vacuum environment, which limits its ability to work only on smooth, non-porous surfaces. On the other hand, magnetic adhesion can be achieved with a relatively simple structure and can generate high adhesive force. However, magnetic adhesion is only applicable to ferromagnetic surfaces, and its applications are severely limited. Electrostatic adsorption is a new type of adhesion technology, which has the advantages of light structure, low energy consumption, and the ability to adapt to different surfaces. Electrostatic adsorption technology generates an induced electrostatic charge by connecting a power source to a specific electrode panel. When adjacent electrodes generate alternating positive and negative charges, the electric field generates opposite charges on the wall surface, thereby achieving electrostatic adhesion between the electrode panel and the wall surface. In recent years, scientists have conducted extensive research on wall-climbing robots based on electrostatic adhesion mechanisms, and experiments have proved that wall-climbing robots with electrostatic adhesion properties have higher flexibility and practicability.

Compared with pneumatic and magnetic adhesion methods, electrostatic adsorption has wider adaptability and application potential. It adheres to a variety of surfaces regardless of smoothness or material. The electrostatic adsorption technology has a simple structure, low energy consumption, and can be implemented lightly. This makes it a great potential for development in robotics and other applications. Through continuous in-depth research and experimentation, scientists are working to improve and optimize technologies based on electrostatic adhesion mechanisms. This will open up more possibilities for future robot design and practical applications, enabling robots to perform tasks on various surfaces more flexibly and practically.

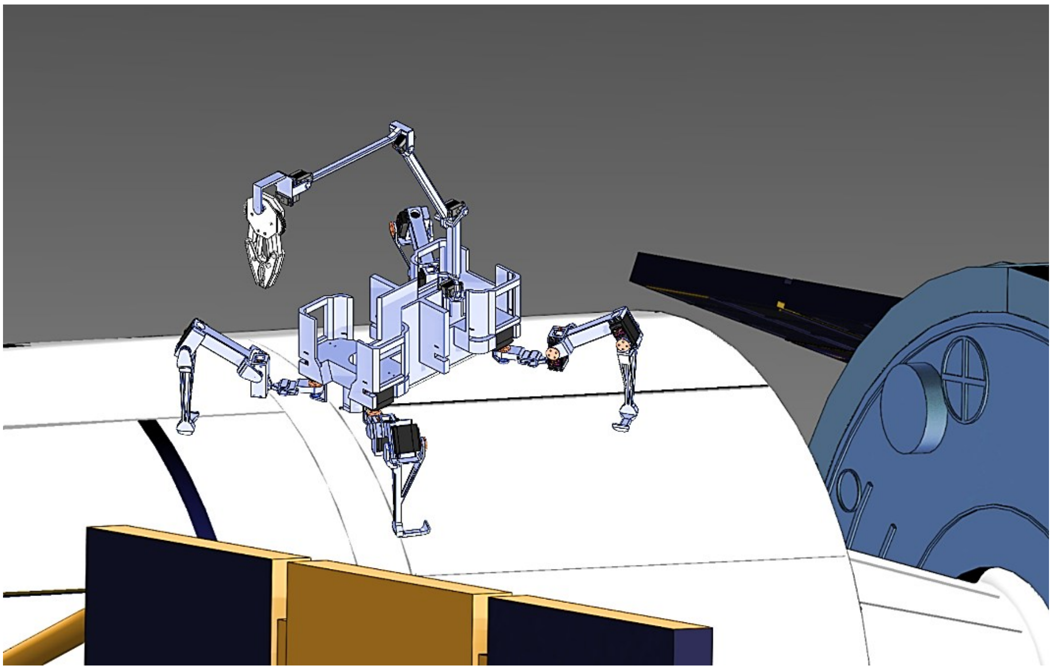


Fig.10 An unfolded CubeSat stuck to the surface of the space station

The CubeSat is unfolded and adsorbed to walk on the outer surface of the cabin, which can be similar to the walking of a spider(See Fig.10).

1.3.4 Dexterous operation module (manipulator arm and gripper)

As these CubeSats increase in sophistication, the application of dexterous operation modules within them is becoming increasingly vital.

The dexterous operation module is a product of the intersection between robotics, control theory, and artificial intelligence. It epitomizes the pinnacle of human ingenuity and innovation in the quest for efficient, precise, and versatile tools to perform complex tasks. At its core, it consists of two primary components: a manipulator arm, and a gripper.

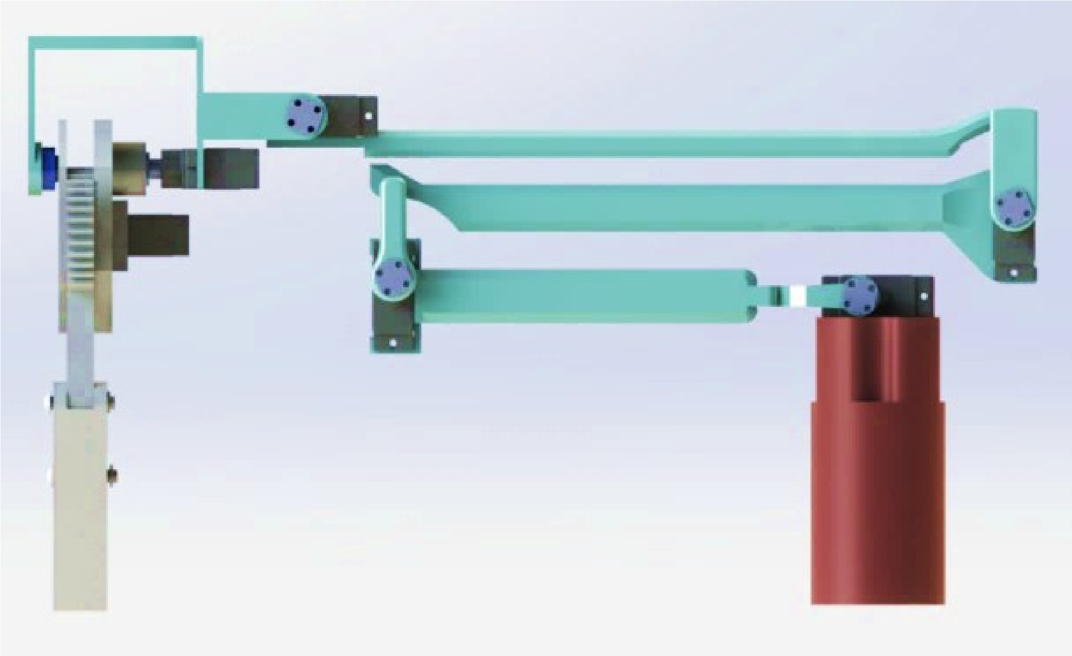


Fig.11 Manipulator Arm

The manipulator arm(See Fig.11) is the "muscle" of the dexterous operation module. It's responsible for moving the end-effector, usually the gripper, to the desired position and orientation. It is an intricate, multi-segmented structure that closely mirrors the function of a human arm. The manipulator arm consists of several interconnected sections called links, joined together by joints. These joints may be either revolute (rotational) or prismatic (linear), and provide the arm with its degrees of freedom, thereby enabling motion in the three-dimensional workspace.

Each joint is driven by an actuator, often a motor, which provides the requisite force or torque for movement. The combination of multiple joints and links gives the arm its unique dexterity, allowing it to move, extend, retract, rotate, and position the gripper with high precision.

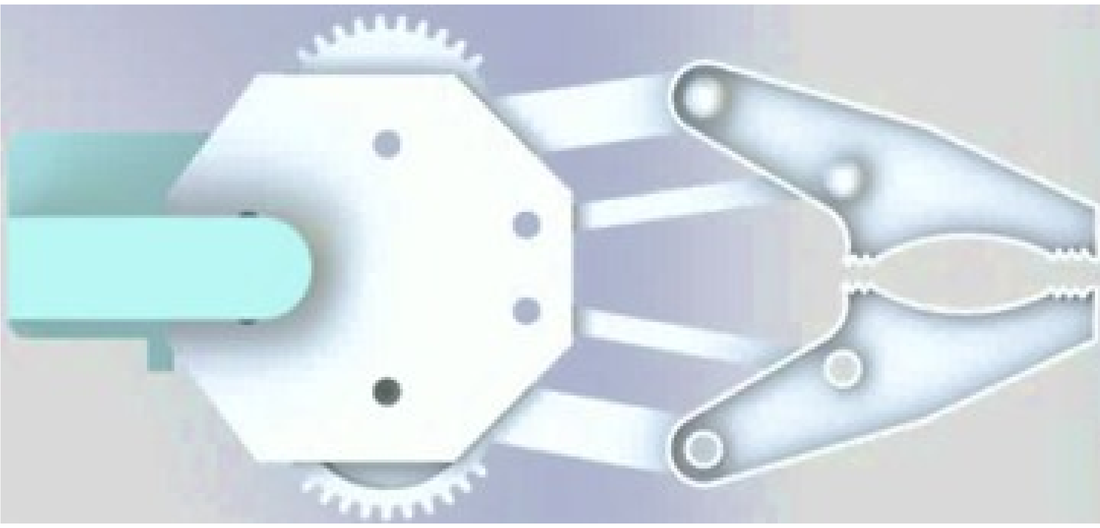


Fig.12 Gripper

Attached to the end of the manipulator arm, the gripper(See Fig.12) functions as the "hand" of the dexterous operation module. Its primary role is to interact with the environment, often by picking up, holding, and releasing objects. It is the critical component that gives a robotic system the ability to influence its surroundings physically.

There are many types of grippers, each tailored for specific applications. The simplest type is the two-fingered (or dual-jawed) gripper, reminiscent of a pair of tongs. This type is best suited for picking up and handling a broad range of shapes and sizes. More complex grippers may have multiple fingers with several joints each, allowing for more sophisticated and delicate operations, akin to the human hand.[2]

Given their size and weight constraints, CubeSats require highly miniaturized yet robust and functional manipulator arms and grippers. These components enable CubeSats to interact with their environment in a multitude of ways, augmenting their capability beyond simple observation.

A dexterous operation module, consisting of a miniaturized manipulator arm and gripper, allows a CubeSat to perform intricate tasks in space. It could be used for active debris removal, where the CubeSat identifies, approaches, and secures space debris before safely deorbiting it. Additionally, these modules could be used for on-orbit servicing missions, such as repairing or refueling other satellites, or even assembling structures in space.

For CubeSats engaged in scientific missions, a dexterous operation module can be indispensable.

To function effectively in the harsh and unpredictable environment of space, the manipulator arm and gripper need to be highly robust and reliable. They must operate under extreme temperatures, resist radiation, and perform tasks with a high degree of precision. This requires advanced materials, innovative engineering, and sophisticated control algorithms.

The use of artificial intelligence and machine learning is also an important consideration for the application of dexterous operation modules in CubeSats. Given the communication latency and limited bandwidth between Earth and space, these modules need a high degree of autonomy. They must be capable of making real-time decisions, adapt to unexpected situations, and learn from their experiences. This is where modern AI technologies can play a significant role.

1.4 Task procedures

According to the structure and mission characteristics of the CubeSat, the CubeSat is in an unfolded state during the execution of the mission. During the process from inside the cabin to outside the cabin, the CubeSat uses a mechanical arm to keep itself stable. At the same time, the quadruped mechanism acts as the outer frame of the load to ensure the stability of the CubeSat structure and the safety of the equipment.

Once out of the cabin, the control system of the quadruped mechanism activates the electrostatic adsorption system. The various parts of the mechanical legs are gradually unfolded, and the feet are attracted to the outer surface of the cabin by electrostatic force. Once the CubeSat is stabilized, it will be able to move slowly outside the cabin to perform associated extravehicular missions. The figure below shows the specific task status(See Fig.13).

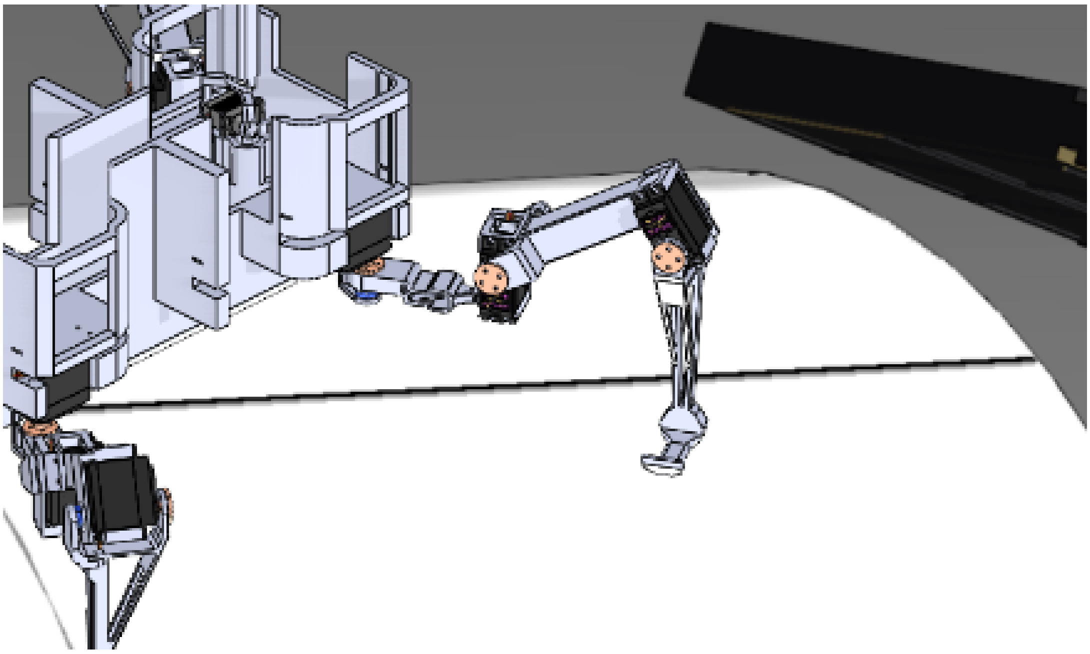


Fig.13 Unfolded mechanical legs in working condition

When performing missions outside the cabin, the CubeSat's robotic arm can be used to manipulate and manipulate objects while keeping the CubeSat stable. The quadruped mechanism provides a good support frame to ensure the stability and reliability of the cubesat on the outer surface of the cabin. Electrostatic adsorption technology generates adhesion between the feet of the CubeSat and the outer surface of the cabin, which ensures the adhesion and mobility of the CubeSat.

Through this structure and operation mode, CubeSat can effectively perform tasks outside the cabin and complete the required extravehicular activities. This deployment mode allows the CubeSat to take full advantage of the capabilities of its robotic arm and quadruped for successful extravehicular missions.

1.5 Innovations

1.5.1 Compact Design

The design motivation of the CubeSat has guided us to integrate its main body with the payloads. The merging of these two crucial elements results in a CubeSat that embodies the principles of compactness, lightweight construction, and cost-efficiency.

The CubeSat's design philosophy, at its heart, is focused on making space technology more accessible and affordable. This drove us to combine the CubeSat's main structure and its payloads into a single entity. This integrated design approach not only simplifies assembly but also maximizes space utilization, leading to a significantly more compact form.

This compactness is integral to the CubeSat's lightweight structure. By reducing the overall volume and meticulously designing each component, we've managed to create a satellite that is not just compact but also lightweight. This is paramount, as every gram matters when launching objects into space, and a reduction in weight can translate into substantial cost savings in launch expenses.

Moreover, the streamlined design of the CubeSat also leads to lower costs. By integrating the main body and payloads, the need for additional support structures or interfaces is eliminated, reducing both the material costs and the time taken for assembly. Consequently, this design approach makes CubeSats an affordable option for various space research and commercial applications.

Thus, the design motivation of the CubeSat has inspired an innovative approach that merges the main body and payloads, resulting in a spacecraft that is not just compact and lightweight, but also cost-effective. This optimization of design elements embodies the future of efficient, accessible, and affordable space exploration technology.

1.5.2 The Bold Proposition of the Folding Concept

Given the constraints of the limited interior space of CubeSats, we are introducing a novel design approach for legged robots. This approach exploits the concept of space compression by incorporating foldable mechanical legs.

Conventional quadruped spider robots are usually of considerable size, especially when all four legs are extended. Even when the legs are folded, their total volume is still large. This characteristic posed a challenge when trying to fit these robots into the confined interior space of a CubeSat.

To overcome this challenge, our proposed design model introduces a unique solution. We ensured that the four legs of the spider robot fold together, which significantly reduces the overall size. This folding mechanism has been carefully designed to allow the legs to be fully retracted into the body of the robot when not in use.

When folded, the entire robot blends seamlessly into the body, forming a cuboid shape. This design fits perfectly with the CubeSat's cubic structure, optimizing the use of internal space while ensuring protection of the robotic components. At the same time, folding into the cube shape will significantly improve the rigidity and stability of the CubeSat body when it is not working.

When needed, the robot can spread its legs, transforming from a compact cuboid form to the typical shape of a fully functional quadruped spider robot. This transformation enables the robot to perform complex tasks that require stability and maneuverability, characteristics provided by its quadruped structure.

Through this innovative design paradigm, we not only optimized the space inside the CubeSat, but also ensured the capabilities and functionality of the embedded spider robot, providing a solution that truly blends form and function.

1.6 Future Work

In the next work plan, we will conduct an in-depth discussion and refinement of the overall design concept of the CubeSat, and focus on optimizing its overall structure in all aspects. We will specifically focus on the mechanical legs of the imitation spider legs and the mechanical claws of the mechanical arm, and strive to improve and upgrade their functions and performances to make the CubeSat perform better when performing tasks.

When optimizing the spider-like mechanical leg, we will investigate how to improve its flexibility, stability and load capacity. This may include improving the joint design and selecting more suitable materials to make the mechanical legs better adapt to various surfaces and better meet the needs of movement and manipulation.

When optimizing the gripper of the robotic arm, we will pay special attention to improving its gripping ability, dexterity and precision. We may modify the design of the mechanical claw, strengthen the force transmission mechanism, and introduce the latest perception technology and control system, so that the mechanical claw can more accurately locate and grasp the target object, and better adapt to various operating tasks.

Through these in-depth optimizations and improvements, we expect to transform CubeSat from the design concept stage into a concrete and executable solution. Our goal is to provide a cubesat design that can provide security in the outer cabin of the space station, complete complex tasks, and effectively respond to various environmental challenges in the outer cabin.

Looking forward to future work, we hope that through meticulous design and continuous improvement, CubeSat can be built into a reliable and efficient robotic system to provide stronger support and protection for the extravehicular operations of the space station.

1.7 Acknowledge

How time flies. During the intense and fruitful competition, we received selfless care and guidance from the teachers. Professor Jinxiu Zhang and Professor Jianing Wu, with their rigorous and realistic academic spirit, deeply imprinted professional knowledge, and dedicated work attitude, have deeply influenced us and inspired our thinking.

Professor Zhang has profound attainments in the aerospace field, and his professional knowledge and perspective can always bring us the latest design concepts and

breakthrough ideas. Under his guidance, we have grown continuously, improved our design concept and practical ability, and benefited us a lot.

Professor Wu's in-depth research in the field of bionics is the source and driving force for our continuous innovation. His teachings inspire new understandings of problems and drive us to be more innovative in problem solving.

Here, we would like to express our deepest gratitude to Professor Zhang and Professor Wu, whose teaching and guidance enabled us to achieve great results in this competition. We will keep in mind their careful teachings and continue to work hard to achieve higher achievements.

We would like to express our deep gratitude to the organizers for their hard work and selfless dedication to this competition. Their careful organization and thorough preparation ensured the smooth running of the competition, which also provided an excellent platform to showcase our skills and talents.

In order to help my team members gain a deeper understanding of the specific content and goals of the competition, I worked hard to organize and hold an in-depth briefing. In this meeting, I explained the rules of the game, goals and our strategies in detail to ensure that every team member has a clear understanding of our goals.

I would like to express my deepest gratitude to our team who work around the clock and whose hard work and dedication make our team stronger. For the success of the team, they are willing to sacrifice their rest time. Even under the pressure of heavy coursework, they always maintain enthusiasm and focus.

At the same time, I would also like to thank every team member. Under the pressure of study and competition, they chose to give up the right to rest and devote themselves to the competition wholeheartedly. I am deeply impressed by their perseverance and dedication.

Words are few, believe it to god will.

2. **References** ***(List of cited references)***

[1] Menon, C., et al. (2004). A biomimetic climbing robot based on the gecko. Journal of Bionic Engineering, 1(1), 1-12.

[2] Matrone, G. C., et al. (2010). Bio-inspired grasp control in a robotic hand with massive sensorial input. 2010 3rd IEEE RAS & EMBS International Conference on Biomedical Robotics and Biomechatronics.

[3] Lewis, F. L., et al. (2016). Reinforcement learning and adaptive dynamic programming for feedback control. IEEE Circuits and Systems Magazine, 16(3), 32-50.

[4] Selva, D., & Krejci, D. (2012). A survey and assessment of the capabilities of Cubesats for Earth observation. Acta Astronautica, 74, 50-68.

3.Attachments ***(videos, animations or 3D models, etc.)***

1) Video: basic introduction of the CubeSat.mp4

2) 3D model: The Design for a Space Station's Foldable, Adhesive Crawling CubeSat with Fixed-point Operations.zip

Attached visit the link

Link：https://pan.baidu.com/s/1XYwXhbqa2Sh60tYSM53oFg

Password：wim6