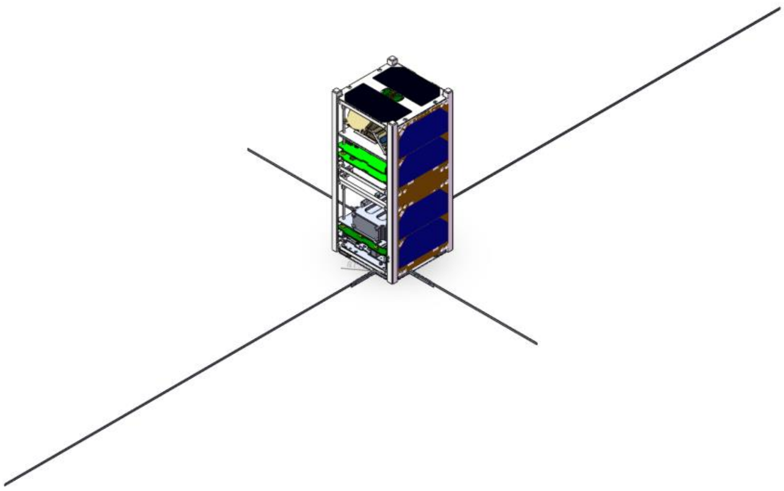
"Di Ting"
——Space Means Assists Wildlife Tracking



Team Name: CubeSaturday Team

Team Members: Guanliang Li

Zeshu Liu

Diyang Shen

Hanzi Zhou

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Contents

Abstract

This article designs a set of aerospace methods to achieve animal tracking, which includes four parts: data acquisition, data collection, data transfer, and data integration. The data acquisition part mainly relies on tags, and this article also provides the design ideas and models of tags. The data collection part is mainly based on aerospace methods, including self-designed cubic constellation, and BeidDou short message form. And data integration in the server segment, utilize mobile apps and web apps to provide services to users.

Next, a detailed introduction was given to the design of the CubeSat. Firstly, orbit design was carried out to determine the number of constellation satellites and lighting conditions for the subsequent subsystem design, including the data transmission subsystem, attitude control subsystem, temperature control subsystem, battery subsystem, and structural subsystem. Finally, it was assembled, link calculation was performed, and the quality and cost were budgeted to obtain its cost.

The system designed in this article can serve more users compared to the previous system, and utilizes the existing system. CubeSat plays a supplementary role and has high feasibility, which can truly be used for animal tracking and protection.

1. Introduction

This part of the article will analyze this small satellite mission, introduce the background significance and research status of the mission, and introduce the possible advantages brought by space technology to the mission. Finally, some cases of animal tracking are introduced.

1.1 Background

The life of wild animals is at a critical point. From 1970 to 2016, the number of wild animals in the world died out by 68% in less than half a century, and the vitality index of the earth fell by more than half on average in less than 50 years [1]. However, it is estimated that the world will lose the same number of species only in the next 20 years. Under the severe background of global temperature rising and the worsening living environment of wild animals, the new generation of technology provides some hope for protecting biodiversity. This article hopes to protect wild animals by combining CubeSat technology with animal tracking.

This paper hopes to track endangered wild animals, study their activities, migration routes and living habits, determine the stopovers and wintering sites on the migration routes of animal populations, and carry out habitat research. According to the tracking information, combined with field observation, the range of animals' activities, residence time, habitat types, vegetation characteristics and food sources of animals will be analyzed. Whether there are new stopovers compared with the existing historical tracking data after satellite tracking of animal populations; Analyze the utilization of natural and artificial habitats and judge whether it is necessary to establish artificial habitats.

For example, in early 2015, scientists installed a satellite tracker on a white crane found in Poyang Lake, China. From April to June, this white crane flew from Poyang Lake to Yana Peninsula in Russia, and from September to November, it flew back to Poyang Lake from far away Siberia, passing through many habitats. Finally, the specific migration trajectory of the white crane and its main stop on the path were obtained through the tracking results.

In addition, human activities are closely related to wild animals. While human beings transform and utilize nature, they have a great impact on human beings and other creatures and their habitats, especially on wild animals, which will have different degrees of impact on the migration route, habitat and diet of wild animals [2]. For example, from 2004 to 2007, researchers conducted research on the migration of Tibetan antelopes along the Qinghai-Tibet railway and highway in China. Through seven years' monitoring, it was found that Tibetan antelopes all passed in a few minutes to dozens of minutes as they became familiar with and adapted to the passage, and no phenomenon of staying and waiting for a long time was found. Another example is that vehicles have an impact on Tibetan wild donkeys. Tibetan wild donkeys are very sensitive in sight, hearing and smell, especially in sight and hearing, but they have a strange habit, that is, they will not run away immediately when they have a premonition of danger, but will wait and see curiously. Tibetan wild donkey has strong running ability and likes to race with various vehicles running in the wilderness, which will increase the possibility of injury to Tibetan wild donkey.

Figure 1.1 Tibetan wild donkey hit by a vehicle

In addition to human activities, there is a food competition or predation relationship between wild animals and livestock. For example, due to the increase in the number of Tibetan wild donkeys, there are more and more phenomena of Tibetan wild donkeys and livestock competing for grassland. The eating habits of Tibetan wild donkeys have seriously damaged the grassland, which is also the main reason for herdsmen's complaints. Besides Tibetan wild donkeys, brown bears and wild yaks worry herders. There are brown bears and wild yaks in Qinghai, Inner Mongolia and other places where grazing nationalities gather. China is the country with the largest number and variety of yaks in the world, with more than 14 million yaks, accounting for more than 95% of the total number of yaks in the world [3]. Wild yaks and domestic yaks have extremely similar feeding habits. A large number of domestic yaks will undoubtedly reduce the carrying capacity of habitats to wild yaks. At the same time, the expansion or migration of wild yak's high-quality habitat brought by climate change may also mean the expansion and migration of domestic yak pasture, and lead to more intense resource competition.

In 2020, the event of Yunnan wild elephants moving northward and returning to the south caused widespread public concern and was reported by various media around the world. How to carry out monitoring and early warning, safety precautions, publicity and guidance for the migration of wild animals is important.

Moreover, wild animals do not necessarily live and move only within a country. Not only long-distance migratory birds, but also animals such as Siberian tigers, reindeer and Mongolian wild donkeys are distributed in many countries. Siberian tigers are distributed in northeast China, North Korea and Russia, reindeer are distributed in Europe, Asia and North America, and Mongolian wild donkeys are distributed in northwest China and Mongolia. Through space technology, it is more convenient to track wild animals living in many countries, and it can also help international wildlife protection.

1.2 Research Status

At present, wildlife tracking is realized in many ways, the first is manual census. As shown in Figure 1.2, researchers are working outside, investigating and tracking wild animals on the spot. Manual census is time-consuming, costly, risky, unable to cover a large area, easy to interfere with wild animals, extremely vulnerable to extreme weather, wild animal attacks, dangerous terrain, natural disasters, etc., and even cause researchers to be injured.

Figure 1.2 Tracking of wild animals by manual census

The second is radar detection. As shown in Figure 1.3, radar monitoring is mostly used to observe bird migration, and a large amount of information such as altitude, direction and speed during bird migration's flight is obtained. Most radar monitoring research works are carried out by using radar equipment in airports or weather stations, so the choice of research sites is limited.

Figure 1.3 Tracking of wild animals by radar detection

The third is the fixed infrared camera technology. The image data of wild animals are obtained by infrared camera, and the image data are analyzed, so as to explore the species, quantity, ecological habits, habitat status and interference pressure of target animals. In recent twenty years, infrared camera technology has been more and more applied to wildlife investigation because of its advantages of less interference to animals, large amount of data and easy standardization and popularization [4]. The investigation and study of cats is one of the most successful fields in the application of infrared camera technology. However, infrared cameras may be damaged by weather, man-made or animals. At the same time, due to the performance defects of the infrared camera itself and environmental factors, many useless photos will be taken by mistake or empty, which often requires a lot of manpower to screen.

Finally, drone technology. Unmanned aerial vehicles (UAVs) carry high-resolution cameras, radar or infrared thermal imaging cameras, and shoot from high air to ground in forests, oceans and grasslands to obtain high-resolution images within several square kilometers. Researchers can identify the population and quantity of all kinds of wild animals in the image map through the data returned by drones, and can also take a complete picture of the areas where wild animals are active to obtain corresponding data. However, UAV's endurance is very limited, and it is highly weather-dependent, and it may bring safety problems to wildlife.

In addition, wild animals need to carry tracking devices or "tags", and different types of tags will be introduced below.

Archival tag: the data collected by animals carrying tags during operation are directly stored in the tag for recycling. When the condition is met, the archived tag is recycled. The information obtained by archival telemetry technology is comprehensive. However, this tag is only applicable to situations that can meet the recycling conditions, such as fish with fixed migration cycles and paths. In reality, the whereabouts of many animals are irregular, which leads to a low probability of recycling archived tags.

At present, acoustic telemetry tags are mainly used to track marine life. The selection and use of acoustic telemetry tags need to master the overall information such as the size of the target individual, sensitivity to the outside world, living habits, activity intensity, activity range and life span, and consider the limitation of the maximum tag weight and fish weight ratio.

Satellite transmission tag: Satellite transmission tag can be regarded as an improvement of archive tag. Generally, this tag does not need to be recycled. Besides the functions of data acquisition and data storage, it can also send data in real time (or delayed) via satellite. When the satellite passes over the research object, the sensor receives the signal from the transmitter and transmits it to the processing center of the ground receiving station. After computer processing, the information such as latitude, longitude, altitude and temperature of the tracked object is obtained. At present, Argos satellite system in Europe and America and BeiDou satellite navigation system in China are used for wildlife tracking.

1.3 Advantages of using space technology

From the above analysis, we can see that satellite transmission tags overcome many shortcomings of archive tags and acoustic tags. Therefor, we hope to use Space technology for this task.

Compared with other means, satellite animal tracking has a wide coverage and saves manpower, and its ground facilities can be arranged centrally, which basically includes the advantages of many conventional animal tracking technologies. At the same time, we can rent satellites, use BeiDou short messages, or design CubeSats. Using CubeSats has the advantages of lower cost, convenient design and expansion, autonomous control, and can play an auxiliary role for the whole system.

1.4 Traceable wild animals

The article hopes to track a variety of animals, including birds, land creatures, some aquatic creatures, as well as migratory animals and species in fixed settlements.

Tracking migratory birds and studying their migration routes can protect their habitats in a targeted manner, thus protecting biodiversity. For example, at present, the global population of cranes is about 4,000, which is listed as an endangered species by the World Conservation Union, with the highest endangered level. The original migration routes of the crane are east, middle and west. The eastern migration route is from the breeding ground in northeast Siberia to the south, passing through the Russian Far East and northern China. Both the central and western migration routes start from the breeding ground in western Siberia, pass through Russia to Kazakhstan, the western migration route reaches Iran, and the central migration route reaches India.

Track land creatures, such as the Tibetan wild donkey mentioned above. Tibetan wild donkeys are distributed in western China, Nepal, Pakistan and northern India. Since it was on the verge of extinction in 1980s, its population has been greatly recovered. Tracking them can study many of their living habits.

Tracking aquatic organisms, such as the Yangtze finless porpoise. They are only distributed in the Yangtze River in China, including Anhui, Hubei, Jiangsu, Jiangxi, Hunan and Shanghai, and the threats they face mainly come from the influence of human activities. The tracking of aquatic organisms can also be used with water quality measurement chips, which can detect water quality while tracking animals.

1.5 Article Outline

The outline of this paper is as follows. The comparative study of the Argos system and the mission requirements analysis are described in Section 2. Various implementation forms of the "Di Ting" system for different application circumstances are proposed in Section 3. The customized design of animal tracking tags is introduced in Section 4. The detailed design of the "Di Ting" CubeSat is introduced in Section 5. The conclusion is drawn in Section 6.

2. Requirements Analysis

This section provides a comparative study of the Argos system in order to obtain the desired service form of the "Di Ting" program and introduces the data management model of the "Di Ting" program, as well as the design of the final client.

2.1 the Argos System

The Argos system is a global satellite-based system that collects, processes and transmits environmental data from fixed and mobile platforms around the world. Such worldwide tracking and environmental monitoring system is the result of France-USA cooperation. In addition to satellite data collection, the main feature of the Argos system is the ability to geolocate data sources based on the Doppler effect to any location on Earth[5].

The Argos constellation consists of the following nine satellites: NOAA-15, NOAA-18, NOAA-19, METOP-B, SARAL, METOP-C, ANGELS, GAZELLE and EOS-6 (OCEANSAT-3), whose orbits cover the Earth like lines of latitude and longitude as shown in Figure 2.1.

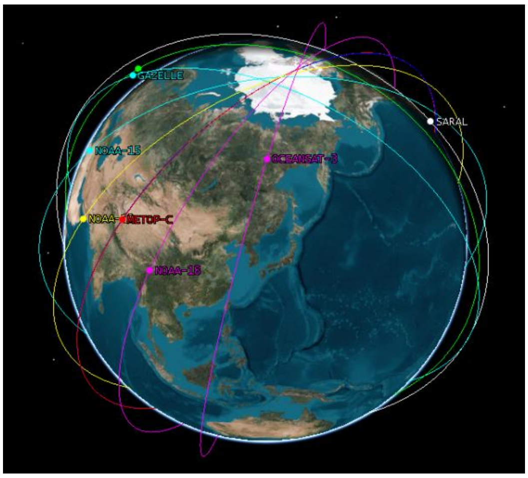


Figure 2.1 The Argos Constellation

Most use of the Argos System makes use of one way data transmission on 401.65 MHz using Argos 2[6]. Each Argos platform features a unique 28-bit ID and the ability to transmit a short 3 to 31 byte message for each transmission. Each platform is restricted to a specified interval, such as every 60 seconds, allowing for a few hundred bytes total per satellite pass. This is enough to contain a couple elements of geographic coordinates or other sensor data.

As mentioned earlier, the positioning function of the Argos satellites is based on the principle of using the Doppler shift on a single satellite to determine the position of the transmitter. To achieve this accurately, approximately 4~6 transmissions are required in succession during a satellite pass. Accuracy can vary between several hundred meters to several kilometers.

The Argos system provides services in the fields of wildlife monitoring, smart agriculture, herd management, oceanography, meteorology, hydrology and glaciology, etc., through two functions: geo-location of the data source and data transmission with the data source.

The business model of the Argos system mainly has two aspects: selling Earth's environmental data through the tens of thousands of tags that currently exist globally; selling platforms including animal tracking tags, moored buoy platforms, drifting buoy platforms, and fishing boat tags.

A comparison of the services of the Argos system with the expected services of the "Di Ting" system is shown in.

2.2 Service Forms

The expected services forms of "Di Ting" include endangered species tracking, online adoption of wildlife, personal purchasing services, tourism guidance, grazing assistance, etc., which are described in more detail below.

Endangered species tracking service takes animal protection organizations as target users. Nowadays, there are many animal protection organizations in China, such as Shan Shui Conservation Center, Guarding the Wilderness, the Paradise International Foundation, Chinese Felid Conversation Alliance, etc. These organizations have good animal protection knowledge and experience, and such tracking of endangered species is beneficial to environmental protection. For example, the tracking of egrets can contribute to protecting the wetland; the tracking of Snub-nosed monkeys can conduce to protecting the forest in Yunnan, Guizhou and Sichuan; the tracking of the Siberian tigers can profit to protect the forest in Northeast China; and the tracking of porpoises can help protect the Yangtze River.

The online adoption of wildlife, aimed at individuals, hopes to achieve a different form of donations, which has precedents. In January 2021, Nanjing Hongshan Forest Zoo launched an online animal adoption campaign to raise funds, which has received wide support due to the public's love for wildlife and the reputation of the zoo. Take the adoption of giant pandas for example, the relevant charges are shown in Table 2.2.

Table 2.1 the Comparison of the services of the Argos System and the “Di Ting” System

Aspects of comparison	The Argos system	The “Di Ting” system
Animal tracking and positioning	the Argos carries out geo-positioning based on the Doppler effect, with accuracy varying between a few hundred meters and a few kilometers.	The "Di Ting" animal tags will use GPS or BeiDou positioning, which can achieve higher accuracy.
Data transmission	The amount of data sent by Argos animal tags to Argos satellites each time is limited.	"Di Ting" has many ways of data transmitting, including BeiDou short message communication services, leased satellites, CubeSats and other services.
Service scope	Argos: Animal tracking research services, environmental monitoring, maritime surveillance, energy and mining, sustainable fisheries, fleet management, etc.	“Di Ting”: tourism services (e.g., tourist guiding), livestock guiding (e.g., resource competition issues between domestic and wild animals).
Users	Argos mainly focuses on scientific research, industrial services, etc.	Di Ting" provides a platform for individual users to enhance their sense of participation, focusing more on domestic wildlife, and strengthening the tracking and research of domestic wildlife.

Table 2.2 Giant Panda Adoption Price

Adoption Form	Price
Individual Adoption	3000 CNY/panda/year
Family Adoption	5000 CNY/panda/year
Unit Adoption	50000 CNY/panda/year
School Adoption	50 CNY/person/panda/year
Class Adoption	100 CNY/person/panda/year
Corporation Adoption	/

Animals adopted online need to fulfil the following requirements as far as possible: non-endangered, of some conservation value, in need of management and protection by state agencies, and non-migratory species. Animals meeting these requirements include giant pandas, jungle cats, clouded leopards, etc.

The form of adoption is to cooperate with national institutions related to animal protection and provide a donation platform for the public. Specifically, the public can choose from the following forms of service: naming the adopted animal - the adopted animal will be given a formal name which will be used for tracking and identification in the relevant scientific research process; providing the activity trajectory of the adopted animal; and providing photographs of the recent activities of the adopted animal - such photographs can be taken using infra-red cameras in the habitat, and additional fees will be required for taking photographs manually.

In addition to wildlife adoption, personal purchase services also include pet adoption. There exist many pet stocking behaviors in both urban and rural areas. shows the pet cat tracking service conducted in Australia, which aims to obtain the animal's movement trajectory, provide the animal's location when trapped and obtain images through satellite photography.

Figure 2.2 Australia Domestic Cat Tracking Project

Tourism guidance mainly provides customers with auxiliary guide tracking services for wildlife viewing (especially migratory wildlife). Migratory species such as migratory birds, Tibetan antelopes, Asiatic wild ass and so on are often seen in large flocks during their migration, crossing hills and mountains, which is magnificent and has good ornamental value. The "Di Ting" system aims to generate viewing maps for public enquiry by tracking wildlife and collecting their activity trajectory data.

"Di Ting" can also provide grazing assistance services. There are often the following problems in grazing: resource competition between wildlife and livestock; overlapping grazing areas; set grazing being the main cause of grassland degradation. Therefore, state agencies or pastoralists can purchase services to better plan grazing routes and frequencies.

2.3 Data Management Methods

The processing of data is mainly divided into four parts: data acquisition, data collection, data transit, and data integration. As shown in Figure 2.3, the general process of data management is as follows: data acquisition of different species of animals through different tag designs, data collection through aerospace technology, ground stations, unmanned aerial vehicles, etc., and relaying to servers for data integration, and ultimately providing it to customers. After being processed by the process shown in Figure 2.3, the raw data can be partially made public for animal protection organizations and relevant social figures to download; it can also be provided to animal protection agencies that purchase the services.

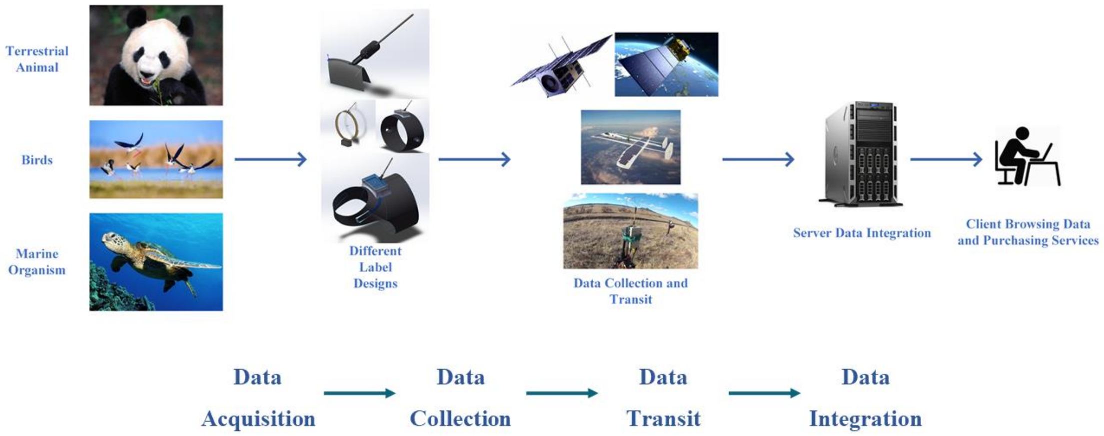


Figure 2.3 Data Management Process

In the process of data integration, the raw data is processed by being inputted into the data decoding software provided by the customers to obtain the movement track and other information. After the animal movement track is extracted, the movement track on the server is updated, and after years of data accumulation, the best viewing route is formed, and such movement track can also be provided to animal protection organizations for horizontal comparisons. After the animal state parameters and environmental parameters are extracted, machine learning technology is used to analyze the data in combination with animal habits, and directly give animal state judgements. For example, users can judge whether aquatic animals are in the water according to the humidity, judge the state of terrestrial animals according to the humidity of the environment, and judge whether birds are flying according to the information of body temperature, position and altitude.

2.4 Client Design Ideas

The "Di Ting" client is expected to be presented to customers in the form of a website and a mobile app, whose content will not be limited to animal tracking, but will include "Di Ting" data and other contents. In fact, there is currently no platform on the market for wildlife enthusiasts to gather and communicate with each other.

Among them, the "Di Ting" data includes the following contents: the raw data is provided to the users together with the data decoding software; the positioning trajectory and current status are provided to users who purchase relevant services, and the positioning data can be fitted to obtain the behaviour of animals, as shown in Figure 2.4; the animal photographs are captured by infrared cameras or solar powered aircrafts; animal habitat photographs are provided by ZeroG Lab.

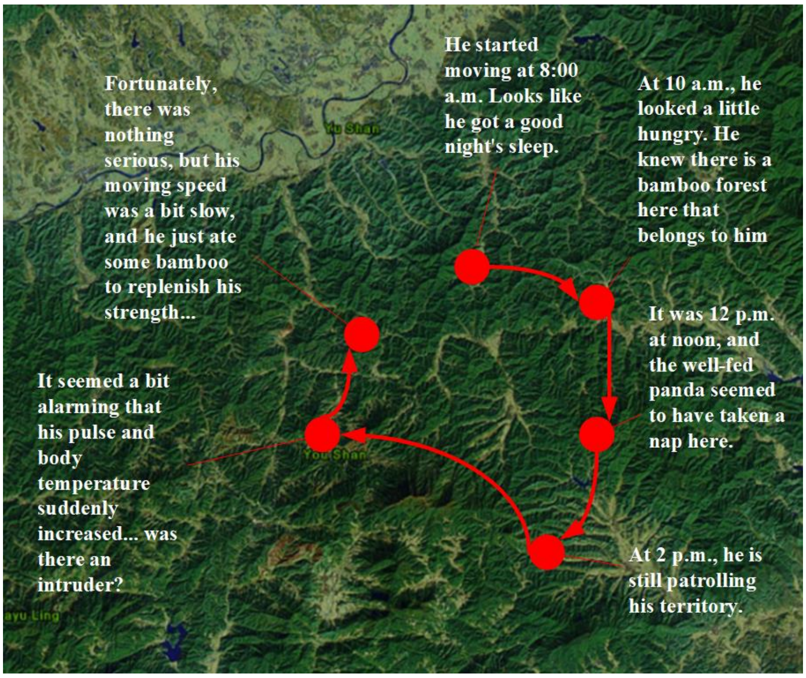


Figure 2.4 Using Data to Fit Wildlife Movement Trajectories

Other content includes the following: invite animal protection organizations to join the "Di Ting" client so that protection organizations and animal enthusiasts can post relevant content, and introduce recent news and projects; meanwhile, big data can be used to portray user profiles and provide targeted content that interests customers more.

2.5 Mission Objectives

Based on the above analysis, the mission objectives of the "Di Ting" project are given. The basic objective is to provide animal tracking services using customized animal tracking tags with the help of space platforms. Subsidiary objectives include: to collect information on animal activities, migration routes and living habits; to provide animal tracking services to domestic and foreign government agencies, social organizations and individuals in the forms of cooperation, charity or sales; and to promote ecological protection.

To achieve the above mission objectives, the data transmission requirements are shown in Table 2.3.

Table 2.3 Data Transmission Requirements

Data Transmission	
Maximum Transmission Frequency	Within China ⩾ 6 times/day
Single Transmission Data Volume	⩾128 bytes
Data Sampling Frequency	At least once an hour

3. Implementation forms

It can be seen from the above that the "Di Ting" project has a relatively wide range of applications; for different requirements, the " Di Ting" project adopts different forms to achieve ideal benefits at the lowest cost.

3.1 Satellite Leasing Service

According to different needs and users, project various in tracked information, tag data capacity and tracking coverage, etc., the " Di Ting " project will choose full time, fixed time, appointment or specific temporary rental time, or according to temporary needs. Set time limits of service to lease entire constellation or part of satellites, purchase service.

At present, many commercial aerospace enterprises have provided satellite leasing services in the market. For example, Beijing Zero Gravity Space Technology Co., Ltd. (Zero Gravity Laboratory), its "LingQue Constellation" plan consists of 132 satellites equipped with RGB full-color cameras. The number of satellites is sufficient, and the optical resolution is better than 4 meters. With key areas Revisit in 30-45 minutes, and can provide photo service for the "Di Ting" project[7].

Another example is CITIC Digital Media Network Co., Ltd. Satellite Communication Branch (referred to as CITIC Satellite), which provides satellite transponder leasing services. Its Asia series satellites are currently operating six in orbit, with stable platforms, high power, large capacity, and coverage capabilities. Strong, superior satellite orbit position, high priority of orbit and network coordination - according to the official website , the Asia series satellites cover Asia, Oceania, the Middle East, Russia and Northeast Africa, providing two-thirds of the world's population A wide range of satellite communications and radio and television services have accepted the test of actual market applications, and have played an important role in emergency communication guarantees such as natural disaster rescue, major event reporting, and emergency response[8]. Therefore, we can also lease CITIC satellites to assist in the transmission of animal tracking data.

3.2 BeiDou short message service

The "Di Ting" project will use the BeiDou short message service to transmit data.

BeiDou short messages include Regional Short Message Communication (RSMC) and Global Short Message Communication (GSMC), the main performance indicators of which are shown in Table 3.1 1~ Table 3.2 2[9]. Obviously, BeiDou short message service has the advantages of all-weather, fast response, wide coverage of the whole area, high reliability, etc., and it has low equipment requirements, low price, high cost performance, and convenient networking.

Table 3.1 1Performance Indicators of BeiDou System RSMC Service

Performance characteristics		Performance index
Service success rate		⩾95%
Service frequency		Generally once/30 seconds, up to once/1 second
Delay in response time		⩽1 s
Terminal transmission power		⩽3 W
Service capacity	Upload	12,000,000 times/hour
	Download	6,000,000 times/hour
Maximum length of a single message		14,000 bits (equivalent to 1,000 Chinese characters)
Positioning accuracy (95%)	RDSS	Horizontal 20 meters, elevation 20 meters
	Generalized RDSS	Horizontal 10 meters, elevation 10 meters
Bidirectional timing accuracy (95%)		10 ns
Usage constraints and instructions		If the user's relative satellite radial velocity is greater than 1000 km/h, adaptive Doppler compensation is required.

Table 3.2 2Performance Indicators of BeiDou System GSMC Service

Performance characteristics		Performance index
Service success rate		⩾95%
Delay in response time		Generally better than 1 minute
Terminal transmission power		⩽3 W
Service capacity	Upload	300,000 times/hour
	Download	200,000 times/hour
Maximum length of a single message		260 bits (equivalent to 40 Chinese characters)
Usage constraints and instructions		If the user's relative satellite radial velocity is greater than 1000 km/h, adaptive Doppler compensation is required.

However, there are still some problems in BeiDou short messages that need to be resolved if they are to be truly and effectively applied to the "Listen to Truth" project.

First of all, BeiDou short message service is not suitable for birds, especially migratory birds. The migration distance of migratory birds is very long, and the range of activities may exceed the short message service area of the BeiDou area. In this regard, the "Di Ting" project needs to choose to lease existing satellites or self-developed cube satellites instead of BeiDou short messages to transmit data.

Secondly, the BeiDou short message service will be limited in the application of aquatic organisms. Most aquatic animals spend a long time underwater, during which time the data recorded by animal tags is difficult to send out, and they can only be transmitted after the creatures come out of the water. At this time, if the BDS short message is still used to transmit data, the data transmission volume may exceed the limit of a single short message and cannot be sent in time. In this regard, the solution of the "Di Ting" project is to use the BeiDou short message + leased satellite/self-developed CubeSat multi-channel data transmission method.

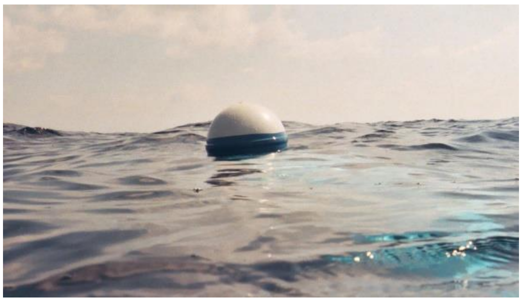
Specifically, BeiDou short messages are only responsible for transmitting tag ID, time information, and longitude and latitude information. Among them, a single short message only sends the data recorded by one animal tag: the tag ID is sent only once as identification; a series of time information, latitude and longitude information recorded by the tag is sent in segments and packaged together. According to calculations, in this way, when data is transmitted using regional short messages, a maximum of 194 pieces of data can be transmitted at a time, which is sufficient for practical applications. The leased satellite/self- developed cube star is responsible for transmitting the tag ID (as identification) and other collected data information not sent by the BeiDou short message.

As for the special and extreme situations required by other customers, we will then provide special services for them.

3.3 Ground station service

In the "Di Ting" project, the ground station will install infrared trigger cameras, artificial intelligence recognition systems, real-time transmission systems, etc. according to local conditions and business needs, to assist in tracking wild animals, collecting and transmitting data. In waters such as oceans, ground stations can also be designed as moored buoys or drifting buoys. In addition to tracking wild animals, collecting and transmitting data, they can also collect marine hydrological information as required.

The ground station of the "Di Ting" project can be designed and arranged by itself, or the existing ground station service can be purchased. As Figure the Argos system provides drifting buoys to collect near real-time surface velocity, sea surface temperature (SST) and sea level pressure observations; in the Arctic and Antarctic regions, the Argos system also provides ice buoys to collect various oceanographic scientific and meteorological data[10].



(a) Drifting Buoys (Drifting Buoys)

(b) Ice Buoys (Ice Buoys)

Figure 3.1 Argos System Buoy

The advantage of the ground station is that it has good stability, mature technology, and ready-made base stations can be used; its disadvantages are also obvious, and it can only cover a limited area, and the coverage capacity is insufficient.

3.4 Solar Airplane Service

According to the needs of animal enthusiasts and other customers, the "Di Ting" project will use solar aircraft to track designated wild animals, take images (panoramic or close-up), collect real-time data information, and feed back to users according to animal tag data or information provided by users. In addition, solar-powered aircraft can also assist in the transmission of animal tag data information.

The advantages of solar-powered aircraft are high data transmission frequency and good maneuverability, while the disadvantages include instability, strong weather dependence, and high cost[11].

3.5 Self-designed CubeSat

In the "Di Ting" project, the self-designed cube star "Di Ting" constellation is mainly used as a backup. First of all, when a certain animal tag or some animal tags are suspected to be out of contact, and the tag information cannot be received through the BeiDou short message module for a long period of time, the "Di Ting" project will try to use the CubeSat to contact the tag and transmit data. Secondly, if the amount of data that the tag needs to send is too large, far exceeding the single sending limit of the BeiDou short message, the "Di Ting" project will use CubeSat to assist in sending part of the data. Finally, the "Di Ting" project can use CubeSat to transmit tag information data of small animals such as birds.

3.6 Summary of Implementation Forms

Based on the descriptions in Sections 3.1 to 3.5 , the implementation forms of the "Di Ting" project in various situations can be summarized as shown in Figure Figure 3.2 3.

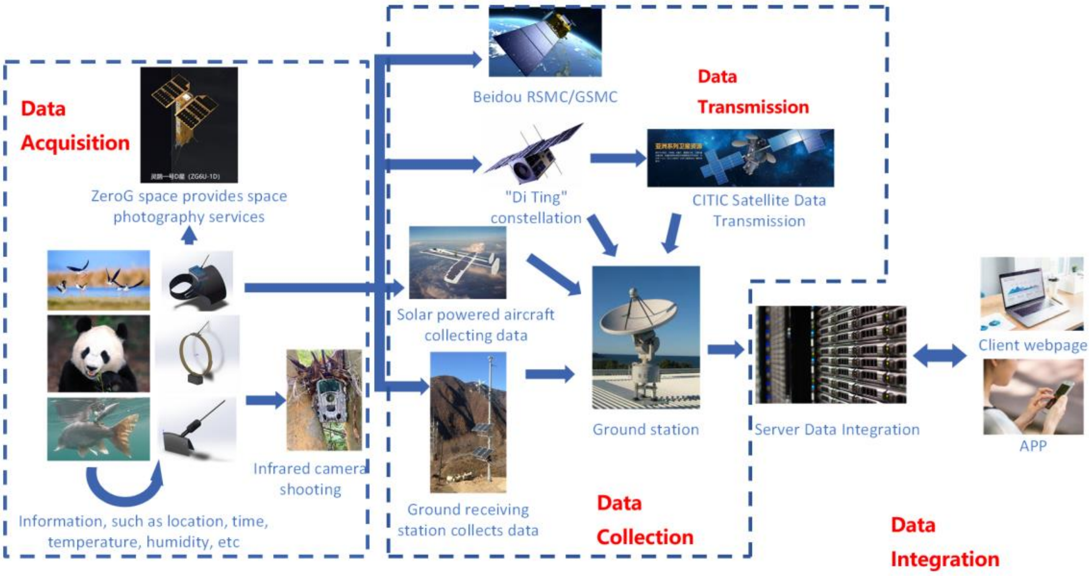


Figure 3.2 3of Implementation Forms

First of all, the "Di Ting" system will customize and install animal tags for tracking targets (birds, terrestrial animals, aquatic animals, etc.) according to customer needs, and use satellite space shooting, ground infrared camera shooting, solar aircraft tracking, etc. to obtain tracking Various types of data information of the target. Then, the collected animal tracking data is transmitted to the ground station through the ground receiving station, solar-powered aircraft, "Di Ting" constellation, BeiDou, etc., and then sent from the ground station to the background server of the Di Ting system for data integration, processing and analysis. Finally, the "Di Ting" system uploads the integrated and processed data to the official website or app of "Di Ting" for customers to log in and query to obtain the data information they need.

In the process of this "Di Ting" system, it is necessary to design by ourselves, including different forms of customized animal tags, "Di Ting" cube star constellation; existing systems that can be rented include BeiDou short messages, zero-gravity space satellites, and CITIC satellites; There are mature products that can be purchased:

infrared cameras, solar-powered aircraft, ground receiving stations, ground stations, servers, and client designs.

In this way, through different forms of application in different occasions and needs, the "Di Ting" project will achieve the established project objectives with a complete, reasonable and effective system, and provide excellent animal tracking services.

4. Tag Design

This part introduces the relevant content of the tag, including tag collection content, tag module design, and tag wearing method design.

4.1 Tag Collection Content

(1) The latitude and longitude, altitude and collection time of the current location

The satellite positioning module is used to obtain satellite positioning information, and the data is transmitted to the tag's MCU through URAT. The module is powered by 3.3V; the working current is 26mA, and the standby current is 20uA; the cold start time is less than 30s, and the hot start is less than 2s; the weight is 0.4g.

Figure 4.1 Location Information Collection

(2) Ambient temperature and humidity

Using DHT11 as a temperature and humidity sensor, the data is transmitted to the MCU through a single bus. Using 3.3V power supply, the average current is 0.5mA, and the standby current is 100uA. Temperature measuring range -20~50° C, ±2.0° C; Humidity measuring range 20%~90%R, ±5.0%; weight about 10g[12].

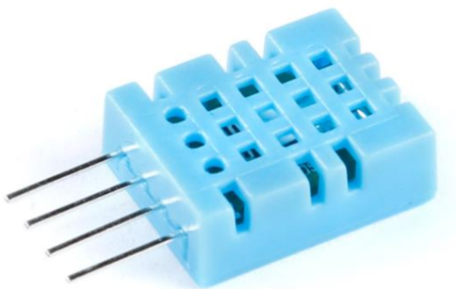


Figure 4.2 Temperature and humidity sensor

(3) light intensity

BH1750 is used as the light sensor, and the data is transmitted to the MCU through the I2C bus; the power supply is 3.3V, the maximum power is 260mW, the standby current is 1uA, the range is 0.11-100,000 lux, ±20%, and the weight is about 1g [13].

(4) Others

If possible, consider collecting more information. For example, the living environment of animals is relatively suitable, and small cameras and other equipment can be added if conditions such as carrying weight and data transmission allow.

(5) Collection of aquatic animal information

Different from birds and terrestrial animals, aquatic animals need to consider their water exit and entry conditions. Aquatic animals have a wide range of distribution, a large range of activities, complex behaviors, and long underwater activities, and usually only limited information can be obtained.

Aquatic mammals that regularly surface (such as whales, seals, sea lions, sea turtles, etc.), and animals that swim close to the surface (sorbet sharks, great white sharks), have a certain time window for tags to send information. For animals that live underwater for a long time, a separate tag can be used to pre-set the separation time, collect information such as pressure (diving depth), ambient light, and temperature inside and outside the animal, and send it after separation.

At the same time, information can be tracked and collected for diving behavior, predation strategy, energy metabolism, habitat identification and vocalization strategy.

For example, the underwater depth, temperature, speed, and sound of cetaceans can be collected, and through the diving method of cetaceans, it can be judged whether cetaceans are hunting. During the diving process, the swimming speed of animals sometimes drops sharply, and then rises sharply. It is generally believed that this sharp change may be predation. Cetaceans vocalize frequently underwater to find and capture prey, detect the environment, and sustain themselves, so their acoustic signatures can be recorded for study.

4.2 Tag Module Design

The tag needs to include: antenna module, sensor module, power supply, signal transmitter, core circuit board, housing, etc. And, depending on the size of the animal, the size of the tag design can change accordingly.

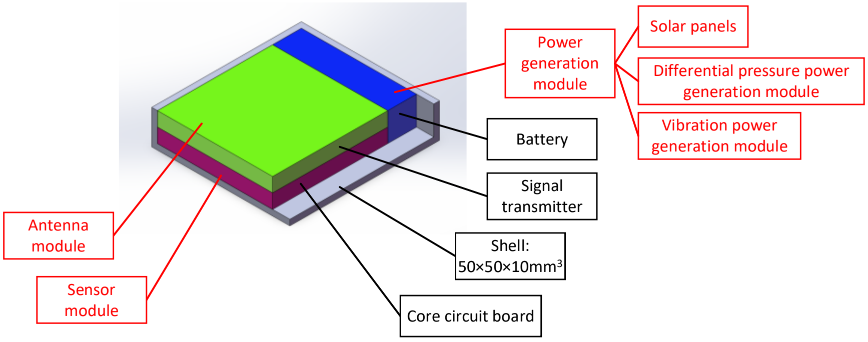


Figure 4.3 Tag module design ideas

(1) Tag MCU selection

The MCU using rp2040 as a tag has a dual-core Arm M0+ processor and works at 133MHz; it is packaged in QFN-56 and has 30 peripheral pins; the working current is less than 50mA under high load and less than 20mA under no load[14].

(2) Core circuit design

There are MCU and crystal oscillator, power management chip, bh1750 light intensity sensor, dht11 temperature and humidity measurement on the core board. The reserved pin headers are connected to the BeiDou positioning and short message module and the power supply device. The internal core circuits of the tags all adopt the same design, and the components of the core circuits can be selectively installed according to the needs of different animals.

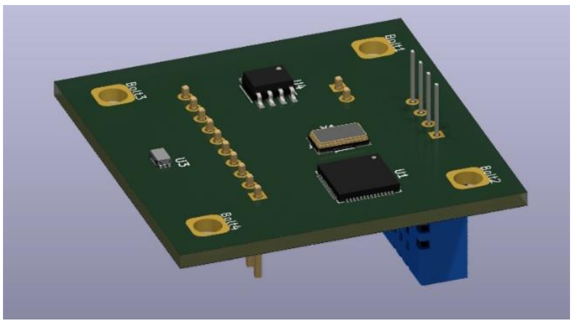


Figure 4.4 Core circuit design

(3) Tag power supply mode

The bird chooses a 5V, 0.3W solar panel. The battery uses a 1000mAh polymer lithium battery. The solar panel weighs 40g and the battery weighs 38g. Considering the power management chip, the total weight is 85g.

A medium-sized terrestrial animal chooses a 5V, 1.9W solar panel powered by a 3000mAh 18650 lithium battery. The solar panel weighs 300g and the battery weighs

40g. Considering the power management chip, the total weight is 350g. Larger animals can be added or subtracted in groups.

Aquatic animals can be charged and powered by a differential pressure power generation device, 180g.

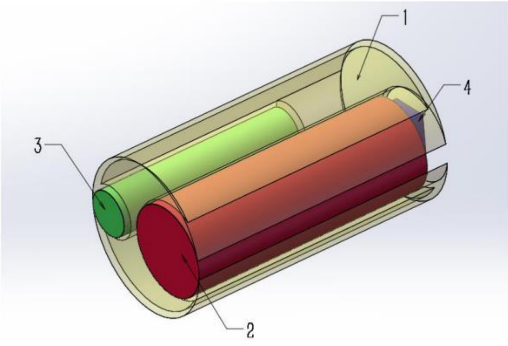


Figure 4.5 Differential pressure power generation device

The generating device consists of 1-low pressure cavity, 2-generating module,-rechargeable battery, 4-reversing valve.

Take arctic elephant seals as an example. The average daily diving depth of arctic elephant seals is 600m, and the pressure difference during their diving can be used to generate electricity. The daily pressure difference can provide 10kJ of energy, about 2.7Wh. Although there is a certain loss in the process of energy conversion, it can still provide objective energy[15].

4.3 How to Wear the Tag

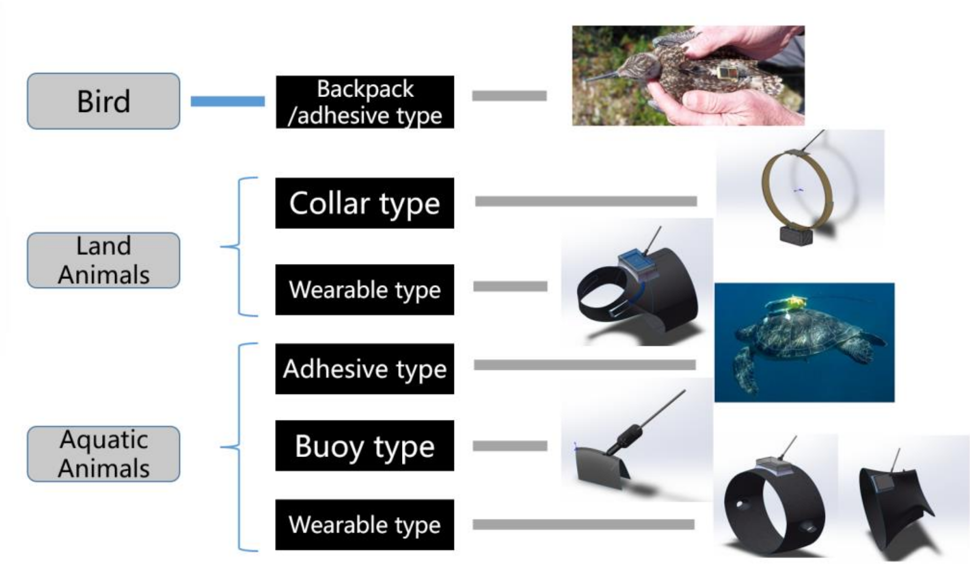


Figure 4.6 Classification of tag wearing methods

(1) Birds

Generally, the tag is installed on the back of the bird by piggyback type.

Figure 4.7 Piggyback tag for birds

(2) Terrestrial organisms

Collar or wearable tags can be installed. For some small and medium-sized terrestrial wild animals, collar tags can be used to track their trajectories.

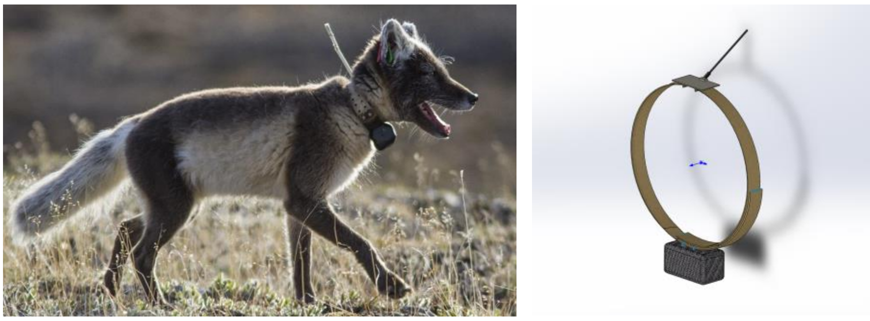


Figure 4.8 Collar Tag

In addition to collar tracking, it can be modeled on the "police uniform" of police dogs to design tracking equipment that can be worn by wild animals. Because the collar rotation may cause equipment failure, wearable tags can prevent this problem; wearable tags have a larger surface area, more interfaces can be designed, and for animals with larger size and weight, some additional sensors can be carried; and wearable tags more relaxed. However, this method may need to consider the issue of wear resistance, whether it will affect the normal activities of animals, weight, heat dissipation, ventilation, and changes in animal size.

Figure 4.9 Wearable tags for land animals

(3) Marine animals

In addition to land animals, wearable tracking devices can also be designed for marine animals. For example, whales can design a tail-shaped wearing coat. Compared with the tethered tags used for sharks and whales, wearable tags may be stronger and reduce the probability of falling off. At the same time, the surface area is larger, and there is more installation space when installing equipment such as seawater pressure power generation devices.

Figure 4.10 Wearable tags for marine animals

For sea turtles, seals and other animals, adhesive tags can be used, and some freshwater fish and silky sharks can use buoy and rope tags.

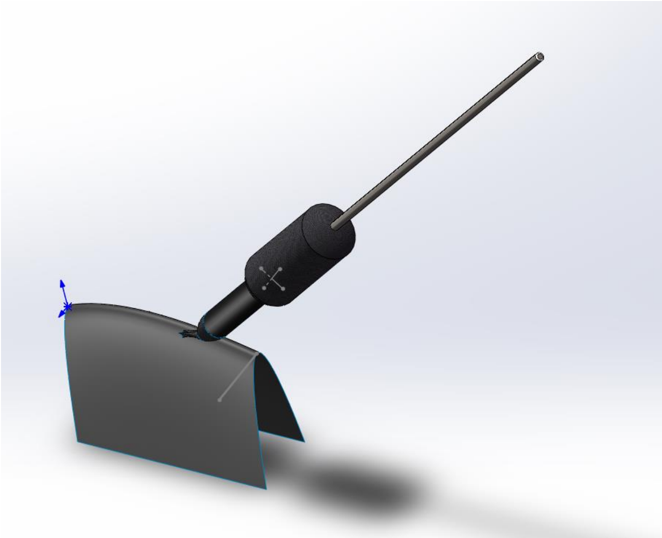


Figure 4.11 Buoy Tag

5. CubeSat Design

5.1 Task Objectives

The self-developed CubeSat "Di Ting" constellation is used to assist tags in data transmission, and the "Di Ting" constellation is used to transmit data in the following situations:

1. Unable to receive tag information through other means for a long time.
2. The amount of data to be sent is too large, greatly exceeding the single transmission limit of BeiDou short messages.
3. Transmission of tag information data for small animals such as birds.

5.2 System Dominant Factors

The system leading factors that affect the achievement of task objectives include:

1. Size: On the one hand, the size of the satellite should comply with the CubeSat specifications, and on the other hand, it should also be able to meet the installation conditions of the satellite payload, subsystems, and other components;
2. Quality: The quality of a satellite determines the cost of design, development, and difficulty of launch;
3. Power: The power of the satellite restricts the selection and performance of the payload;
4. Attitude: The satellite needs to have the ability to orient towards the ground, ensuring that the antenna is approximately pointing towards the ground;
5. Communication: Satellites need to receive signals sent by animal chips and forward the signals to the ground. At the same time, it is necessary to transmit telemetry and receive remote control commands.

5.3 Functional Requirements

The functional requirements of the "Di Ting" constellation are shown in Table 5.1.

Table 5.1 Function Requirements

Function Requirements	Content
Basic Function	Realize the collection of global animal tag data;
Coverage Rate	Achieve global coverage with at least four transmissions per day within China;
Communication Capability	Capable of exchanging information with ground stations: receiving ground commands, returning satellite status information, and remote sensing data; Able to receive signals from animal tags and package them for aggregation before forwarding to the ground

5.4 Operational Requirements

The operational requirements of the "Di Ting" constellation are shown in Table 5.2.

Table 5.2 Operational Requirements

Operational Requirements	Content
Run Time	1-2 years
Data Distribution	Tag data is summarized on the satellite and then transmitted to the ground;
Track Type	Sun synchronous return orbit on the morning dusk line

The data format for tag sending is shown in Tabel 5.3. When the satellite in the "Di Ting" constellation receives the information sent by the tag, it summarizes the information and sends it to the ground station.

Table 5.3 Format of tag data transmission

Tag Data	ID	Time	Longitude and Latitude Information	Height Information	Temperature Information
Occupied Bits(bit)	16	8	64	16	8
Illustration	65535	Pseudo-random number	Second Level	Decimeter Level	20~50℃

Tag Data	Humidity Information	Animal Status Information	Tag Status Information	Additional Information	Check Bit
Occupied Bits(bit)	8	4	4	7	1
Illustration	5%~95%	Evaluate based on pulse, temperature and other factors;	Evaluate based on tag power and other factors;	Additional information can be provided for special animals;	-

5.5 Constraint Conditions

The constraints that need to be considered in the design of the "Di Ting" constellation task are shown in Table 5.4, and the launch opportunities available for carrying and launching are shown in Tabel 5.5.

Table 5.4 Constraint Conditions

Constraint Condition	Content
Single Star Scale	2U
Cost	3 million RMB per satellite(including lauch);
Management	Comply with national legal and policy requirements, and comply with relevant national and military standards and regulations;
Orbit	Orbits that China can carry and launch in recent years

Table 5.5 Launch opportunities can be carried out from 2023 to 2024.

Serial Number	Mission	Launch Window	Orbit(km)/Orbit Type	Emission Type
1	Mission 1	2023.8	500/SSO (LTDN 6:00)	Carrying
2	Mission 2	2023.10	530/SSO (LTDN 10:30)	Shared Rocket
3	Mission 3	2023.11	630 29° /LEO	Carrying
4	Mission 4	2023.12	500/SSO (LTDN 10:30)	Shared Rocket
5	Mission 5	2024.Q1	638/SSO (LTDN 10:30)	Carrying
6	Mission 6	2024.Q1	520/SSO (LTDN 10:30)	Shared Rocket
7	Mission 7	2024.3	500/SSO (LTDN 10:30)	Shared Rocket
8	Mission 8	2024.5	500/SSO	Shared Rocket
9	Mission 9	2024.Q3Q4	To be determined	Shared Rocket

5.6 Orbit Design

Due to being launched on board, the orbit type cannot be designed. Select the typical morning and evening track in Tabel 5.5 for analysis, with a track height of 500km, and use software for simulation.

The simulation of communication with the ground station is shown in Figure 5.1, assuming that the ground station receiving the information is located in Beijing and the maximum transmission distance is 1200km. Within a day, it can communicate twice, with each communication lasting more than 200 seconds.

The simulation of communication with tags carried by animals is shown in Figure 5.2. The communication system capability of animal carrying devices is limited. Assuming a maximum transmission distance of 1000km and a fixed location, sometimes there may be situations where communication is only once a day, with a communication time of 86 seconds. If it is two satellites, it can be guaranteed to communicate at least twice a day.

The simulation of communication with birds carrying tags is shown in Figure 5.3. Due to the smaller weight that birds can carry, the maximum transmission distance is assumed to be 800km. Assuming a flight process with a speed of 40km/h and a duration of approximately 5 days.

The simulation results of communication with regional migratory animals are shown in Figure 5.4. The migration route is: Tibetan antelopes migrate from Sanjiangyuan to Zhuonai Lake, assuming a migration process with a speed of 10km /h and a duration of about 5 days.

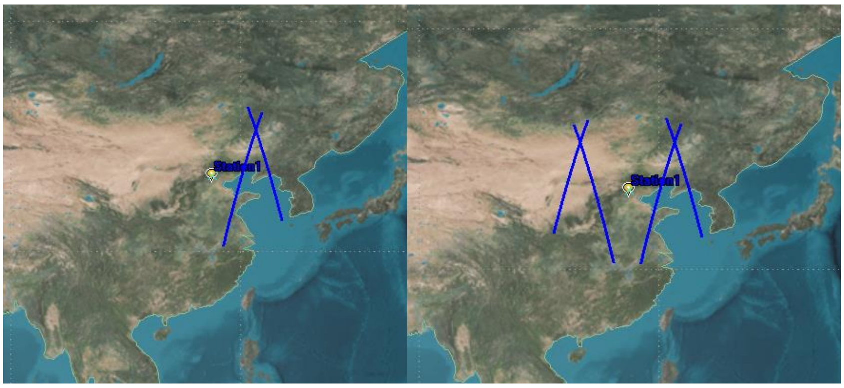


Figure 5.1 Communication with Ground Station

Figure 5.2 Communication with Animals Carrying Tags

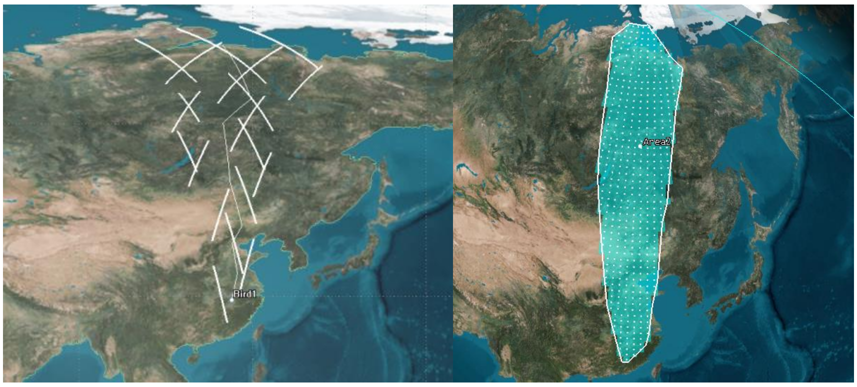


Figure 5.3 Communication with Bird Carrying Tags

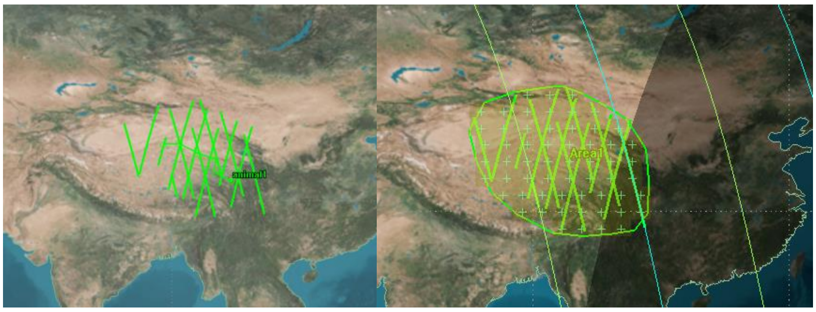


Figure 5.4 Communicating with Regional Migratory Animals

Simulate different numbers of satellites in this orbit to obtain their communication with the above four targets, as shown in Table 5.6. In order to ensure four daily communications with ground animals, six cubic stars were ultimately selected to form a constellation.

Table 5.6 Number of Different Satellites and Tag communication Situation

Number of constellation satellites		1	2	3	4	5	6
Station	Minimum communication times per day	2	4	6	8	10	12
	Minimum time for single communication(s)	414.5220	924.2740	1.4538×10^3	1.9265×10^3	2.4436×10^3	2.9158×10^3
Target	Minimum communication times per day	1	2	2	3	4	5
	Minimum time for single communication(s)	86.5790	307.4770	423.1580	582.7600	700.6760	890.7050
Animal	Minimum communication times per day	1	1	2	2	3	4
	Minimum time for single communication(s)	185.3350	205.4850	352.2790	387.5570	497.8000	718.4400
Bird	Minimum communication times per day	1	2	4	4	6	7
	Minimum time for single communication(s)	128.8810	315.5890	429.6680	594.2790	751.5750	909.3790

5.7 Subsystem Design

5.7.1 Data Transmission Subsystem

According to task requirements, the payload is a VHF band receiver capable of receiving signals emitted by animal tags, which can be classified in the data transmission subsystem for analysis. In addition to receiving VHF signals from animal tags, telemetry and remote control signals also need to be transmitted through the UV band. At the same time, the collected data is large and needs to be transmitted to the ground through S band. VHF transmission frequency is 145MHz, UHF transmission frequency is 435.75MHz, and S band transmission frequency is 2.4GHz.

The UV band antennas and receivers we selected are the ISIS Deployable Antenna System and ISIS UHF downlink/VHF uplink Full Duplex Receiver, as shown in Figure 5.5.

The S band antenna and receiver we selected are EXA SSA01 and ISIS TXS High Data Rate S-Band Transmitter, as shown in Figure 5.6.

According to the maximum number of animal tags supported (65535), all data needs to be forwarded by CubeSat for calculation and $1416 \times 65535 = 92797560$ bits are required to be forwarded every day. The transmission rate is required to be at least $92797560 \div 500 = 185.59512$ kbps. The maximum transmission rate of ISIS TXS High Data Rate S-Band Transmitter is 4.3 Mbit/s, which can meet the data transmission requirements.

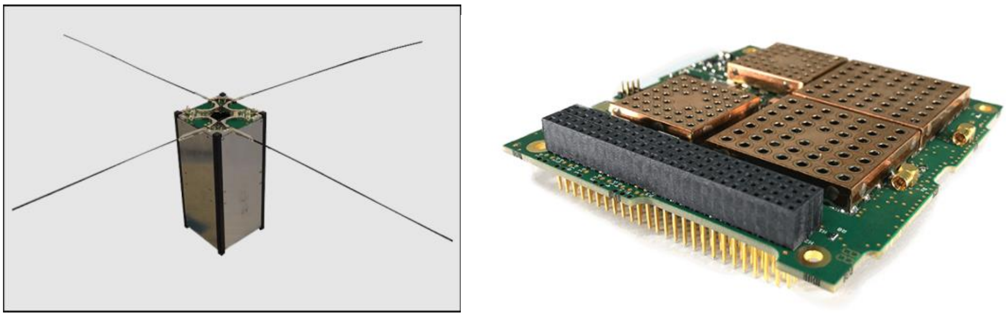


Figure 5.5 The U/V band antenna and receiver selected for the task

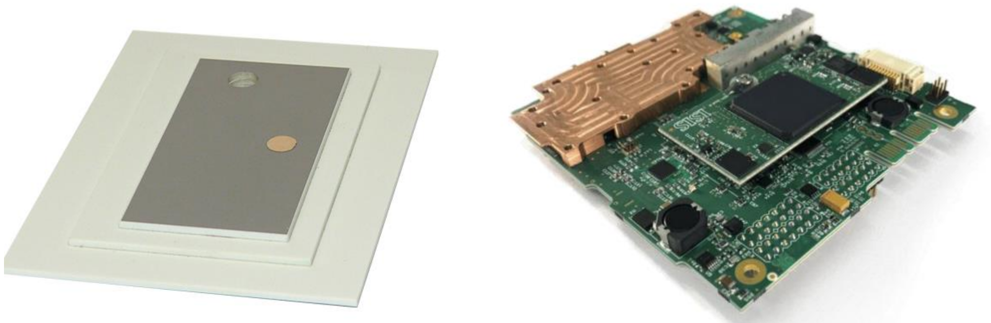


Figure 5.6 S band antenna and receiver selected for task

5.7.2 Attitude Control System

The satellite antenna needs to be kept to the ground and needs high pointing accuracy, so we choose to use a three-axis magnetometer to determine the attitude, use flywheels for large angle pose determination, such as initial pose determination, and use a magnetic torque for small angle pose stabilization.

The specific model selection is ISIS Magnetorque board, as shown in Figure 5.7, with the following parameters:

- Integrated three-axis Magnetometer, two torque rods and one hollow torque rod.
- Power consumption: 175mW without drive, less than 1.2W for three-axis drive.
- Quality: 196g.
- Voltage: 5V.
- Price: €9750.

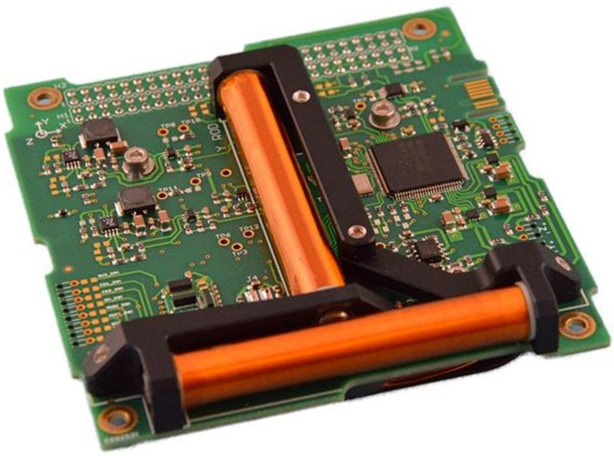


Figure 5.7 ISIS Magnetorquer board

The flywheels are selected to use CubeWheel Small Plus of Gen 1, with the following performance parameters:

- Speed Range: ±6000 RPM
- Max Momentum: 3.6 mNms
- Max Torque: 2.3 mNm
- Static Imbalance: <0.004 g/cm
- Dynamic Imbalance: <0.0014 g/cm^2

- Price: € 5,973.60

Figure 5.8 Gen 1: CubeWheel Small Plus

Its installation on the CubeSat requires the help of a motherboard. In order to provide CubeSat with three-axis attitude determination capability, a four wheel design is used, and it can be seen on the device shown in the Figure 5.9. That the momentum direction vectors of the four wheels are: (1,1,0), (0,1,-1), (-1,1,0), (0,1,1), thus possessing three-axis attitude determination capability and redundant design.

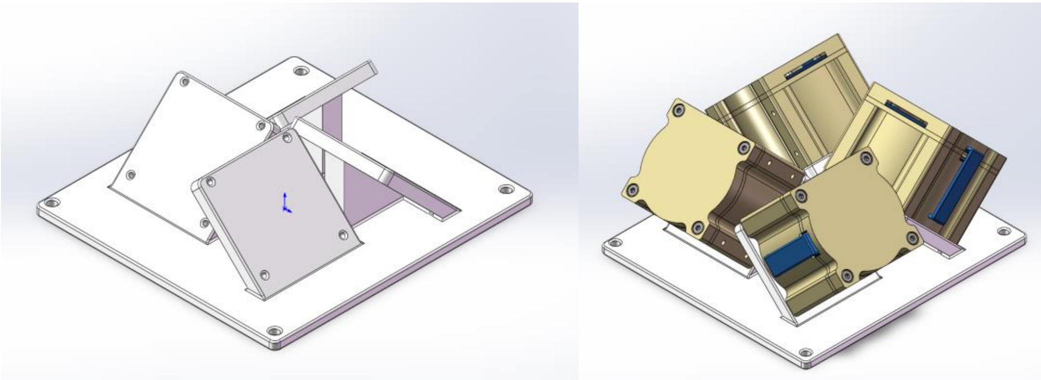


Figure 5.9 Installation Diagram of Four Flywheels

5.7.3 Thermal Control Subsystem

Due to the small volume and mass of the satellite in this mission, as well as its simplicity and low power, a passive thermal control method of internal insulation and external insulation is adopted. By using isothermal design, the interior of the CubeSat should be kept at the same temperature as possible while minimizing the influence of external heat flux. The smallest operating temperature range is the data transmission subsystem: $-24^{\circ}C \sim +50^{\circ}C$, which determines the control temperature and margin.

Apply low absorption emission ratio coatings on high-temperature surface, such as S781 white paint, LP-10A white paint, etc;

Apply coatings with high absorption emission ratio at low temperatures, such as TXT-1 organic paint, organic gray paint, etc;

The interior of the satellite body is coated with organic black paint with high absorption and high emissivity to enhance the heat exchange inside the satellite body and balance the temperature field inside it. The outer surface of the celestial body is wrapped with multiple layers of insulation material (MLI) to minimize the impact of external heat flux.

According to the temperature requirements of each component, the control temperature us determined to be $-14^{\circ}\mathrm{C} \sim +40^{\circ}\mathrm{C}$, with a margin of $\pm 10^{\circ}\mathrm{C}$.

5.7.4 Satellite Service Subsystem

Using a distributed system architecture to connect various systems through CAN bus, the schematic diagram of the architecture is shown in Figure 5.10.

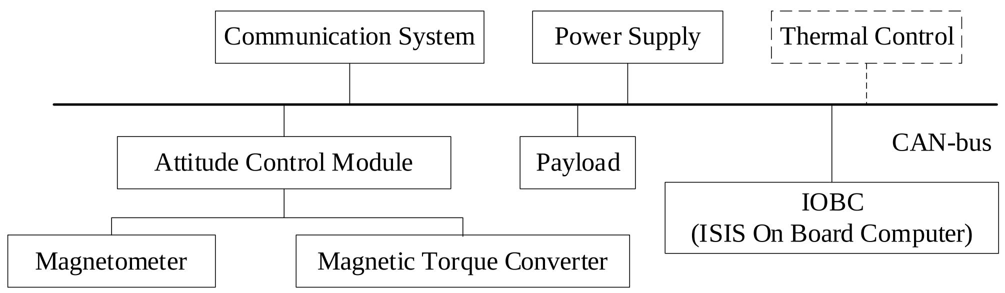


Figure 5.10 Distributed architecture diagram

Select ISIS On Board Computer as the main controller, as shown in Figure 5.11, with the following parameters:

Processor: 400MHz, 32-bit ARM9 processor.

- FRAM：64MB
- Code storage: 1MB NOR flash memory
- Key data storage: 512KB memory
- Working temperature: $-25^{\circ}\mathrm{C} \sim 65^{\circ}\mathrm{C}$
- Power supply: 3.3V
- Size: $96 \times 90 \times 12.4\,\mathrm{mm}$
- Quality: 94g motherboard

- Power consumption: average 400 mW, designed according to 1 W.
- Price: € 4900

Figure 5.11 ISIS On Board Computer

5.7.5 Power Supply System

Because satellites need to receive signals from global tags, it is believed that they have been in data reception mode, and the minimum system mode will only enter after the satellite encounters a malfunction. The satellite operating mode obtained from this is shown in Table 5.7. According to calculations, the average power consumption is 3.475 W.

During the mission period, the table of satellite light conditions is shown in Table 5.8. It can be seen that the satellite light conditions in June are the worst. The following calculation will also be based on June data.

The solar cell selected for the task is CubeSat Solar panel DHV-CS-10, and its performance parameters are shown in Table 5.9.

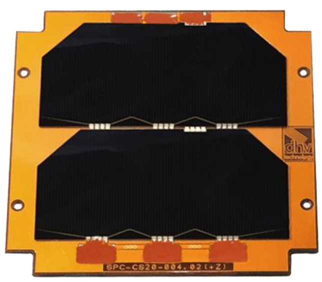


Figure 5.12 CubeSat Solar panel DHV-CS-10

We have calculated that the minimum power output required for the solar array is:

$$\begin{aligned}
P_{SA} &= \frac{\dfrac{P_e T_e}{X_e} + \dfrac{P_d T_d}{X_d}}{T_d} \\
&= \frac{\dfrac{3.475 \times 614110}{0.7} + \dfrac{3.475 \times 1977890}{0.85}}{1977890} \mathrm{W} \\
&= 5.630\mathrm{W}
\end{aligned}$$

The meanings of each item are as follows:

- P_e : Average power consumption of ground shadow area of onboard devices;
- P_d : Average power consumption in the illumination area of onboard devices;

Both of the above quantities can be calculated, and since both the shadow zone and the illumination zone need to work, the following formula is obtained:

$$\begin{aligned}
P_e &= P_d \\
&= 3.4 \times 99.4\% + 15.9 \times 0.60\% \mathrm{W} \\
&= 3.475\mathrm{W}
\end{aligned}$$

- T_e : Shadow zone time;
- T_d : Illumination zone time;
- X_e : Output efficiency of solar array from battery pack to load, taken as 0.70 for arsenic potassium batteries;
- X_d : Output efficiency from solar array to load, taken as 0.85 for arsenic potassium batteries.

Energy output per unit area of solar cells at the beginning of their lifespan:

$$\begin{aligned}
P_{BOL} &= S \times \eta_{SC} \times AVE\left\{\sum_{n=1}^{k} \cos\theta_n\right\} \times I_d \\
&= 1368 \times 0.25 \times 0.92 \times 0.75\mathrm{W/m^2} \\
&= 235.98\mathrm{W/m^2}
\end{aligned}$$

The meanings of each item are as follows:

- S : Solar irradiance constant, $1368\ \mathrm{W/m^2}$;
- η_{SC} : Solar cell efficiency, 25% when the solar cell is new;

- θ_n : The angle between the solar vector and normal of the solar cell array, take the experience value of $AVE\left\{\sum_{n=1}^{k}\cos\theta_n\right\}$ as 0.92;
- I_d : Filter factor, taken as 0.75;

Energy output per unit area of solar cells at the end of their lifespan:

$$P_{EOL} = P_{BOL} \times L_d = 205.3026\mathrm{W/m^2}$$

Among them, L_d is the degradation factor of solar cells, and its calculation formula is as follows:

$$\begin{aligned} L_d &= \eta_{uv} \times \eta_{tc} \times \eta_m \times \eta_r \times \eta_{con} \times \eta_s \times \eta_{rad} \times \eta_t \times \eta_{op} \\ &= 0.98 \times 0.99 \times 0.975 \times 0.98 \times 0.99 \times 1 \times 0.9725 \times 0.9745 \times 1 \\ &= 0.870 \end{aligned}$$

- η_{uv} : Power loss caused by ultraviolet radiation, taken as 0.98;
- η_{tc} : Power loss caused by thermal cycling, taken as 0.99;
- η_m : Power loss caused by mismatched battery cells, taken as 0.975;
- η_r : Power loss caused by internal resistance of battery cells, taken as 0.98;
- η_{con} : Power loss caused by external pollution sources, taken as 0.99;
- η_s : Power loss caused by external obstruction, taken as 1;
- η_{rad} : Power loss caused by radiation damage, due to a 2.75% annual performance decrease in GaAs batteries, the calculation formula is as follows: $\eta_{rad} = (1-2.75\%)^{lifetime}$, taken as 0.9725;
- η_t : Power loss caused by temperature regulation during operation. The temperature variation range of the satellite's four sided battery array is $-14^\circ\mathrm{C} \sim +40^\circ\mathrm{C}$, and the normal test temperature is $25^\circ\mathrm{C}$. Therefore, $\eta_t = 1 - 0.0017 \times (40-25) = 0.9745$;
- η_{op} : Adjust the solar irradiance constant at the orbital position, taken as 1.

Minimum area of solar array:

$$A'_{SA} = P_{SA} / P_{EOL} = 4.2941 / 205.3026 \approx 0.0275\mathrm{m}^2$$

Therefore, the minimum number of solar cell arrays required can be obtained:

$$n = A'_{SA} / A_{SA} = 0.0275 / 0.008085 = 3.40$$

where A_{SA} represents the area of solar cells per square decimeter, taken as $0.008085\mathrm{m}^2$. And the calculation results indicate that solar panels of 3 square decimeters is required.

The required capacity of the battery pack can also be estimated from the above data:

$$\begin{aligned} C' &= 1.2 \times \frac{P_e T_{e,max}}{DOD \times \eta \times N \times V_{bus}} \\ &= 1.2 \times \frac{3.475 \times 0.38}{0.3 \times 0.25 \times 2 \times 3.3} \mathrm{Ah} \\ &= 3.201\mathrm{Ah} \end{aligned}$$

The meanings of each item are as follows:

- $T_{e,max}$: The maximum shadow time in a day, which can be simulated from the simulation software, is set to 0.38 hours;
- DOD: Depth of discharge, taken as 0.3;
- η: Discharge efficiency, taken as 0.25;
- N : Number of battery cell, taken as 2;
- V_{bus}: Charge voltage, which means the voltage of CAN-bus, taken as 3.3V.

We chose ISIS iEPS Electrical Power System as the battery pack, and its performance parameters are shown in Table 5.10.

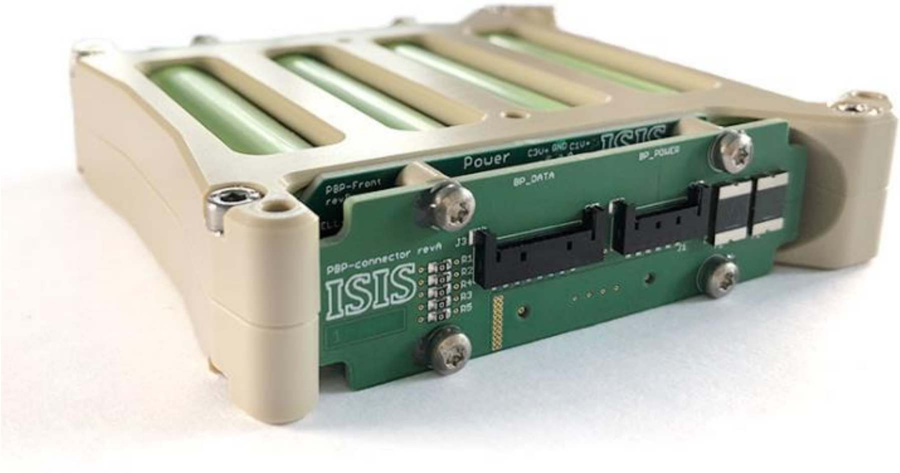


Figure 5.13 ISIS iEPS Electrical Power System

Table 5.7 Satellite Working Power Meter

Subsystem		Minimum System Mode	Data Reception Mode	Data Download Mode
Communication Subsystem	Antenna	0	2W	2W
	Communication Motherboard	0	0.5W	13W
Attitude Control Subsystem	Sensor	0	0	0
	Magnetic Torque Converter	0	0	0
On-board Computer		0.9W	0.9W	0.9W
Total Power Consumption		0.9W	3.4W	15.9W
Working Hours/Day		0s	85882s	518s
Time Proportion		0%	99.4%	0.60%

Table 5.8 Table of Lighting Conditions during the Task Period

Month	Illumination Time	Shadow Time	Light Shadow Time Ratio
Jan.	2678400	0	\
Feb.	2419200	0	\
Mar.	2678400	0	\
Apr.	2588080	3920	660
May.	2221350	457050	4.86
Jun.	1977890	614110	3.22
Jul.	2109653.4	568746.6	3.71
Aug.	2555678.8	122721.2	20.83
Sept.	2592000	0	\
Oct.	2676150.4	2249.6	1189.64
Nov.	2592000	0	\
Dec.	2678399	0	\

Table 5.9 Performance Parameter of Solar Cells

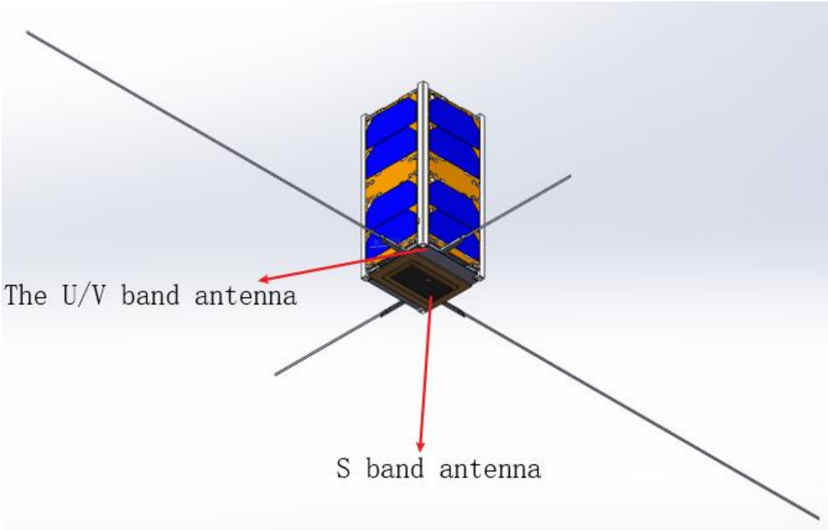
Output Power	2.41W
Efficiency	30%
Quality	50g
Operation Temperature	-120° C~+150° C
Nominal Thickness	1.6mm
Size	82.5 mm x 98 mm x 2.4 mm
Working Voltage	3.3 V

Table 5.10 ISIS iEPS Electrical Power System Performance Parameter

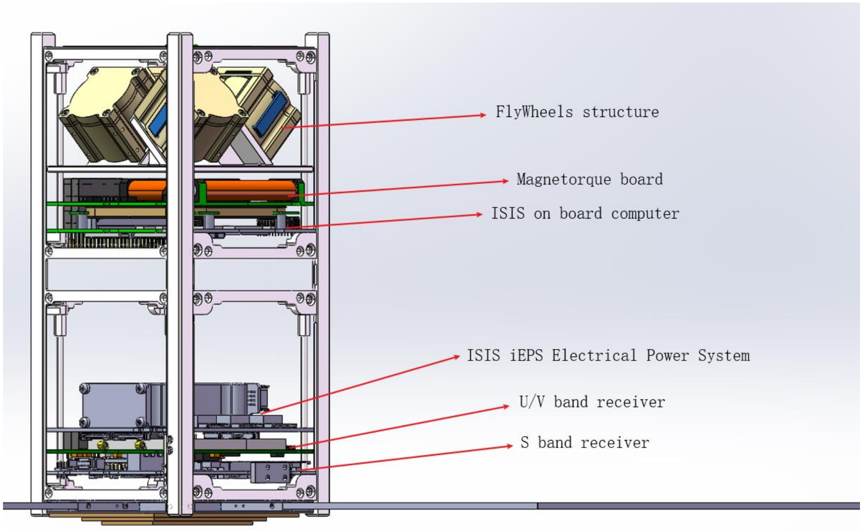
20W@5V, four channels
184g (2-cell battery pack)
-20°C~+60°C
96 mm × 92 mm × 26.45 mm
6.3Ah

5.7.6 Structure Subsystem

Select the 2U satellite frame, as shown in Figure 5.14 for the satellite diagram.



(a) Assembly Appearance Diagram



(b) Internal Assembly Drawing

Figure 5.14 Satellite Structure Assembly Drawing

5.8 Signal Link Budget

The tag and satellite communication link are calculated using softwares, and the parameters used in the calculation are shown in Table 5.11, with the first item means effective isotropic radiated power (EIRP). The calculation results are shown in Table 5.12, and it can be seen that the error rate, which is displayed by bit error rate (BER), is above 1e-9, so the transmission can be considered reliable.

UV measurement and control and S band data transmission link budget are shown in Table 5.13, Table 5.14 and Table 5.15. The link has more than 5dB margin.

Table 5.11 Tags and Satellite Communication Links

Launch EIRP（dBW）	-3 （0.5W, equivalent to a regular walkie talkie)
Transmission Frequency（MHz）	145
Bandwith （MHz）	5.76
Orbit Altitude（km）	<600
Satellite Antenna Gain（db）	3
Code Rate（bps）	9600
CDMA Chip Rate（Chips/bit）	300

Table 5.12 Tag and Satellite Communication Link Calculation Results

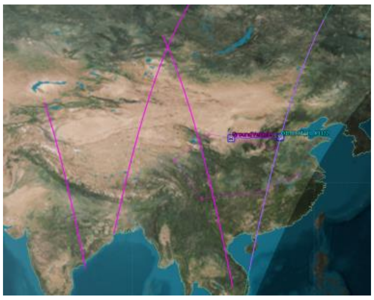
Simulated Orbit Substellar Point Trajectory	Time (UTCG)	EIRP (dBW)	BER
	30 May 2023 00:31:08.377	-3.010	7.948e-09
	30 May 2023 00:32:08.000		2.088e-10
	30 May 2023 00:33:08.000		5.849e-12
	30 May 2023 00:34:08.000		5.102e-13
	30 May 2023 00:35:08.000		3.942e-13
	30 May 2023 00:36:08.000		3.047e-12
	30 May 2023 00:37:08.000		9.330e-11
	30 May 2023 00:38:08.000		3.729e-09
	30 May 2023 00:38:25.594		1.038e-08

Table 5.13 Remote VHF Uplink Calculation

Project	Remote VHF uplink
Transmitting Power（dBW）	50
Launch EIRP（dBW）	34
Transmission Frequency（MHz）	145
Orbit Altitude（km）	500
Ground Elevation Angle（°）	10
Antenna Gain（dB）	-6
Receiving Cable Insertion Loss（dB）	1
Sensitivity（dBm）	-95
Margin（dB）	5.79

Table 5.14 Telemetry UHF downlink Calculation

Project	Telemetry UHF Downlink
Transmitting Power（dBW）	-3
Launch EIRP（dBW）	-10
Transmission Frequency（MHz）	435.75
Orbit Altitude（km）	500
Ground Elevation Angle（°）	5
BAUD（bps）	9600
Demodulation Loss（dB）	2.00
Coding Gain（dB）	6.00
Margin（dB）	5.78

Table 5.15 Data Transmission S Band Downlink Calculation

Transmitting Power（dBW）	-2
Orbit Altitude（km）	500
Ground Elevation Angle（°）	5
G/T（dB/K）	15.01
BAUD（bps）	9600
Demodulation Loss（dB）	3
Coding Gain（dB）	0
Margin（dB）	14.29

5.9 Quality and Cost Verification

The quality budget for a single satellite in the "Di Ting" constellation is shown in Table 5.16, and the cost budget is shown in Table 5.17. The total weight is 1.82kg, and total cost is approximately RMB 270000.

Table 5.16 Satellite Quality Budget

Subsystem Name	Quality
Communication Subsystem	245 g
Attitude and Orbit Control Subsystem	203.5 g
Satellite Computer Subsystem	100 g
Power Supply Subsystem	934 g
Structure Subsystem	340 g
Total	1822.5 g

Table 5.17 Satellite Cost Budget

Subsystem Name	Cost
Communication Subsystem	€10100
Attitude and Orbit Control Subsystem	€32892
Satellite Computer Subsystem	€4400
Power Supply Subsystem	€9100
Structure Subsystem	€3300
Total	€59792

6. Conclusion

Based on mission requirements, the "Di Ting" project utilizes aerospace platforms, applies various implementation forms such as satellite leasing services, BeiDou short message communication services and ground station services, and customizes the use of animal tracking tags for different application scenarios to assist animal tracking and achieve ecological protection.

Chinese President Xi Jinping pointed out that "A sound ecosystem is essential for the prosperity of civilization. We must work together to promote harmonious co-existence between man and Nature, build a community of all life on the Earth, and create a clean and beautiful world for us all". Humanity is weaved into “the rich tapestry of life that makes up our world’s biological diversity”, said Secretary-General of the United Nations António Guterres. “All human civilizations have been, and continue to be, built on the use of wild and cultivated species of flora and fauna, from the food we eat, to the air we breathe”.

As evidence including COVID-19 grows, any doubt about the huge potential impact that neglect of the health of wildlife and surrounding ecosystems can have on human well-being should have been ended. The 2030 Agenda for Sustainable Development, proposed by the United Nations, is an integrated plan of action born of an understanding of human-nature interdependencies and the importance of a healthy planet to continued human progress, to lifting all people out of poverty, and to achieving shared prosperity by 2030, which promotes stabilizing the Earth’s climate, slowing and reversing biodiversity loss, and conserving and sustainably utilizing renewable natural resources, including those of our vast oceans, for the well-being of present and future generations. China has made active efforts to promote ecological progress and biodiversity protection and has found a path of biodiversity protection with Chinese characteristics. Going forward, China will continue to advance ecological progress, and plan its development in the context of promoting harmonious co-existence between man and Nature.

It is obvious that the "Di Ting" project serves the times and reality, fully considers official and civil needs, realizes ideal benefits at low cost, is easy to carry out extensive cooperation, has outstanding advantages of being systematic, comprehensive and unique in innovation. Generally, the "Di Ting" project enjoys excellent market opportunities and rich practical significance.

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