Design and Implementation of Container Global Monitoring Device Based on Low-Orbit Satellite Communication Module

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Abstract—Containers are important equipment for global cargo transportation. After the USA 9/11 terrorist attacks and, safety of container transportation has attracted much attention. The real-time monitoring of containers has become an inevitable trend for future container intelligent development. In this paper, current development status and advantage of application on monitoring container of low-orbit satellites are introduced, and circuit design and development solution based on low-orbit satellite module is elaborated, finally the monitoring device is proved that has great practicability by actual test experiment.

1. INTRODUCTION
With the prosperity of global trade, container transportation plays a very important role in the international cargo transportation industry. The efficiency and safety of its transportation have attracted much attention. At the same time, because the container belongs to a sealed container, when the container is closed, what is in the container and what happened in it that is difficult to be found in time. In order to master the container situation well, container-related intelligent products are emerging, including container electronic locks, container electronic seal, container safety intelligent equipment, etc. These device through the integration of sensors, positioning modules and data transmission modules to achieve real-time monitoring of containers, collecting the position, safety, environmental information and other status of the goods, to ensure the safety of goods, prevent smuggling, promote the visualization level of container transport. However, in these devices, the biggest bottleneck problem occurs in the data transmission process. We all know that containers are transported globally. In the distant seas, mountains, and inaccessible wilderness, data transmission encounters huge challenges, even in some countries, they have different levels of infrastructure construction, data transmission also often suffers from data loss and other problems. In order to meet the needs of global 24 hours monitoring of containers, satellite communications have been proposed. However, early satellite communication modules not only have big volume and high power consumption, but also have the higher operating expense, the satellite modules have been difficult to apply to container monitoring. In recent years, due to the continuous development of satellite technology and rocket technology, the size of satellites and power consumption has become smaller and smaller, and the application of multi-star, recycling rockets has made the cost of launching satellites lower and lower. With the commercial operation of IOT(internet of things) satellites and mature of technology, low-orbit satellite modules, with the advantage of their price, low power consumption and other characteristics, that have become possible to apply low-orbit satellite module on the container visual monitoring for the whole transport process. In this article, the development status of low-orbit satellite modules will be analyzed, and
related intelligent equipment will be opened, which has been tested and proved to be able to achieve the aim of global monitoring of containers.

2. DEVELOPMENT STATUS QUO OF LOW-ORBIT SATELLITE
At present, the number of companies making micro-satellites in the world is gradually increasing. Due to the low manufacturing cost and short development cycle of micro-satellites, the entry barrier for micro-satellite manufacturing is relatively low. In 2019, SpaceX has launched 120 of the planned 12,000 small broadband satellites into low-Earth orbit. The company is placing its first 1,584 satellites in a 550-kilometer orbit, and then uses the remaining satellites for higher and lower altitudes. In 2013, there were only 146 small satellites successfully launched globally, and the satellite and satellite launch industries showed an explosive growth. Satellite applications in the future will gradually enter public life. Skybox in the United States has successfully integrated micro satellite remote sensing technology with new technologies and new fields such as big data, cloud services, and customized services. In low-orbit satellite communication systems, the more mature ones are mainly Iridium system, Globalstar system and Orbcomm system.

2.1 The Iridium system
The Iridium system is the first low-orbit global satellite communication system and the first satellite communication system to use a large-scale inter-satellite link. It has strong on-board processing capabilities and can provide global personal mobile communication for handhelds service. The system began commercial operation in November 1998. The basic goal is to provide global personal communication services, including voice, data transmission, and positioning services. The main business of Iridium II will change from traditional voice service to data transmission service.

2.2 The "Global Star" satellite system
The "Global Star" satellite system is a global satellite communication system developed by Alcatel Alenia Space Company, which can continuously cover all areas within the 70° latitude of north and south latitudes and provide low-cost satellite communication services, including voice and fax, data, short messages, positioning, etc. Transmission delay and processing delay is less than 300ms. "Global Star" can be communicated with any person in any way at any time, at any place and at any time in the global scope, so-called global personal communication. There are three types of "Global Star" user terminals: handheld, vehicle-mounted and fixed. The handheld terminals include Global Satellite single-mode, Global Satellite/GSM dual-mode, and Global Satellite/CDMA/AMPS tri-mode. Multi-mode handsets can work either in terrestrial cellular communication mode or in satellite communication mode (where the terrestrial cellular network cannot reach). Since its commercial operation in November 1999, it has more than 110,000 users in 120 countries around the world.

2.3 The Orbcomm system
Orbcomm system consists of 36 satellites with an orbital height of approximately 825km. It is a commercial low-orbit satellite constellation system specifically designed for short data transmission. It is the first and only two-way short data low satellite Orbit satellite communication system. Since its application in 1995, the system has obtained operation rights in nearly 90 countries around the world. Since the Orbcomm system is specifically designed for short data transmission, the price is lower than other systems. User terminals include handheld, vehicle (machine, ship), fixed and semi-fixed terminals. The short data service of the system is mainly used for information transmission, remote monitoring of infrastructure and automatic data collection and processing. Because the system is very suitable for the military to use in the battlefield environment, intelligence data collection and transmission, and emergency rescue, it has attracted considerable attention.
2.4 Other developing satellite system
China’s low-orbit satellites started later, The “Hongyan” of China Aerospace Science and Technology Group Co., Ltd., the “Hongyun”, the “Xingyun” of China Aerospace Science and Industry Corporation, and the low-orbit broadband constellation of Galaxy Aerospace Science and Technology Co., Ltd. Some of these constellations can realize global space-based real-time interconnection of broadband internet systems, and some can provide Internet of things access services and alternative mobile communication services. Most of these constellations are currently in the early stage of network construction, it is hard to provide real-time data service, it can be used in areas that do not require real-time, with the increasing number of low orbit satellites, real-time ability will be improved.

3. ADVANTAGE OF ORBIT-SATELLITE FOR APPLYING ON CONTAINER MONITORING
Compared with the ground mobile communication network, the low-orbit satellite system has a wide signal coverage, is less disturbed by ground buildings and terrain, is not easily affected by man-made and natural disasters, and can achieve global coverage.

Compared with medium and high-orbit satellite systems, low-orbit satellites are small and light, do not require large booster rockets, and have short launch preparation time. Compared with geostationary satellites, the earth's surface coverage is more comprehensive. At the same time, the low-orbit satellite system has short transmission delay, low path loss, high spectrum utilization rate and high communication capacity. The terminal weight, volume and transmission power are similar to ordinary handheld mobile communication terminals, and can be integrated with ordinary mobile terminals.

Low-orbit satellite communication systems also have inherent shortcomings, such as the need for a large number of satellites, which are high-speed movements relative to the ground, and the ground terminals will frequently switch between different satellites, thus bringing user resource management, data management, ground control, and maintenance systems are relatively complex.

Generally speaking, for the end user, the low-orbit satellite terminal communication module has the advantages of low power consumption, small size, small antenna, low cost, etc. It is very suitable for application on container monitoring devices.

4. DESIGN AND DEVELOPMENT OF MONITORING DEVICE BASED ON LOW-ORBIT SATELLITE MODULE

4.1 Design requirements and circuit solutions
According to the special characteristics of container transportation, the design of related circuits should meet the following design requirements, mainly including: environmental adaptability design, equipment explosion-proof design, low-cost design, low power consumption design, reliability design, extended compatibility design.

- Environmentally adaptable design: The working environment of the container is harsh, and the circuit design requires resistance to salt haze, corrosion, etc. At the same time, it is required to work in an environment with an ambient temperature from minus 40 degrees Celsius to 60 degrees Celsius. Therefore, in the circuit design process, the entire electronic components and circuit boards need to be protected from moisture and salt mist. In the case of extreme low temperature, it is also necessary to carry out thermal insulation treatment of the equipment, so that even if the external ambient temperature is -40 degrees Celsius, the working temperature of the battery can be maintained at -20 degrees Celsius. In this way, the problems of fast discharge and easy damage of the battery under extremely low temperature environment can be greatly improved.

- Explosion-proof design: Containers are often stored in shipping or stacked in the yard, so it must be ensured that the equipment installed on the container has good explosion-proof performance, otherwise the consequences will be very serious in the event of an explosion. It is not enough to choose a battery with good explosion-proof performance, and other measures need to be added to strengthen the explosion-proof performance. We choose to use an explosion-proof shell design to protect the main...
equipment. Even if the circuit explodes, the shell can ensure that the device will not affect the surrounding environment.

- **Real-time design of data transmission**: At present, data transmission is mainly achieved through 4G network, but some countries and regions still mainly use 2G network. The data communication based on the low-orbit satellite module is mainly to solve the problem that when the 2G or 4G main network has no signal, the monitoring data can be transmitted to the remote monitoring system through satellite communication. This requires that the device be designed to have both 2G/4G network and low-orbit satellite communication network. When one of the transmission networks fails to transmit data, the data communication module will automatically switch the network to find available data transmission network. Satellite communication is susceptible to occlusion. If neither mode can communicate, the time stamp and the environmental information and location information collected by the sensor should be temporarily stored in the circuit memory. Once the network is connected, these stored data will be sent to the remote monitoring system together, so that there is no blind spot in the management system.

- **Low cost design**: The cargoes transported by the container mainly include ordinary goods, high value-added goods, fresh goods, chilled goods and hazardous goods etc. ordinary goods account for a large proportion of container transport, but the value of the cargoes may be not high. Therefore, by reducing the cost of equipment, it can be beneficial to the promotion and application of equipment. This design uses all the commonly used components in the market. For example, the temperature and humidity sensor selects the general SHT1X sensor, and the inclination selects the SCA100T sensor. The monitoring device has lower cost.

- **Low power consumption design**: The design of the low power consumption of the device is mainly to meet the needs of the device to work for a long time. In the design of low power consumption, in addition to selecting a chip circuit with low power consumption, it is more important to optimize the work flow of the hardware circuit to reduce power consumption. We use a power management module to implement multi-branch power network management, so that the power supply of each functional module of the system is relatively independent, and the working time of each module can be effectively controlled, especially for the communication module, because positioning and communication are very power consuming. The working current of general 4G modules and satellite positioning modules can reach tens of milliamperes, and the average working current of satellite communication modules is higher. Therefore, when the device does not work, it enters a low-power standby state. Only when the sensor senses changes of state, such as changes in position, vibration, temperature, etc., the monitoring device will be woken up, and usually a timer can be used for long-term wake-up.

- **Power supply design**: Since container transportation is a global transportation, the frequency of battery replacement determines whether the container tracking device can be successfully applied to the container. Basically, it is better no to replace the battery for 5 years, and the capacity of the current existing battery is difficult to meet the requirements. Therefore, we design it as a dual power supply mode, one-time lithium battery power supply plus rechargeable solar battery power supply, usually the main power supply is powered by solar cells. When the outside temperature is too low or the solar cell voltage is too low, the battery management module can quickly switch the battery and reduce the frequency of data transmission. At present, it is designed to send out a data every 3 hours. When the container is in a stationary state, the device remains dormant. After the container is detected to start shipping, it will enter a new timing cycle, which can maximize the working time of the device. After calculation, the monitoring equipment can meet the needs of 5-year of use.

### 4.2 Circuit module design and physical realizations

The circuit design of the container monitoring device includes the main control circuit, sensor module, power management module, positioning module, communication module and so on. This circuit integrates temperature and humidity sensor, light sensor, acceleration sensor and power management module. The positioning module selects the Beidou/GPS combination, the communication module adopts GPRS/4G module and low-orbit satellite module, and the battery power supply selects lithium
battery and solar rechargeable battery for common power supply. The specific circuit design diagram is shown in Figure 1.

![Circuit Diagram](image)

**Figure 1. Circuit design of monitoring device based on low-orbit satellite**

The temperature and humidity sensor, light sensor, acceleration sensor send the collected environmental information to the main controller chip through the IIC bus, Beidou/GPS module sent location information to the main controller chip through SPI bus, and then the main controller sends the monitoring data to the remote management system through the data communication module.

![Monitoring Device](image)

**Figure 2. Monitoring device based on low-orbit satellite**

As shown in Figure 2, it is a physical picture of the monitoring equipment. The circuit board is very small and can be directly installed into the container vent. It is hidden and does not affect the operation. At the same time, the solar panel is installed on the top of the container.

5. **TEST VERIFICATION**

In order to better verify the performance of the monitoring equipment, we chose to test on the China-Europe train. There are two routes for testing. The monitoring equipment has to undergo various weather changes along the way, including the severe cold at a minimum temperature of -30 degrees Celsius.

The monitoring equipment is installed in the position of the vent of container as shown in Figure 3.
In order to test the accuracy of monitoring, we chose two experimental routes.

The first route starts from China and arrives in the UK. The countries covered include: China-Kazakhstan-Russia-Poland-Germany-Netherlands-Belgium-France-UK. Test result is shown in figure 4. Monitoring device recorded location and related information of container. These information includes temperature, humidity, transmission way and battery power.

The second route starts from Jiangsu, China, and arrives in Belgium. The following countries include: China-Mongolia-Russia-Poland-Germany-Netherlands-Belgium. Test result is shown in figure 5.
Monitoring device also recorded location and related information of container. These information includes temperature, humidity, transmission way and battery power.

Through testing, we found that the device can work normally, and the recorded position information and sensor information are completely correct. Of course, we found the low-orbit satellite will replace the 4G/2G network when in the area far away from city, we also found that in some areas, there are failure cases of data communication, mainly because of terrain and other occlusions, resulting in satellite data transmission failure, in response to this situation, we have optimized the monitoring equipment, recorded the collected sensor information, positioning information and collection time in the data storage, once out of the data collection blind area, immediately send the sensor and positioning information with collecting time.

6. CONCLUSION
The container tracking device using the low-orbit satellite module will be an important option for the monitoring of container transportation in the future. With the increasing number of low-orbit satellites, the data communication capability will have a qualitative leap. From this research, we can draw a basic conclusion that the application of low-orbit satellite modules for the global tracking of containers is completely feasible, but due to the limited number of experiments, there are still uncertain problems in large-scale commercial use. The next step is to plan a larger scale test application and accumulate more practical experience.

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REFERENCES
[1] Shibo Xu, Qingzhou Li, Peng Ni, Wensheng Cao, “The Application of Ad-Hoc Network in Smart Container Tracking System,” 2016 IEEE TrustCom/BigDataSE/ISPAs, Tianjin, 2016, pp. 2068-2072.
[2] I.F. Akyildiz, W. Su, Y. Sankarasubramaniam, E. Cayirci, “A survey on sensor networks,” IEEE Commun. Mag. 2002, 40, 102-114.
[3] Yujie Jiang, “Research on Handover Algorithm in Satellite Mobile Communication System”, Chongqing, Chongqing University of Posts and Telecommunications, 2016.
[4] Longlong Xiao, Xiaojuan Liang,. “Development and Application of Satellite Mobile Communication System”[J].Communication technology, 2017, 50(06):1093-1100.
[5] Fengping Yu, Kai Chen. “The current status and trend of satellite mobile communication development” [J]. Digital communication world,2016(11):34-37.
[6] Zhuzhu Fu. “LTE-based multi-user frequency offset estimation and compensation for low-orbit satellite systems” [D]. 2017
[7] Wei Zhang, Bo Li,Xiaohe Zhang. “Overview of the development of foreign communication satellites in 2017” [J],International space, 2018(02):23-30.
[8] R. Divyabharathi; C. Abdul Hakeem; A. Mohammed Mian; C. Abdul Hakeem. Design and simulation of Zigbee Transmitter using Verilog. International Conference on Information Communication and Embedded Systems (ICICES). 2013. Pp. 882 – 888.