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Feasibility Study and Prospect of Discharge Measurement Based on Satellite Remote Sensing

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Abstract. Satellite remote sensing has the characteristics of real-time, efficient, large amount of data, wide observation range and so on, which makes up for the limitations of traditional ground observation in time and space, and can provide new data sources for areas without data. In order to study the feasibility of using satellite remote sensing technology for liquid flow measurement, this paper studies and discusses the technical route and technical obstacles of satellite remote sensing discharge measurement from the demand of hydrometry, and on this basis, puts forward the future development direction of satellite remote sensing discharge measurement. The results show that at present, the satellite discharge measurement uses indirect methods to extract the geometric parameters and hydrological and hydraulic parameters of the river section by satellite, and to calculate the discharge through the model, which has some problems on the technical route, such as unable to penetrate the water body, insufficient spatial and temporal resolution, low service timeliness and so on. On the basis of satellite technology analysis and current measurement technology route research, puts forward four future development technical routes, such as traditional algorithm, space-time paradigm transformation, artificial intelligence algorithm and hydrological satellite, it can provide reference ideas for the development of satellite discharge measurement technology.

Keywords. Satellite remote sensing, flow test, hydrological test, feasibility, technical route

1. Introduction

Rivers are the most important freshwater resources for human beings and the main channels of the global water cycle. To find out the water resources of a river basin or region, to provide basic data for the development and protection of water resources, and to provide scientific support for national water security, energy security and national rights and interests, the premise is that river runoff data must be mastered [1,2].

The runoff is generally obtained through long-term monitoring of the sections arranged on the rivers. Countries around the world have arranged a large number of flow sections on various rivers for different purposes, also known as hydrological stations or hydrological sections. There are relatively mature hydrological norms or standard

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systems for flow measurement methods and accuracy indicators. The basic principle is mostly by measuring the section and the flow velocity of different positions, and calculating the section flow according to the velocity area method [3].

By the end of 2021, China has set up 3,293 basic hydrological stations and 4,598 special hydrological stations to monitor the runoff of major rivers, lakes and reservoirs. However, due to bad weather, traffic, economy and other factors, there are only a few hydrological stations on most remote rivers, and many rivers cannot be measured on the spot, especially in the alpine regions of the western plateau of China, where some rivers have no monitoring station network [4].

In recent years, the research on the runoff process in no data areas has attracted the attention of scholars [5,6]. The researches have important scientific significance for a comprehensive and complete understanding of global hydrological characteristics and the deduction of the impact of climate change on runoff and water resources in different types of regions. However, the technical route of satellite current measurement is simple, the accuracy is not high, and there is a lack of comprehensive and systematic hydrological observation data, which makes it difficult to carry out more in-depth research.

Satellite remote sensing plays an important role in obtaining hydrological model parameters due to its advantages of real-time efficiency, large amount of data, and wide observation range [7,8]. However, there has been no major progress in directly monitoring the river runoff process. If satellite remote sensing can be used to directly measure the river section flow, or by measuring the influencing factors of the river section flow, and calculating the section flow through hydrology or hydraulic methods, the hydrological problem can be solved. The problem that the model lacks verification data can greatly improve the calculation accuracy of the hydrological model.

2. Current Situation of Satellite Remote Sensing in Flow Test

2.1. Technical Route

Due to factors such as resolution and water obstruction, there is no mature method for direct observation of cross-sectional flow velocity by satellite remote sensing. At present, the use of satellite remote sensing for the collection of river flow is all indirect methods.

Hydrological data is the basic data required for the development of modern society, but in many areas, due to the harsh natural environment and lagging economic development, it is difficult to establish traditional hydrological stations, resulting in a lack of hydrological data. In order to obtain effective hydrological data in these areas, a large number of studies and technology on the application have been carried out of remote sensing to monitor river flow, and a series of results have been achieved [7,9,10]. These achievements can be classified into two categories: the first is to use remote sensing to observe flow indicators in rivers, and then establish relationship between indicators and flow, and estimate flow by observing changes in these indicators. For example, Ling et al. [11] selected Jiangxinzhou in the Yangtze River, used long-series remote sensing data to obtain the exposed area in different periods, and established the relationship curve of "island area-flow" to monitor the flow changes of the Yangtze River. The main limitation of such methods is the difficulty in finding an ideal flow indicator in practical applications. The other is to use remote sensing to observe the river water surface width, water level, river slope, ripple and other objects that characterize the hydraulic geometry of the river, and use hydraulic equations to estimate the flow. For example, Huang et al. [12] used remote sensing to observe the river width and water depth in the upper reaches of the Yaluzangbu River, and calculated the cross-sectional flow through the improved Manning formula. Compared with the first type of method, the second type of method has greater promotion and application value because the hydraulic geometry parameters are widely present in rivers and are easier to obtain.

2.1.1. Extracting the extent of water bodies using satellite imagery

In recent years, scholars at home and abroad have begun to use various remote sensing images to extract surface water bodies (optical remote sensing images of different resolutions; radar remote sensing images; LiDAR remote sensing images and domestic satellite remote sensing images, and have proposed a large number of surface water bodies automatic extraction algorithms [13-15]. These algorithms can be generally divided into five categories: (1) pixel-based statistical pattern recognition methods, including supervised, unsupervised and machine learning classification algorithms; (2) single-band threshold method; (3) Object-oriented image analysis method; (4) Subpixel mapping method of spectral mixture decomposition; (5) Spectral water body index method.

2.1.2. Water Level Measurement with Satellite Altimeter

Radar altimeter is an active microwave remote sensor. Early radar altimeters were mainly used for ocean measurement to obtain sea surface height, effective wave height and backscatter coefficient. The data measured by radar altimeter can be further used for ocean gravity anomalies, geoid, sea surface topography, seafloor topography, ocean tides, wind waves and ocean dynamics [16,17].

In addition to oceanographic measurements, radar altimeters can also monitor water level and flow changes in inland waters and rivers, which have become a hotspot in satellite altimetry application research over the past decade. At present, satellite altimetry can be used to monitor the water level of many major rivers in the world. High-resolution 20Hz altimetry can also be used on some rivers, and re-tracking technology is used to correct the distance of the observation waveform, thereby improving the observation accuracy. In recent years, some foreign institutions have released a series of inland water level data sets using multiple altimetry satellites, such as DAHITI from DGFI-TUM in Germany, SOLS from LEGOS in France, and PEACHI from CNES in France.

2.1.3. Calculating Flow Using Multi-Source Information Fusion

The main idea of multi-source information flow calculation is to estimate the model based on the multi-source hydraulic information and measured data modeling of satellite remote sensing. Mainly include based on the theory of hydraulic geometry, such as establishing a digital model representing the hydraulic geometry of the river through low-altitude remote sensing data; using satellite remote sensing long-series data to extract the water surface width in different periods, and establishing a hydraulic geometry digital model to estimate the flow; and then use the measured flow to evaluate and calculate error, and analyze the reliability of multi-source information flow estimation methods [7,9,10].

From the perspective of image processing algorithms, most of the current research is based on satellite image data, combined with specific rivers, to design identification algorithms, and the portability is not high. At present, the mainstream application architecture is based on multi-source remote sensing data for knowledge extraction, combined with the knowledge map of the professional field of hydrology, and constructs an estimation model.

2.2. Technical Barriers

2.2.1. Inability to Penetrate Water

Velocity changes in water flow in rivers occur primarily within the body of water, often at deeper locations. The method of satellite remote sensing is electromagnetic waves (mainly including visible light and electromagnetic waves in the nearby frequency range). It is possible to use electromagnetic waves to remotely sense the condition of the earth's surface, but it is difficult to penetrate the water surface and penetrate deep into the water body for remote sensing and sensing of water flow. The complex changes in flow mainly originate from changes in the water body, and the representation of the water surface is often poor. This is also the fundamental reason why non-contact monitoring methods are difficult to accurately measure traffic.

2.2.2. Insufficient Spatial Resolution

Satellite remote sensing has achieved good results in large-scale, large-area natural monitoring and analysis. Significant progress has also been made in monitoring water bodies with large projected areas such as lakes and reservoirs. However, rivers are generally confined in relatively narrow channels. Although the accuracy of the current high-resolution remote sensing satellites is high for large-scale monitoring (up to 0.3m), it is still inaccurate for rivers whose widths are generally only a few meters to hundreds of meters.

2.2.3. Temporal Resolution Is the Opposite of Spatial Resolution

On the one hand, the small-scale river width requires higher spatial resolution; on the other hand, the ever-changing water flow situation requires higher temporal resolution. The inherent characteristics of remote sensing satellites determine the inherent contradiction between temporal resolution and spatial resolution. For example, satellites with higher spatial resolution have extremely low temporal resolution—such as WorldView-3, which has a resolution of 0.3 meters and a revisit period of 13 days; satellites with higher temporal resolution have extremely low spatial resolution— —For example, Gaofen-4, the revisit period is minute-level, and the spatial resolution is 400m.

In recent years, with the advancement of satellite technology, the arrival of the large-scale constellation application stage of "multi-purpose, multi-satellite networking, and multi-network integration" is promoting the improvement of satellite time and spatial resolution.

2.2.4. The Timeliness Is Not High

The main reasons for the poor timeliness of traditional remote sensing services include cumbersome data acquisition process, poor scalability, scattered resources, and low processing efficiency. At present, the information service system provided by commercial satellites such as Jilin-1 has achieved the coordination and integration of internal and external resources through the optimal design of satellite-ground integration.

It has the characteristics of fast demand response and strong service capabilities. A complete set of fully automatic and rapid response processes from data production to data distribution. Through synchronous parallelism and intelligent scheduling, decryption and decompression efficiency and hardware resource utilization are greatly improved. For routine programming photography tasks, standard images can be provided within 36 hours; emergency tasks can be digitally transmitted at the same time during imaging, and users can obtain standard images completed in production within 15 minutes at the earliest. However, it is still difficult to meet the needs of traffic testing, and the timeliness needs to be further improved.

3. Technology Roadmap for Future Development

The characteristics of remote sensing satellites make it difficult to apply them to flow monitoring. The current remote sensing satellites cannot directly measure the velocity and flow, and they are mainly calculated by relevant methods, and are calibrated and verified by traditional methods. Through investigation, we found that the research practice of remote sensing satellite for river flow monitoring is very limited, and it is almost blank whether domestic or foreign. However, satellite remote sensing represents one possible direction for hydrological monitoring after all. This paper analyzes and studies several possible technical approaches of satellite current measurement, which can be used as the focus and development direction in the future.

3.1. The Route of Traditional Calculation Method

In this way, satellites are used to monitor the water level, and the traditional water level-discharge relationship curve is used to estimate the flow. In the application of remote sensing satellites, the water depth can be estimated by means of reflection spectrum, and the water depth and water level of a fixed section can be measured by various methods, such as using the angle reflector to calibrate the position, and then the flow can be estimated by the traditional conversion relationship. In essence, it is still the traditional way of estimating the relationship between water level and flow, can be used in large lakes, reservoirs, or scenarios where the installation and operation of water level facilities are difficult.

3.2. Routes for the Transformation of Space-Time Paradigms

The traditional flow monitoring is characterized by "limited fixed section + long-duration monitoring". The characteristics of remote sensing satellites, contrary to the characteristics of traditional flow monitoring, are characterized by "large-scale space + instantaneous perception". If want to make use of the advantages of remote sensing satellites, the characteristics of satellites mast be understanded and make full use of, through the transform the space-time paradigm, exchange space for time, and use a large amount of space data to compensate for long-duration time data. The spatial scale information of the height of the water surface along the route and other information, using the hydrodynamic method, analyzes the evolution characteristics of the water flow along the length of the river, and then calculate the flow information.

3.3. The Route of Artificial Intelligence Algorithms

Although remote sensing satellites cannot obtain traditional hydraulic factors such as flow velocity and water depth, they can obtain a large amount of relevant information such as water surface width, storage capacity line, underlying surface, surrounding environment, and changes in human activities on a large spatial scale. In traditional hydrological monitoring and analysis, there is no way to establish the relationship between these factors and flow, but only use limited and well-defined hydraulic factors to carry out hydrodynamic methods (or simplified hydrological methods on this basis) calculations to obtain hydrological data such as flow. The advantage of the current artificial intelligence algorithm lies in abandoning the original known dynamic methods, using massive relevant information, self-learning and improving the algorithm, and establishing the relationship between this information and traffic.

3.4. Routes of Satellites Dedicated to Hydrology

As an extremely special industry, hydrology cannot fully meet the actual needs of hydrology by any current satellite. For the long-term development of flow monitoring, special hydrological satellites should be developed and launched, and a special hydrological satellite monitoring system should be established. This move not only enables high-scoring remote sensing of designated areas and at designated times, but more importantly, develops telemetry methods that specifically acquire relevant hydraulic factors, and conducts high-precision flow tests and other hydrological services.

4. Conclusion

At present, the technology of remote sensing satellites is advancing by leaps and bounds, the types are very rich, and the applications are relatively extensive. Revolutionary progress and applications have been made in some industries. Through investigation and analysis, we found that due to the great difference between the technical characteristics of satellites and the demand for flow monitoring, we have not found any actual cases of remote sensing satellite monitoring flow, nor have we found the use of satellites for high-precision flow testing in the short term. signs. Through research, this paper proposes future development technical routes such as traditional algorithm methods, space-time paradigm shifts, artificial intelligence algorithms, and dedicated hydrology satellites. Satellite remote sensing hydrological monitoring will be an important direction of future development.

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