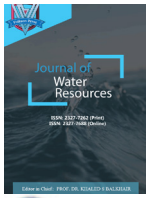
Journal of Water Resources (JWR)

DOI: *http://doi.org/10.7508/jwr.01.2020.01.05*

ISSN: 2327-7262 (Print)
ISSN: 2327-7688 (Online)
CODEN : JWROB9



ARTICLE

RESEARCH ON THE APPLICATION AND EFFECT OF SATELLITE LEAKAGE DETECTION TECHNOLOGY IN URBAN WATER SUPPLY NETWORK

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ARTICLE DETAILS

Article History:

Received 28 April 2020
Accepted 15 July 2020
Available online 21 July 2020

ABSTRACT

As a new remote sensing application direction of long-band radar satellites, satellite leakage detection technology is in the exploratory stage of application in the field of leakage control of urban pipeline networks. This paper summarizes and analyzes the application practice of satellite leakage detection in Shanghai Pudong area, and discusses the characteristics, advantages and limitations of satellite leakage detection. In terms of leak detection efficiency, through two applications of satellite leak detection technology, the number of leaks found per person per kilometer in ground manual leak detection has been greatly increased, which is more than 10 times more efficient than traditional manual inspection. Among the leaks detected by the two satellite leak detections, the proportion of road pipeline leaks and residential pipeline leaks was 30.8% and 69.2% respectively; in terms of diameter distribution, the proportion of small diameter (≤ DN50) pipelines detected leaks The proportion of leaks detected by large-diameter (>DN50) pipelines is 59.0%, and the proportion of leaks detected by large-diameter (>DN50) pipelines is 41.0%; the pipeline material has no significant effect on satellite leak detection, but the depth of burial has a greater impact on the detection of leaks. Compared with the manual inspection of leaks in the same period, the results show that satellite leak detection can significantly improve the efficiency of traditional leak detection, but the algorithm needs to be further optimized for the leak detection rate of large-diameter pipelines buried deep on the road.

KEYWORDS

Leak detection of pipe network, satellite leak detection, L-band radar satellite, urban water supply pipe network

1. RESEARCH BACKGROUND

The urban water supply network is an important infrastructure of the city. Due to the aging of the pipeline, the external environment and many other factors, the leakage of the water supply network has increased after long-term operation, and the leakage rate has remained high for a long time. Waste also brings huge direct economic losses to urban water supply enterprises [1-2]. Therefore, early detection of pipeline leakage points is the key to reducing the leakage rate of the pipeline network and the difference between production and sales, and improving the efficiency of water supply.

At present, the methods used for leakage detection of pipe network mainly include traditional listening method (listening rod, correlator, etc.) [3], minimum night flow method [4], water balance analysis method, noise monitoring equipment, and optical fiber monitoring method [5], combined with the analysis of the simulation model established by the sensor equipment to locate the leak point and other technologies. The traditional listening method uses manual inspection to traverse all pipelines for leak detection, which is the most common leak detection method in the water supply industry [6-7]. The influence of various factors such as methods often leads to low leak detection efficiency. However, methods such as the minimum night flow method, the water balance method, and the noise monitoring method all require a large amount of initial equipment investment and operation and maintenance costs [8-9], and the implementation period of the census is long.

Different from the detection principle of other leak detection methods, satellite leak detection technology obtains surface and even underground information by long-distance, non-contact, and large-scale earth observation from a high-altitude perspective [10]. It extracts and analyzes the properties and states of ground objects through data collection, transmission and processing. The core of its algorithm is "anomaly detection + water source identification". The satellite leak detection technology utilizes the strong penetrability of long-band synthetic aperture radar satellites. It can scan and obtain radar remote sensing data in the area of thousands of square kilometers at one time, and then analyze and extract the soil moisture content around the pipeline caused by pipeline leakage through algorithm model analysis. It can detect and identify the suspected water leakage area [11], assist the ground leak inspectors to quickly find and locate the leakage point, and focus the past large-scale blind inspection method to the suspected area verification in the range of 100-150 meters, which can greatly improve the leakage detection. efficiency, effectively reduce the leakage rate of the pipe network, and can detect areas that are difficult to reach by traditional inspections.

The following is a comparison of satellite leak detection technology and other leak detection technologies. Through the comparison, it can be found that satellite leak detection has obvious advantages in improving

Table 1: Comparison of satellite leak detection and other leak detection techniques

Detection method	Principle	Operating costs	Scope of test	Detection accuracy	Scope of application
listening rod	acoustic	Low	Small range	Middle	Pipes with exposed points
Correlator	acoustic	Middle	Small range	High	Deeply buried pipelines with certain external interference
Noise monitoring	acoustic	High	Small range	High	Monitoring the surrounding area of 100 meters through pipelines or valves, metal pipelines are better
Smart ball	acoustic	High	Small range	High	It is suitable for leakage monitoring of large-diameter pipelines, which need to enter the pipeline.
Optical fiber	Pressure sensor	High	Small range	High	It is suitable for monitoring new pipelines.
Satellite leak detection	Difference analysis of soil moisture and dielectric properties	High	Large range	To be evaluated, no additional equipment and O&M required	Applicable to large leak detection areas, select key leak areas for inspection

leak detection efficiency in a large area. (see Table 1)

Judging from the application and implementation effects of using radar satellites for auxiliary leak detection in many countries around the world, the accuracy of the suspected leaking areas confirmed by satellite detection is between 40% and 60%. In China, satellite leak detection has only been tested in a few cities such as Shanghai, Beijing, Zhengzhou and other local areas, and the actual effects are different. This research is based on the empirical analysis of the actual application cases in Shanghai Pudong area. At the same time, it improves the satellite-ground coordination and the continuous tracking and supervision of the leak detection platform, which improves the application effect and puts forward suggestions for the improvement and development of satellite leak detection technology in the future.

2. SATELLITE LEAK DETECTION TECHNOLOGY AND APPLICATION

2.1 Satellite Leak Detection Technical Solutions

Synthetic Aperture Radar (SAR) satellites transmit radar waves and receive echo signals from the ground. After the satellite collects data and returns it to the ground, it acquires a wide range of image information through ground imaging, radiation and geometric correction processing. Radar waves have certain penetrability and can penetrate clouds and vegetation. The longer the wavelength band, the stronger the penetrating ability. The L-band can penetrate bare soil and even asphalt roads to obtain the information contained in the underground soil. Synthetic Aperture Radar is sensitive to the dielectric properties of different ground objects. In radar images with the same imaging observation conditions such as wavelength, incident angle, and azimuth angle, the abnormal dielectric properties are extracted by extracting the difference of the backscattering coefficients of ground objects, and then Indirect access to differences in soil water content.

The main algorithm steps of satellite leak detection include image value domain transformation, feature transformation and electromagnetic noise calculation, denoising, water roughness feature map construction, water source type distinction and drinking water identification, blind spot area calculation and false alarm filtering, road and pipeline fit calculation, normalized output of suspected water leakage areas, etc. The technical process of satellite leak detection is shown in the following figure.

Satellite leakage detection must be combined with heaven and earth. First, use the wide-area coverage of satellites to conduct a census of the target area, obtain the distribution of suspected water leakage in the entire urban area at one time and quickly, and then focus on the suspected leakage areas within a radius of 100-150 meters. (Points Of Interest, POI). After the satellite scan results come out, it is also necessary to carry out manual leak detection and verification on the ground to verify and report the leakage point information. The process of satellite leak detection is shown in the following figure.

2.2 Application of Satellite Leak Detection Technology in Shanghai

In July 2021, the radar satellite was used to image the area east of Pudong, Shanghai, and the application verification of satellite leakage detection of water supply pipelines was carried out. After algorithm processing and analysis, POIs of all suspected water leakage areas in the Pudong area were obtained. In the first phase, a total of 91 POIs of suspected water leakage areas in the two small areas of Area A (with

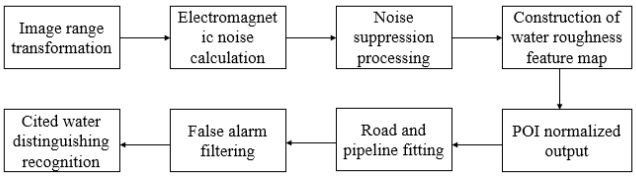


Figure 1: The technical process of satellite leak detection

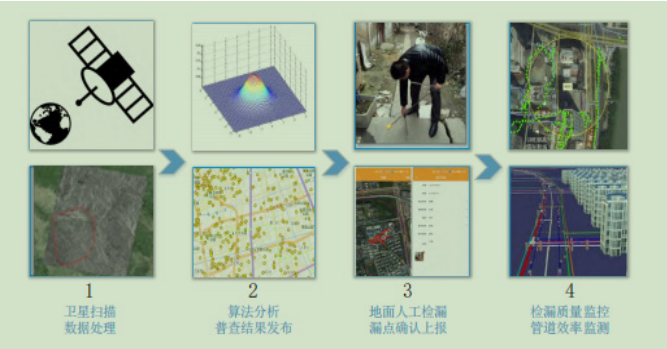


Figure 2: Satellite leak detection business process (1. Satellite scan data processing, 2. Algorithmic analysis census results released, 3. Manual leak detection on the ground to confirm and report, 4. Leak Detection Quality Monitoring Pipeline Efficiency Monitoring)

Figure 3: Coverage of the first and second phase of satellite leak detection scanning in Shanghai

an area of 8.7 square kilometers) and Area B (with an area of 26 square kilometers) were selected for ground verification and confirmation. In December 2021, radar satellites were used to image the west-south area of Pudong, most of Puxi, and Fengxian in Shanghai (the total area of satellite scanning was 923 square kilometers), and the second phase of satellite leak detection application practice was carried out. The distribution of satellite scanning coverage and ground inspection areas and suspected water leakage areas is shown in the figure below.

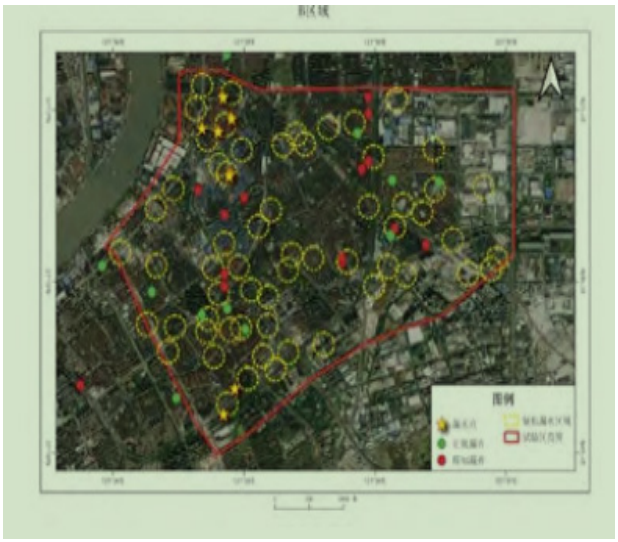
3. SATELLITE LEAK DETECTION APPLICATION CASE AND ANALYSIS OF LEAK DETECTION EFFECT

3.1 Satellite Leak Detection in Shanghai

3.1.1 The First Phase of Satellite Leak Detection

Through the inspection of 31 POIs in area A and 60 POIs in area B, the search and location of leaks were completed. Among them, 17 leaks were found in area A, and 28 leaks were found in area B. The POI accuracy rates of areas A and B were 54.8% and 46.7%, respectively. The distribution of leaks is shown in the figure below.

(Area A)



(Area B)

Figure 4: Distribution map of leaks in the first phase of satellite leak detection

In terms of leak detection efficiency, using satellite leak detection technology and satellite-ground coordination, ground-based leak detection inspectors confirm that the length of the pipeline that needs to be covered by a leak point is greatly reduced, the number of leak points found per person per day and the number of leak points found per person per kilometer The number of points increased by 9.9 times and 15.4 times respectively.

3.1.2 The Second Phase of Satellite Leak Detection

After data processing and analysis, 190 POIs in the Pudong area were obtained. Through the manual inspection of Tinglei Company, a rapid initial inspection was carried out on 190 suspected water leakage areas in the Pudong area, and 51 leaking points were found; after that, some pipelines were inspected. The POIs with incomplete coverage were re-inspected. A total of 80 POIs were re-inspected, and 21 new leaks were found. Since some other real leaks from other sources have been discovered or fixed during the inspection period, a total of 41 leaks are located in POIs. Therefore, among the 190 POIs provided by the satellite leak detection technology, a total of 113 leaks were found, and the POI accuracy rate was 59.5%.

In terms of leak detection efficiency, through the second phase of satellite leak detection and satellite-earth collaborative practice in Pudong, the distance of pipeline inspection by ground leak detectors for leaks has also been greatly reduced. The number of leaks increased by 12 times and 19 times, respectively.

Through the application practice of the above two phases of satellite leak detection, it is found that the satellite leak detection technology provides a total of 281 POIs and detects 158 leak points. The POI leak detection efficiency provided by the satellite leak detection technology is 56.2%. The percentages of leaks in the pipelines of point and community are 30.8% and 69.2%, respectively.

3.1.3 Diameter Distribution of Satellite Leak Detection

In order to study whether the satellite leak detection efficiency is affected by the pipe diameter, through the analysis of the effective leak repair data (as shown in Figure 5), it is found that the proportion of small diameter (≤ DN50) pipeline detected leak points is 59.0%, and the large the proportion of leak points detected in the diameter (> DN50) pipelines is 41.0%, and there is one leak point for DN300, DN500, and DN1000 among the large-diameter leak points. The analysis shows that the current satellite leak detection technology has relatively high detection efficiency for small-diameter leaks, and the algorithm needs to be further optimized in the future to improve the leak detection efficiency of large-diameter pipelines.

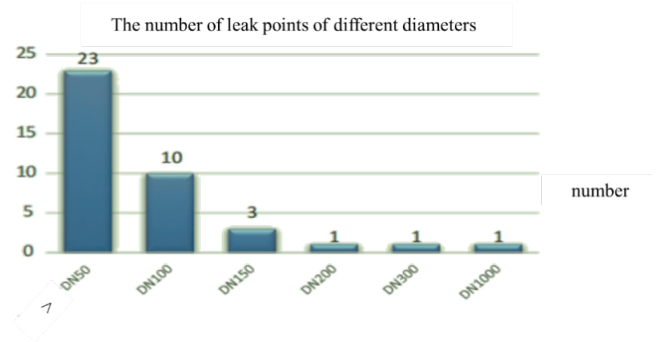


Figure 5: Distribution of calibers of effectively repaired leaks by satellite leak detection

3.1.4 Distribution Law of Fault Elements in Satellite Leak Detection

It is assumed that the amount of water saved after repairing a certain leak point is called the amount of leakage repair revenue. In the data of this satellite leak detection, it is found that the leakage points of water meter accessories and valve accessories account for 43.6% of the effectively repaired leakage points, which is a relatively high proportion. However, this type of leaks are mainly leaks, and the average leak repair revenue is only about 3.01 L/min. In comparison, the leaks in the pipeline and pipe fittings have a relatively large amount of water leakage, and the average leak repair revenue can be up to 114.12L/min. In addition, this satellite leak detection found that the secondary water supply tank overflowed in 2 places, and the average water volume of leak repair revenue was 60.52 L/min, and the water volume was relatively large. From the perspective of leakage control, we hope that the satellite leakage detection technology can find more leakage points with large water leakage such as pipelines, pipe fittings and overflow of secondary supply facilities.

The above analysis shows that the satellite leak detection technology has a good effect on the detection of obvious leaks such as water meters,

valves, and secondary supply overflows, but it is still necessary to continue to improve the leak detection efficiency of pipelines and pipe fittings.

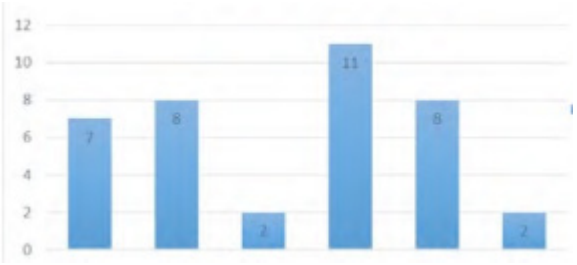


Figure 6: Distribution of fault elements in satellite detection leaks: The number of leakage points of different fault elements

3.1.5 Distribution Law of Materials in Satellite Leak Detection

In the practical application of satellite leak detection technology, it is found that the pipe material does not have a great influence on the leak detection. It can be seen from Figure 7 that PPR and copper, which account for a relatively large proportion, are leaking water meter fittings, while PVC and white iron are mainly caused by damage to old pipes and fittings in some intensive areas, while valve fittings leaking accounts for 67% of cast iron materials. All three pipes of PVC, white iron and cast iron can detect hidden leaks, indicating that the correlation between satellite leak detection and pipes is low.

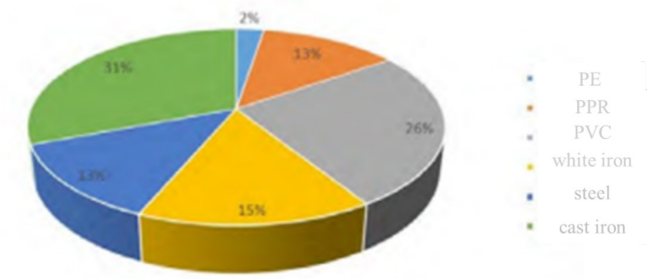


Figure 7: Distribution of materials in satellite detection leaks: Number of leaks

3.1.6 Distribution Law of Buried Depth of Satellite Leak Detection

The buried depth of the pipeline is also one of the factors affecting the efficiency of leak detection. Among the effective samples of leaks detected and repaired by satellite leak detection, 29 leaks were detected in pipelines with shallow depths (≤ 0.5m), accounting for 74.4%; m) 10 leaks were detected, accounting for only 25.6%. According to the preliminary analysis of the data, the satellite leakage detection technology under the current algorithm can quickly locate small-diameter, shallow buried depth, water meters, valves and other visible leakage on the ground, but whether it can accurately locate large-diameter and deeply buried pipelines The leakage needs to be further verified by follow-up practice.

3.2 Comparative Study on the Effect of Satellite Leak Detection and Traditional Leak Detection

3.2.1 Analysis of Water Volume Control for Satellite Leak Detection

Through the analysis of 39 valid sample leak points detected and repaired by satellite leak detection, combined with photos and videos of leak point excavation, and estimated the amount of water lost through measuring cylinders, beakers, etc., it was found that satellite leak detection and artificial patrols without satellite detection were used. The ratio of revenue to water for leak detection (hereinafter referred to as "self-detection") is about 1:4. Among them, the water volume of repairing revenue of 27 leakage points is less than 1 L/min, and the main leakage points are water meters (Figure 9a), valves (Figure 9b), and pipe fittings (Figure 9c). 1 L/min, mainly due to pipeline leakage (Figure 9d). The results show that the leakage of leaks detected by the satellite leak detection technology under the current algorithm is still relatively small, and the detection ability of road pipelines with large diameter, deep burial depth and large water leakage needs to be improved.

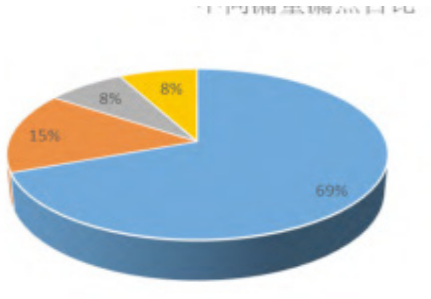


Figure 8: Distribution of water leakage detected by satellite: The proportion of different leakage points

Figure 9: On-site photos of satellite detection leaks

3.2.2 Efficiency Analysis of Satellite Leak Detection and Autonomous Leak Detection

Before the application of satellite leak detection technology, leak detection mainly relied on the traditional manual inspection and hearing leak detection (autonomous leak detection) method. After obtaining images from satellites in the first phase, autonomous leak detection was carried out, and a total of 67 leaks were found in the community. After obtaining POI through satellite image analysis, a total of 27 leaks were detected in the cell, of which 17 were newly detected leaks and 10 were detected leaks. The data shows that there are 84 leaks detected in the

Table 2: Efficiency analysis of satellite leak detection and autonomous leak detection

Leak location	The number of leak points detected by satellite leak detection			Total number of detected leaks	Proportion of satellite leak detection
	New discovery of satellite leak detectio	Self-discovery has been mastered	Subtotal		
Community	17	10	27	84	32.1%
Road	12	0	12	25	48.0%
Summary	29	10	39	109	35.8%

first phase area, and 27 of them were detected by satellite leak detection, with a detection rate of 32.1%, and the detection rate of satellite leak detection on roads was 48.0% (details). See Table 2). This means that satellite leak detection POIs with a radius of 100-150 meters can detect about one-third of the cell leaks and about half of the road leaks in the target area.

The proportion of satellite leak detection in the community is slightly lower than that on the road. The reason is that the long-wave satellite will be affected by factors such as the angle of the photo, the nature of the ground, whether there is a building, and whether there is an overhead block. The leak detection technology was originally used to find water sources in relatively dry desert areas. However, due to the high soil moisture content in Shanghai area, the soil dielectric constant will be quite different. Therefore, a large number of leak points need to be passed through the soil dielectric constant range in Shanghai area. Only after review and optimization can the leak detection efficiency of satellite leak detection technology be further improved.

4. CONCLUSIONS AND RECOMMENDATIONS

The above application practice shows that the ratio of detectable leak points in the POI in the suspected leak area with a radius of 100-150 meters provided by satellite leak detection can reach 56.2%. The increase is more than 10 times, and it has full practical value.

The means to improve the efficiency of satellite leakage detection technology in the future can include three aspects. The first is the satellite technology itself, the second is the improvement of the satellite leakage detection algorithm, and the third is the combination of heaven and earth and the coordination of satellite and earth. With the continuous advancement of domestic satellite technology for civilian use, the convenience of obtaining satellite images is getting higher and higher, and the cost is lower and lower, which has laid the foundation for the further development of satellite leak detection technology. Through the above analysis, it can be found that the existing satellite leakage detection technology can only find about one-third of the residential water leakage points and about half of the road water leakage points in the target area, and there is still room for improvement in this regard. At the same time, the satellite leak detection technology also has problems such as the small amount of water leakage in the detection of leakage points, and the lack of detection ability for large-diameter pipelines, deeply buried pipelines, and leakage points with large water leakage, which need to be improved by improving the algorithm. In addition, the POI provided by satellite leak detection technology still needs to use other leak detection methods (such as traditional artificial listening method or related instrument method) to determine the location of the leak point. The leak detection efficiency of satellite leak detection technology can be improved to a greater extent.

Satellite leak detection technology is not a substitute for traditional manual inspection leak detection technology, but an efficiency multiplier for manual inspection leak detection and other technologies. It can quickly provide the POI of the suspected leakage area, which greatly saves the leakage detection time and improves the leakage detection efficiency. The advantages are obvious, and it is worthy of further research and promotion.

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