ADVANCED LEAK DETECTION TECHNOLOGIES FOR PUBLIC WATER NETWORKS

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ABSTRACT: *Water leakage in public water distribution networks presents a major challenge for municipalities and utilities, leading to resource depletion and financial inefficiency. This short paper explores the application of advanced technologies – Hydrogen Tracer Gas, Acoustic Leak Detection and Satellite Leak Detection – to improve early detection and elimination of leaks. The tracer gas method, using the Hydrolux HL7000, is a non-invasive, highly sensitive and environmentally safe method, but requires careful handling of the gas and can be affected by soil conditions and pipe depth. Acoustic leak detection, demonstrated by the LeakPen device, is based on the capture and analysis of sound waves generated by pressurized water escaping through holes in the pipe. This method offers portability and accuracy, but can be influenced by pipe material and background noise. Satellite leak detection, using spectral analysis and microwave reflectometry (as used by Utilis), allows for large-scale, remote leak detection by identifying surface anomalies such as unusual vegetation growth or increased soil moisture. This approach offers broad coverage and integrates with Geographic Information System (GIS) data for precise location, although it faces challenges such as resolution limitations, weather dependency, and high initial costs.*

The paper highlights that while each technology has distinct advantages and limitations, their combined application can significantly improve leak detection and water conservation efforts. Integrating these innovative methods with existing infrastructure and data analytics can provide a more efficient and proactive approach to water network management. Future advances in sensor technology, artificial intelligence, and automation are expected to further refine these methods, contributing to the sustainable management of water resources and reducing operational costs for utility companies around the world.

Keywords: *leak detection; tracer gas; acoustic sensors; satellite detection; public water networks*

1. Introduction

Water is a precious resource, and water loss from distribution networks due to failures and inefficiencies poses a significant challenge to utilities and municipalities.

In its early stages of development, leak detection relied on manual probing and reactive maintenance, which can be time-consuming, labor-intensive, and less effective in identifying small or hidden leaks.[1] The adoption of advanced technologies, including hydrogen gas, acoustic leak detection, and satellite imaging, offers new possibilities for early and accurate detection of water leaks.

This paper aims to provide a review of these technologies, examining their operating principles, applications, and potential for integration into water leak detection systems. We also discuss future trends and innovations that could further improve their effectiveness.

1.1. Experimental. Tracer gas – using Hydrolux HL7000 equipment

The circulation of water in nature is a complex process, involving a number of other processes: evaporation, condensation, precipitation, surface runoff, infiltration, groundwater flow, etc., which cause water to pass from one state of aggregation to another along the way.

This circulation conditions the runoff from the land surface (running waters come from atmospheric precipitation), contributes greatly to the formation of groundwater reserves, and also provides water in the soil needed by vegetation.[2]

Hydrogen can be detected using a variety of methods, including gas chromatography, thermal conductivity detectors, and electrochemical sensors. The choice of detection method depends on the required sensitivity, environmental conditions, and specific application.

Gas chromatography is often used in the laboratory due to its high accuracy, while electrochemical sensors are more practical for field applications due to their portability and ease of use.

Tracer gas is used to locate leaks in water pipes that are not identified with the acoustic method used traditionally. More difficult to implement, this method allows for a timely mapping of all leaks, thus prioritizing damage repairs and scheduling pipe replacements. The helium used is odorless, tasteless and has no impact on water quality. It is injected in very small doses into a drinking water network without interruption in service or in the distribution or use of water. The location accuracy is less than one meter.[3] Hydrogen, being the smallest and lightest molecule, escapes even through the smallest leaks / holes, where it can be detected at the surface using specialized sensors, such as the SebaKMTHydrolux HL7000 equipment (Fig. 1).

Fig. 1. Gas tracer device

Highly sensitive hydrogen detectors are used to scan the surface above the pipe, identifying the exact location of the leak. Locating leaks with hydrogen tracer gas requires the use of an inexpensive gas mixture (95%N2/5%H2). This gas mixture is environmentally friendly, non-toxic (approved as a food additive), non-flammable, non-corrosive and available from most common gas suppliers. Information about the location of the pipe, its size and length are important factors for successful leak detection. Preparation for leak detection begins by emptying the pipe or can be done with the pipe water pressurized but sectioned.

The section of the pipe to be tested is inject with the gas at low pressure (0.5 - 1 bar) into one end and release it at the other end Fig. 3. This will ensure that the entire length of the pipe is filled with tracer gas. Wait until the gas rises to the surface. Various geological materials (structures), to be considered aquifer materials, contain water and have the capacity to transport or allow the transfer of water (through the soil and subsoil).[2]

The time required for preparation can vary considerably depending on the soil material and the depth of the pipe Fig. 2.

MATERIAL	DEPTH	TIME
Dry sand	1 m	25 min
Dry soil/wet sand	1 m	1 h
Wet soil/dry clay	1 m	4 h
Wet clay	1 m	13 h
Asphalt	5 cm	15 h
Concrete	20 cm	23 h

Fig. 2. Table of time it takes of the gas to emerge

To summarize there are three major and simple steps:

- Inject Gas – Fill the pipe to be tested with tracer gas and ensure that it has reached the full length of the pipe by measuring the gas at the far end (Fig. 3);
- Locate Leak – Walk along the pipe and determine any gas leaks to the surface, stopping every 50 cm to extract new samples with the surface probe Fig. 3, by creating a

Fig. 3. Preparation and injecting tracer gas

vacuum. Clear alarm indications on the LCD screen will guide you to the leak point (Fig. 4);
- Verify Repair – Repair the fault and verify by performing a pressure test. There is no need to evacuate the tracer gas after locating the leak (Fig. 5).

Fig. 4. Detecting the gas

Fig. 5. Repairing the leak

1.2. Acoustic leak detection – using LeakPEN

Some authors consider leak detection technology to be divided into two broad categories: direct and indirect or inferential methods.[4]

Acoustic leak detection is a direct technique that detects the sound emitted by pressurized water in a pipe. Acoustic sensors, such as hydrophones or geophones, are deployed along the pipe to capture the noise generated by the leak, which is then analyzed to identify the location.

The LeakPen is a portable acoustic leak detection device (Fig. 6), designed to detect water leaks in both water distribution pipes. Its design emphasizes ease of use, accuracy, and portability, making it an attractive option for water utilities and maintenance teams.

Acoustic detectors, such as the LeakPen, use sensitive microphones to capture these sound waves. The device amplifies and filters the sounds, allowing the operator to identify the location of the leak. By moving the sensor along the pipe (Fig. 7), the operator can listen for changes in sound intensity, which indicates the approach to or distance from a leak.

Advanced acoustic devices also use algorithms to analyze sound patterns, helping to differentiate between water loss sounds and other background noise.[5]

Fig. 6. LeakPEN – acoustic detection device

Fig. 7. Device in action

To turn on the LEAKPEN from sleep mode (OFF) we must shake it once along any axis until all ten LEDs are lit for 3 seconds to verify their operation and display the battery voltage level, the device now goes into measurement mode (ON). Also in this mode it initializes its software and internal sensors (Fig. 8).

Fig. 8. Starting the device

LEAKPEN is a battery-operated acoustic measurement and identification device, that picks up sounds from the water pipes under inspection or directly on accessible parts of the pipe, such as valves, hydrants or exposed pipe sections.

The device transmits audio signals to headphones using Bluetooth technology. To provide the best audio quality, automatic analog-gain control is used.

The device continuously measures the audio signal level and displays the minimum measured value at one-second intervals via the 9 red LEDs (Fig. 9).

Fig. 9. Display level intensity

1.3. Satellite method – using Utilis

Over the past four decades, satellite remote sensing techniques have played an increasingly important role in assessing groundwater quantity and quality, largely due to technological advances, including improvements in instrumentation/sensor and image algorithm/processing.[6]

Satellite imaging is a remote sensing technology that uses high-resolution satellite data to monitor large areas for signs of water leakage. This method involves analyzing surface anomalies, such as soil moisture, that may indicate the presence of underground water pipe damage. Using the same satellite technology used to search for water on other planets, water utilities will now have the ability to locate water leaks over thousands of square kilometers—all through aerial scans from space (Fig. 12).

Satellites (Fig.13), equipped with multi-spectral and infrared sensors capture images of the earth's surface, which are then analyzed for patterns that indicate water loss. For example, unusually high levels of soil moisture or abnormal vegetation growth along a pipeline's route can signal a leak.

Utilis technology uses spectral aerial imagerytaken from satellite-mounted sensors- to identify leaks in underground distribution pipes. The raw images are then overlaid over GIS systems maps and processed by Utilis' unique algorithms. [7]

The algorithm detects potable water by looking for a spectral "signature" specific to potable water. The customer is then presented with a graphical report of the identified leaks, overlaid on a map with information about streets, pipes, and dimensions.

The detection process is based on microwave reflectometry, a technique that uses electromagnetic microwave signals to detect the presence of water below the surface of the earth.

Microwaves are particularly effective for this application due to the relatively high dielectric permittivity of water. This physical property makes water very responsive to microwave signals, allowing for precise detection and measurement even underground.

Images received from satellite are subjected to rigorous mathematical manipulation and analysis by a primary algorithm specifically designed to

Fig. 12. Satellite method

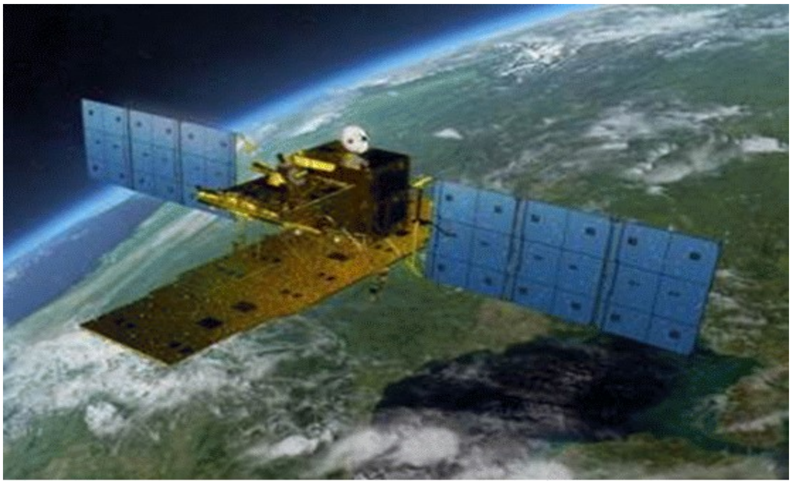

Fig. 13. Multi-spectral imaging satellite

identify signs of underground leaks. The algorithm detects anomalies in the spectral data that suggest the presence of water leakage and subsequently generates a coordinate vector indicating the potential locations of the leaks.[8]

A critical aspect of the Utilis technology is the selection of a specific microwave wavelength, chosen for its dual advantages: its ability to penetrate the ground and its increased sensitivity to the characteristics of the treated water. This sensitivity ensures that the system can distinguish between different types of water sources, increasing the accuracy of leak detection.

One of the key operational advantages of Utilis satellite scanning technology is its ability to perform periodic topography (Fig. 14). Depending on the customer's needs, Utilis can provide monthly or quarterly updates on the status

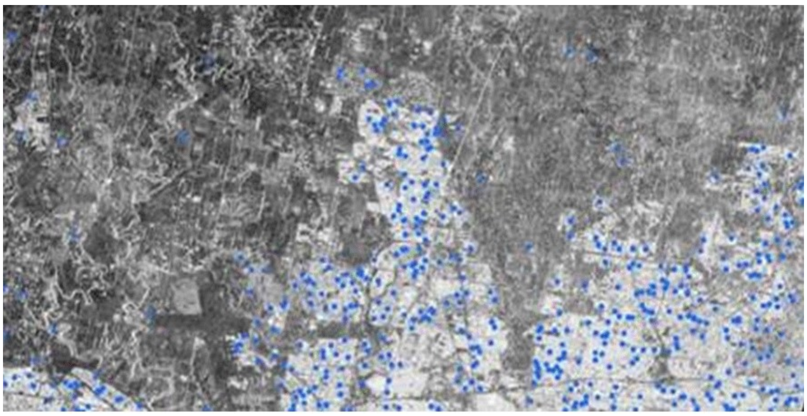

Fig. 14. Blue dots represent water losses identified from satellite

of the entire network. Once potential leaks are identified via satellite, the information can be used to guide detection teams, significantly reducing the time required for field correlation. Typically, only 2-4 days of field work are required to isolate the leak to a precise location, allowing detection teams to focus their efforts only on the identified areas.

2. Results and discussion with advantages and limitations

2.1. Hydrogen gas tracing

The key advantage of tracer gas is its ability to detect very small faults that may not be detectable by other methods. It is also non-invasive and can be used without interrupting the water supply. However, the method requires careful handling of the gas, and the detection process can be influenced by soil conditions and the depth of the pipe. Despite its potential, the use of hydrogen for water leak detection is not without its challenges. Some of the primary limitations, such as detection in complex environments, soils with high organic content, or areas with significant background hydrogen levels, can be challenging. The presence of other gases or chemicals can interfere with hydrogen detection, reducing accuracy. Another limitation is that implementing hydrogen tracking in large water pipelines can require significant investment in infrastructure, such as specialized sensors and monitoring equipment.

This can be a barrier to adoption, especially in resource-limited regions, as while hydrogen is generally safe to use, it is also highly flammable. Proper safety protocols must be followed when using hydrogen, especially in industrial environments where the risk of ignition is higher.

2.2. The LeakPen

The LeakPen is designed to be lightweight and easy to use Fig. 10, allowing operators to conduct water leak detection surveys with minimal training. Its portability makes it ideal for use in a variety of settings, from large municipal systems to small residential properties (Fig. 15).

Fig. 15. Portable

Accuracy and Sensitivity

LeakPen's sensitive microphone and advanced sound processing capabilities allow it to detect even the smallest leaks (below 1 mc/h). This high level of accuracy ensures leaks are identified before they can cause major damage or significant water damage (Fig. 16).

Fig. 16. Easy operation and detection

Cost-Effectiveness

By enabling quick and accurate leak detection, the LeakPen device helps reduce water losses and the associated costs. Its relatively low cost compared to other advanced leak detection technologies makes it an affordable option for utilities and maintenance teams.

Dependence on Pipe Material

The effectiveness of acoustic leak detection can vary depending on the material of the pipe. For example, metallic pipes tend to transmit sound better than plastic pipes, making leaks in plastic pipes more challenging to detect with acoustic methods.

Background Noise Interference

Like all acoustic devices in noisy environments, such as urban areas or industrial sites, background noise can interfere with the detection of leak sounds. While the LeakPen device includes filtering algorithms to minimize this interference, highly noisy conditions can still pose challenges, but not impossible.

Lack of phone/tablet application

The lack of a dedicated phone app for a device or software updates limits accessibility and ease of use for technicians. Without an app, users may face challenges in real-time data analysis, remote monitoring, and the ability to quickly share results with other team members.

A mobile app could streamline the detection process, offering features such as real-time acoustic signal visualization, GPS tagging of damage detected in the field, and integration with cloud-based systems for data storage and analysis. This functionality gap can hinder the efficiency and effectiveness of leak detection operations.

2.3. Satellite Imaging

Comprehensive Coverage with Periodic Updates

One of the towering features of Utilis' technology is its ability to survey an entire water system within a single screening. This capability allows for the efficient monitoring of very large areas, eliminating the need for the years-long surveys typically required by conventional methods. Instead, Utilis provides periodic updates-monthly or quarterly-offering a dynamic and continuous assessment of the water network's integrity over time. This ongoing monitoring helps utilities stay ahead of potential issues and maintain optimal system performance.

High Leak Detection Rate

Utilis significantly improves the efficiency of ground detection teams by providing actionable data that leads to the identification and verification of a significant number of leaks every day. With reports issued by Utilis, detection teams can identify and confirm anywhere from 5 to 15 leaks daily. This high detection rate not only ensures consistent results over time, but also contributes to a significant reduction in non-revenue water, which is a critical concern for drinking water companies.

Sensitivity to Small Leaks

The Utilis system is designed to detect even the smallest leaks, with a minimum detectable size of just 0.1 liters per minute. This level of sensitivity ensures that leaks are identified and addressed before they can escalate into more significant issues, further protecting the integrity of the water distribution network and reducing water loss.

Integration with GIS Data

Another key feature of the Utilis system is its integration with Geographic Information System (GIS) maps. The system output is overlaid with detailed location data, such as water main positions in the distribution network. This integration enables precise location of leaks and improves the accuracy and usability of the data provided to field teams..

No initial installation costs

Utilis' remote sensing technology does not require installation or modifications to existing infrastructure, making it a cost-effective solution. The technology operates remotely, using sensor input and combining it with data that is either publicly available or managed by local authorities or utility companies. This eliminates the need for costly and time-consuming installations, allowing utilities to implement the system with minimal disruption.

User-Friendly and Intuitive Output

Unlike many remote sensing technologies that require specialist knowledge or external consultancy to interpret results like GPR, Utilis offers an intuitive and accessible service. The output is designed to be user-friendly, allowing untrained personnel to easily understand and act on the data. This ease of use reduces the need for extensive training and allows utilities to quickly integrate the technology into their operations.

Proven Effectiveness in Reducing Non-Revenue Water

The effectiveness of Utilis' technology is best evaluated by its impact on reducing non-revenue water—both economically and logistically. By identifying leaks early and accurately, the technology helps utilities significantly reduce water loss, thereby improving their financial performance and resource management. This makes Utilis not only a technological innovation but also a valuable tool for achieving sustainable water management goals.

Resolution Limitations

The spatial resolution used by satellite imagery can be a limiting factor, especially for detecting small damage. The area identified by satellite imagery is large (around 150 – 200 m2) and requires narrowing down the damage area with the help of field detection teams.

Weather Dependence

Weather conditions, such as cloud cover, can affect the quality of satellite images, particularly in the visible and infrared spectra. This can lead to gaps in data or reduced accuracy in leak detection during adverse weather conditions.

High usage costs

Although there are no initial installation costs, setting up to use satellite data, including purchasing high-resolution imagery and investing in analysis software, can be expensive. However, these costs can be offset by the long-term benefits of effective fault detection and water conservation.

3. Conclusions

In the context of modern water management, the detection and mitigation of leaks are paramount to conserving resources and enhancing the efficiency of distribution systems. This paper has explored three advanced technologies-Hydrogen Gas Tracing, Acoustic Leak Detection, and Satellite Imaging-each offering unique advantages and addressing specific challenges associated with traditional leak detection methods.

Hydrogen Gas Tracing, using technologies like the Hydrolux HL7000, demonstrates exceptional sensitivity in detecting even the smallest leaks. This method's non-invasive nature and ability to function without disrupting water supply make it particularly valuable for precise leak localization. However, its effectiveness can be influenced by environmental factors such as soil conditions and pipeline depth, and the necessary safety protocols for handling hydrogen must be diligently followed.

Acoustic Leak Detection, exemplified by the LeakPen device, offers a portable and cost-effective solution for pinpointing leaks through sound analysis. Its ease of use and high accuracy make it an attractive option for both residential and commercial applications.

However, its performance can be hindered by background noise and the material composition of pipes, and the lack of integration with mobile technology presents a barrier to more streamlined operations.

Satellite Imaging, as employed by Utilis, represents a cutting-edge approach to large-scale water loss detection. This method's ability to cover extensive areas and provide periodic updates allows for continuous monitoring of water networks, significantly reducing the time and labor associated with traditional leak detection. While the technology excels in its comprehensive coverage and integration with GIS data, it faces challenges related to resolution limitations, weather dependence, and the initial costs of implementation.

Each technology reviewed in this paper brings distinct strengths to the table, offering utilities and municipalities a range of options to enhance their leak detection capabilities. As the industry moves forward, the integration of these technologies, coupled with ongoing innovations, will be crucial in developing more robust and efficient systems for water management. By adopting these advanced methods, water utilities can achieve significant reductions in non-revenue water, improve operational efficiency, and contribute to the sustainable management of this vital resource.

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