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Modern methods for monitoring water leakages in water networks

Abstract: The main idea of this article is to adopt the thesis that the main and, at the same time, the most effective (apart from proper maintenance and operation) element of the strategy of limiting water losses in water supply networks is continuous integrated monitoring of the network using the latest achievements of IT technologies, including GIS (Geographical Information System), GPS (Global Positioning System), GSM (The Global System for Mobile Communications) and software based on a cloud platform.

Considering the above, the paper highlights the problem of leakages against the background of water deficit in the world and proposes a classification of methods for detecting and estimating the size of leakages. On the basis of available literature sources, selected modern and, in the authors' opinion, most interesting water loss monitoring systems enabling leak detection and estimation of the amount of wasted water are presented. Then, these methods are analysed, pointing to their strengths and weaknesses in terms of leak detection efficiency.

Keywords: water supply networks; monitoring; water leakages.

1 Introduction

Water losses constitute a serious operational issue for water networks all over the world. This is reflected, for instance, in their amount. According to the World Bank,

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the water losses, specifically the global amount of non-revenue water (NRW), was estimated at approximately 48 billion m^3 per year in mid-2010s, which translated into financial losses of 14 billion USD [Kingdom et al., 2006]. It should be noted that more than half of this amount was lost in developing countries. In 2018, the amount of NRW increased to about 126 billion m^3, that is, 2.5-fold, which generated approximately 39 billion USD of financial losses [Liemberg & Wyatt, 2018].
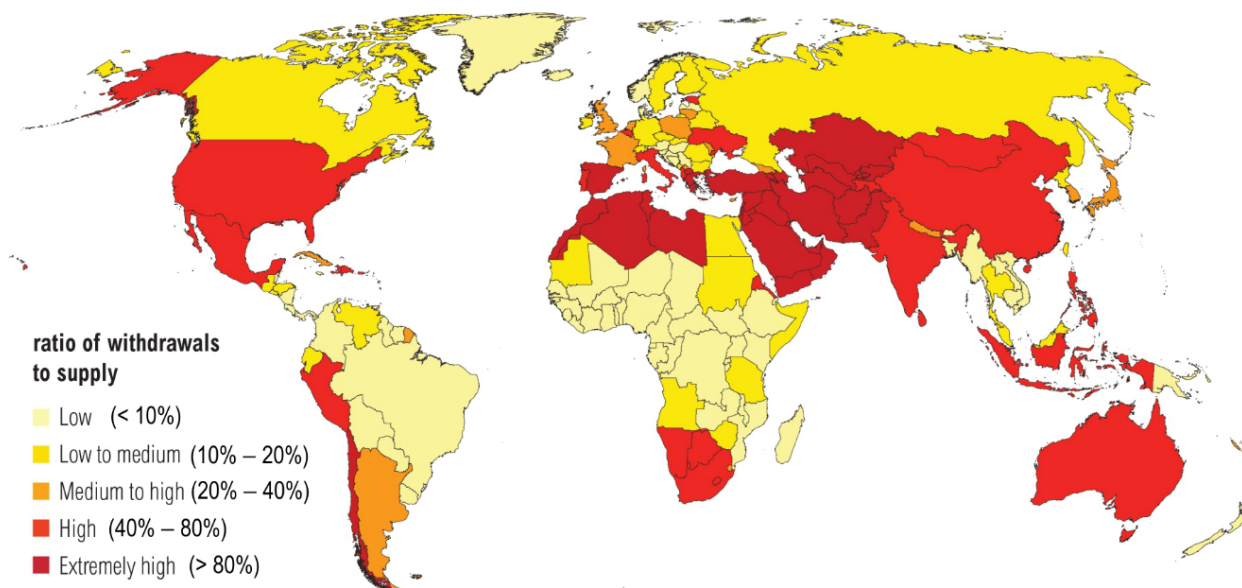
Such great amounts of drinking water are lost in the times of apparent global water deficit. The global fresh water resources are modest, increasingly polluted and unevenly distributed in regard to recipients. The share of freshwater in global water resources is estimated at about 2.5%, with only 1% being suitable for drinking. Simultaneously, according to the World Health Organisation (WHO), over a billion people have no access to drinking water. In Europe alone, it is as many as 100 million people (over 13% of European citizens). The main reason is the constantly deteriorating water quality as a result of industrial development, urbanisation, agriculture as well as the increasing global population, and more recently, climate change. The rate at which the amount of freshwater suitable for consumption is declining shows that it will become a highly sought-after resource in the near future. According to the forecast of the Organisation for Economic Cooperation and Development (OECD), the demand for water is expected to more than double by 2050 [EEA, 2018; OECD, 2012].

It is worth quoting the World Resources Institute's forecasts for the water deficit until 2040. As many as 33 countries will experience extreme water deficit, including 14 located in the Middle East. Large countries such as the USA, China and India were also mentioned in the research report, occupying the positions near the top (Fig. 1) [wri.org]

Compared to European countries, Poland has very little water resources available for use. Annually, it is on average about 1600 m^3 per capita. In periods of drought, this indicator drops to the level of 1000 m^3/(year • inhabitant), which means that the country is threatened with water deficit. For comparison, the same indicator per European is 4500 m^3 per year, on average, and the global

Water Stress by Country: 2040

**ratio of withdrawals
to supply**

- Low (< 10%)
- Low to medium (10% – 20%)
- Medium to high (20% – 40%)
- High (40% – 80%)
- Extremely high (> 80%)

NOTE: Projections are based on a business-as-usual scenario using SSP2 and RCP8.5.

For more: ow.ly/RiWop

WORLD RESOURCES INSTITUTE

Figure 1: Predicted water stress in the world by 2040 according to WRI.

mean is 7300 m³/inhabitant and year [http://www.pfozw.org.pl].

Water leakages from water supply systems are generally the result of randomly occurring pipe failures. However, their scale is important. In general, water from the damaged pipe flows to the ground surface, which makes it easier to locate the leakage point. However, in many cases, the leak does not reveal itself so easily, spreading in the ground and going unnoticed for a long time. The most difficult to detect are the leakages that never show up and are located at the bottom of the pipeline. In this case, the water flows out with little intensity and usually soaks into the ground.

Most leaks cause damage to the immediate and further surroundings of the damaged pipe, that is, damage to the soil structure and weakening of its load-bearing capacity, flooding of low-lying rooms in buildings, tunnels and underground passages, flooding streets and pedestrian ways (communication difficulties, damage to vehicles), and even lead to construction disasters (destruction of underground building structures, washing the foundations and collapse of the building). This results in economic, social and environmental costs.

It should be emphasised that the highest quality water is lost as a result of failure. Commonly, water supply networks distribute water of the quality intended for human consumption despite the fact that it is also used for other purposes that do not require such quality, for example, irrigation, street watering, maintenance of urban greenery, washing vehicles, etc. Therefore, there is systematic work in the world to improve the methods of the most accurate detection and estimation of leakages in order to save drinking water. These activities will now also be supported by the new Drinking Water Directive (2020/2184), according to which all EU Member States in the next 5 years will have to determine the size of leakages and reduce them if they exceed a certain threshold. In order to determine this threshold of water losses, the Directive recommends the use of the Infrastructure Leakage Index (ILI), [European Commission, 2015; Ramm, 2021], which is the ratio of actual water losses to unavoidable losses [European Commission, 2015; Ramm, 2021; Lambert & McKenzie, 2002; Kwietniewski, 2013].

2 Method and scope of work

The main idea of this paper is the assumption that continuous, remote monitoring of water networks, including integrated measurements of pressure, flow and noise accompanying the flow of water in pipes and using the latest achievements of IT technologies (including GIS, GPS, GSM and software based on a cloud-based platform), currently constitute the most effective solutions in reducing water losses in its distribution systems. The main effect of such monitoring is effective leak detection and creating possibilities of estimating the amount of lost water. The possibilities of using the monitoring system both in a stationary and mobile way are highly important.

This assumption is justified by the intensive development of new, innovative technologies of online network monitoring in terms of leak detection and estimation of the amount of lost water. It is noticed by both network operators and companies implementing such technologies, followed by producers of appropriate devices.

The basis for presenting the latest achievements in the field of remote monitoring of water leakages in water supply networks was the literature studies taking into account various types of available source materials, including mainly scientific and technical publications, as well as the materials obtained directly from the authors of certain technologies. The aim of the work was to investigate the modern systems for monitoring water leakages from water supply networks on the example of selected systems.

Bearing the above in mind, the paper presents modern and interesting leakage monitoring systems associated with the possibilities of estimating the amount of water lost. At the same time, attention was paid to the issue of system classification. Then, they were analysed, pointing to their strengths and weaknesses in terms of the effectiveness of reducing the drinking water leakage from water supply networks.

3 Classification and selected water leakage monitoring systems

Currently, there is a huge variety of methods and technical devices for leak detection, specialised computer software and, to a lesser extent, leak detection methods with the possibility of simultaneously estimating the amount of water lost. This diversity is followed by various classifications of methods in relation to many criteria

[Hamilton & Charalambou, 2013; Mutikanga et al., 2013; Brockett, 2021]. Presumably, due to the abundance of methods and related devices as well as the specificity and scope and accuracy of the tools used, it has not been possible to classify them unequivocally so far. Taking into account too many criteria would lead to fragmentation of the classification of methods [Miszta-Kruk et al., 2015].

Considering the above, in this paper, it was decided to present the most modern solutions in the strategy of reducing water losses, according to the authors. They involve continuous integrated pressure, flow and noise monitoring systems in water supply networks using modern achievements of information technology. On the basis of an in-depth analysis of the available source materials, a dozen systems were analysed in this group, out of which the following systems have been discussed as the most interesting and effective: AQS-SYS, FIDO system, WLM system, PermaNET system and SmartFlow system. Additionally, an interesting solution for internal water supply systems as the last link in the drinking water supply system has been presented.

3.1 ASQ-SYS system

The system enables data collection, analysis and visualisation of results. The principle of the system is based on continuous automatic acoustic monitoring water supply network through special sensors, permanently placed on the elements of utilities (hydrants and gate valves) at 300–500 m (steel, asbestos-cement and polyvinyl chloride [PVC] pipes) or 300–400 m intervals (polyethylene [PE] pipes) (Figs 2 and 3) [Aquarius-spectrum, 2020].

These highly sensitive thin film sensors are the basis of the monitoring system and can be configured to match the frequencies of pipelines made of various materials such as metal, asbestos-cement, plastics and others. The sensors operate in the frequency range of 1–2000 Hz and are equipped with GPS modules and GSM data transmission modems, ensuring fast communication and data transmission on the sensor–software path. Broadband GSM technology enables cellular transmission of large amounts of data to servers, without an external antenna, which gives wider possibilities for mounting sensors and increases the accuracy of the analysis [Aquarius-spectrum, 2020]. Appropriate configuration of sensors allows for equally accurate handling of all types and diameters of pipes. The multitude of cases studied, combined with the precision of the sensors, allows establishing the trends and noise profiles for individual diameters and materials.
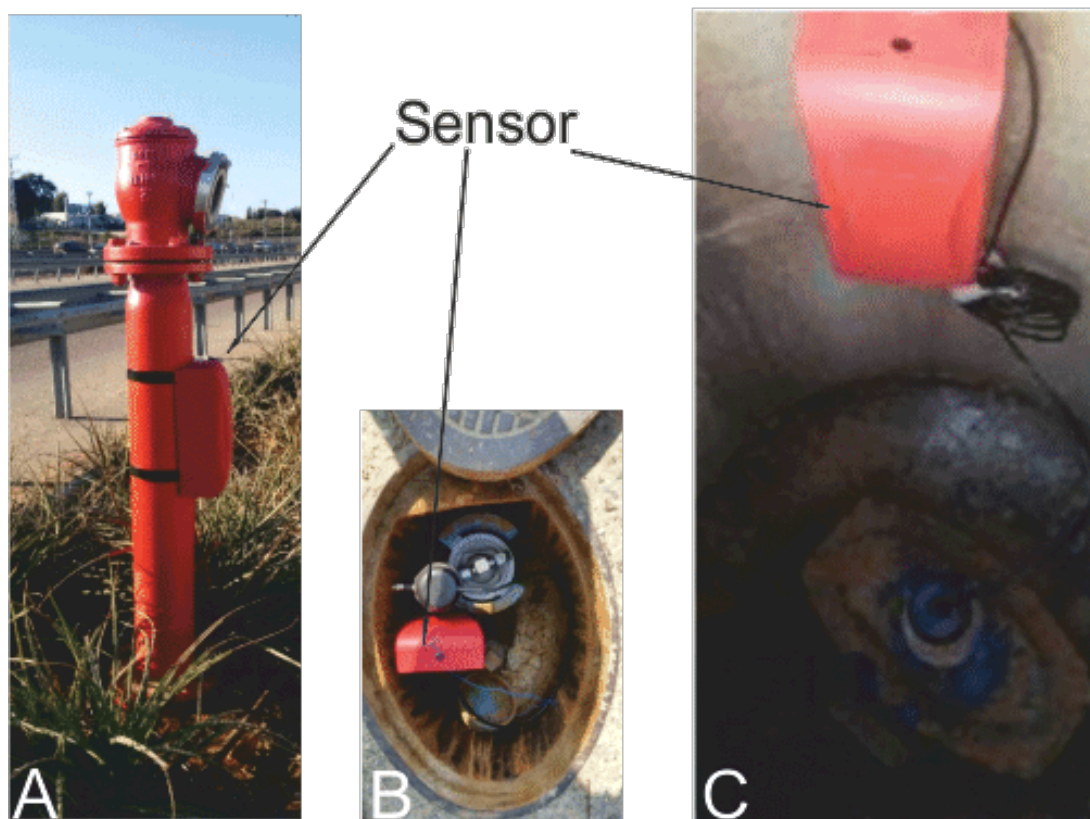
Figure 2: Methods of installing a stationary sensor: (A) on an above-ground hydrant, (B) on an underground hydrant, (C) in the gate valve chamber
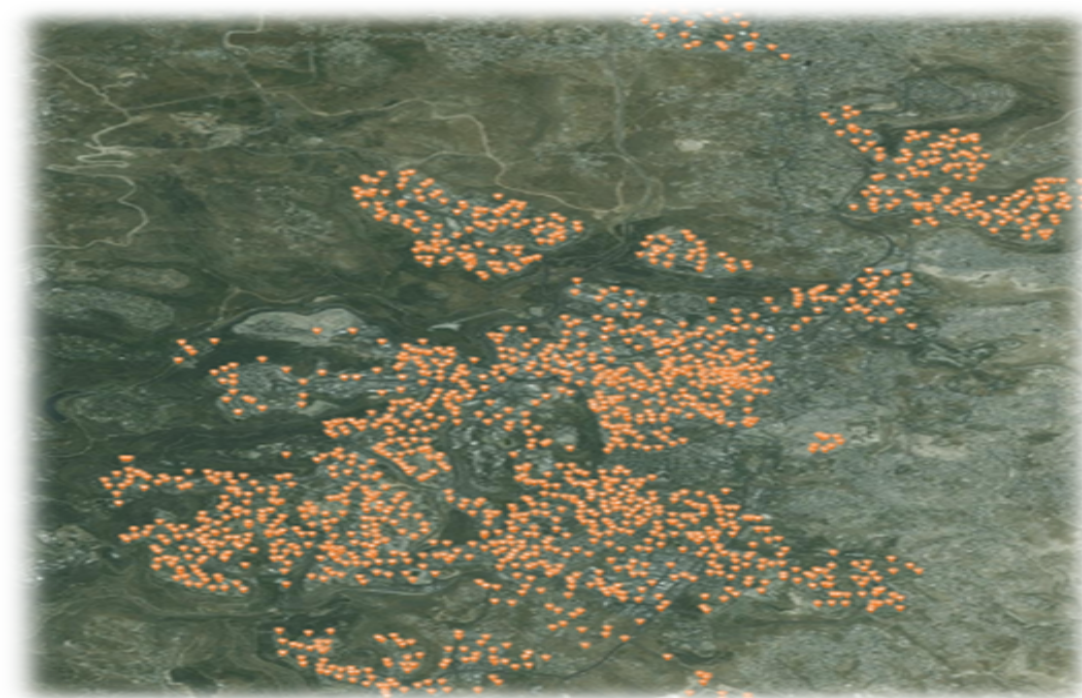
Figure 3: Location of acoustic sensors on the map (water supply network) of Jerusalem (1600 sensors, 750 km of the network).

Analysis of the discrepancy between the noise recorded on the pipes with leakage and the noise on the sections working properly gives the possibility of estimating the size of the leak. In the AQS-SYS technology, all sensors in the system measure noise and send data to the cloud every day at the same time (sampling, e.g. 1–3 times a day). The supervisory system then analyses the noise, filters it and automatically correlates it with water leaks. With the use of algorithms based on artificial intelligence, the system enables classification of the probability of the size of the leak. However, it is sensitive to sound attenuation in pipes, which is not always predictable. Thus, it is possible to also indicate the leak location with an accuracy of <2% of the distance between the sensors [Specification, 2016]. High sensitivity allows registering leaks of even 1.5 mm at a pressure of 3 bar. Integration with the GIS system allows for the automatic marking of the leakage location on the water supply network map associated with the city map. The software based on a cloud platform provides access to the data anywhere and anytime, both in stationary form and on mobile devices, for example, smartphones. The presentation of the results of analyses in various forms (tables, diagrams, maps) gives a clear view of the state of the network and reports options with practical tips. Notifications about leaks, sent automatically as soon as they occur, significantly support decision-making regarding liquidation of water leaks in the network. The software also allows running own simulations and leak analyses on the network related to the GIS map [Specification, 2016; Sejcom, 2020; Ziółkowski, 2016].

An example of an effective application of AQS-SYS is the Israeli water and sewage company Hagihon-Water Utility, where water losses amounted to about 2 million m^3 per year and caused about \$3 million in financial losses. Already after 9 months of use, the costs of implementing the system were reimbursed. It is interesting to note that in one particular place, the system detected a small leak, which was decided not to be removed and subsequently subjected to control. After a few months, the sensors showed an almost twofold increase in leakage intensity to about 15 m^3/d. It was subsequently repaired and the leak was removed. Moreover, it turned out that due to the pressure buildup after the first repair, a second leak was created, which was also revealed by the system. Examples of correlation results obtained on one of the sections of the studied network are illustrated in Fig. 4 [Efrat et al., 2020]. The first chart shows a small leak detected right after the system was launched. In the middle one, a significant increase in the size of the leak can be observed (the situation after several months of monitoring). The

final, third graph shows the situation after the second repair – there are no visible leaks.

The discussed implementation confirms the high effectiveness of continuous monitoring of the water supply network, which in the first case allowed for tracking of the leakage development to the value considered significant (necessity to remove the leak) and in the second case revealed another weak point on the pipeline, related to the previously performed repair of the section. This practical example very well justifies the assumption about the effectiveness of continuous integrated monitoring of leakages from the water supply network, adopted at the beginning of the study.
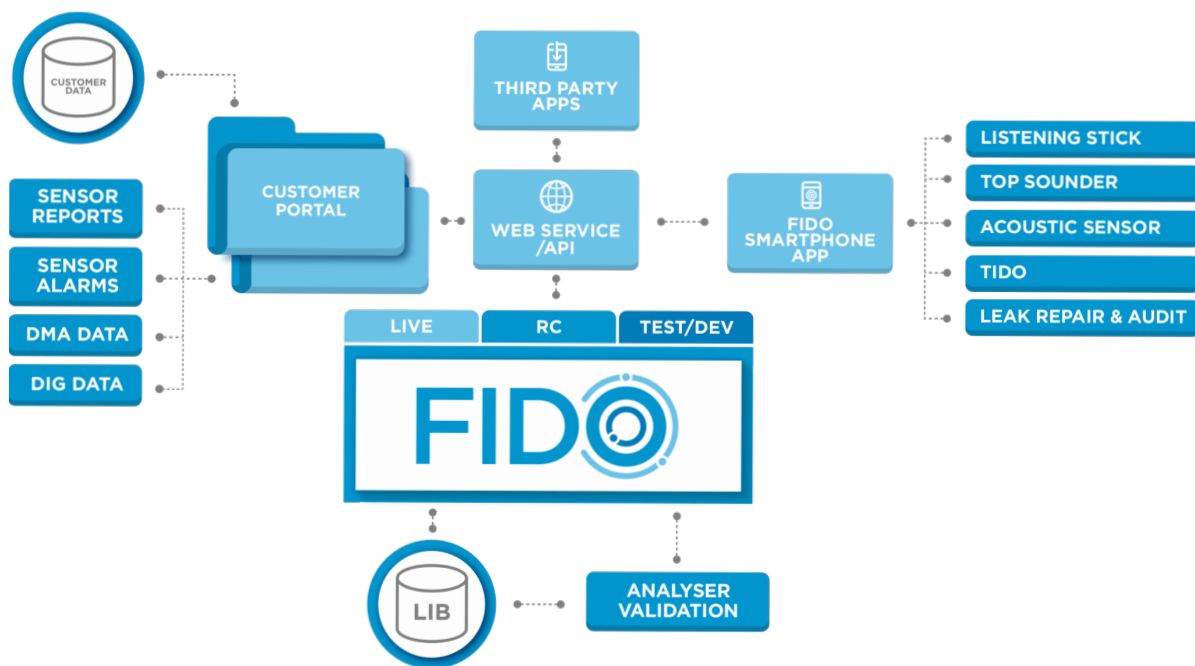
3.2 FIDO system

This system uses artificial intelligence to detect leaks and determine their size. The basis of the system is also a network of sensors installed on the water supply network, on fittings selected by the user, using the built-in magnet or the attached handle. They allow for regular recording of measurements, for example, every 15 minutes. In turn, the core of the system is a special hybrid calculation algorithm, based on differential analysis, which analyses vibration frequencies and wave functions stored in the files from these sensors. It detects and compares minor changes in sound, vibration, speed and turbulence. Then, it decides whether there is a leak in the processed file, determines its probable size in relation to the baseline and determines where it is located. The algorithm used can automatically and precisely filter out background sounds originating, for example, from pumps, increased consumption by users, nearby generators or from traffic, which often trigger false alarms. Following the tests, the filtering efficiency was estimated at 92%. The learning algorithm creates history and reanalyses old data to find other patterns, enabling it to continuously improve the accuracy of leak detection. The aim is to achieve a state where for each sound, it will be possible to indicate the absolute leakage volume per hour [Fido-Tech, 2021a]. The FIDO system manages the entire process, controls the algorithm, data processing and results transfer. It is available from a standalone web platform and can be linked to the existing software via the REST API interface. The FIDO system can function as an independent product, consisting of its own components, but also provides support for other systems, owing to cooperation with the existing devices and applications. These and other possibilities create a fairly extensive structure of the system (Fig. 5)
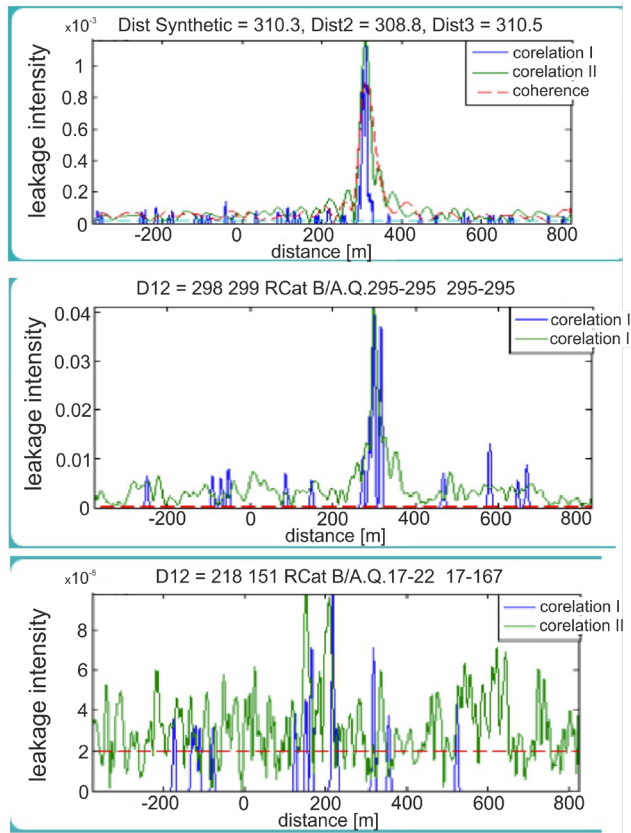
Figure 4: Graphical representation of the correlation of leakages on the tested section of the pipeline in Shamir street.

Fig. 5 shows the interaction and dependencies between the various components of the system. The central part is the FIDO algorithm with access to the platform via the cloud. All obtained data from any resources, that is, external sensors, applications, services and FIDO own components, are sent to a common platform for analysis. The algorithm then compares the delivered new files with its own library of verified leak and leak samples (estimated at over 1.7 million samples), resulting in feedback on the probability and size of a leak. After verifying the correctness of the failure indication, the leak data (including its size) is transferred to the library, thus expanding the database and developing the algorithm, making it even more accurate [Fido-Tech, 2021a].

The FIDO system was implemented, among others, at Thames Water in England; however, in this case, it was mainly used to check the correctness of the existing leak localisation system, which consists of approx. 27,000 sensors. In the first step, the sensor records from the previous 4 months were tested with the FIDO algorithm and each point of interest was classified as leakage, possible leakage and no leakage. The program analysed over 35,000 archive files in 2.5 hours. Then, 33 points were identified for field verification. Out of them, 11 turned out to be caused by the recorder decalibration and 20 were correctly confirmed as leaks. Additional points that were not indicated by the system used by Thames Water were identified as well. As a result, 13 repairs of the correctly

Figure 5: Structure of the FIDO system [Fido-Tech, 2021b].

sensor instalation using a saddle clamp

protective housing of the sensor
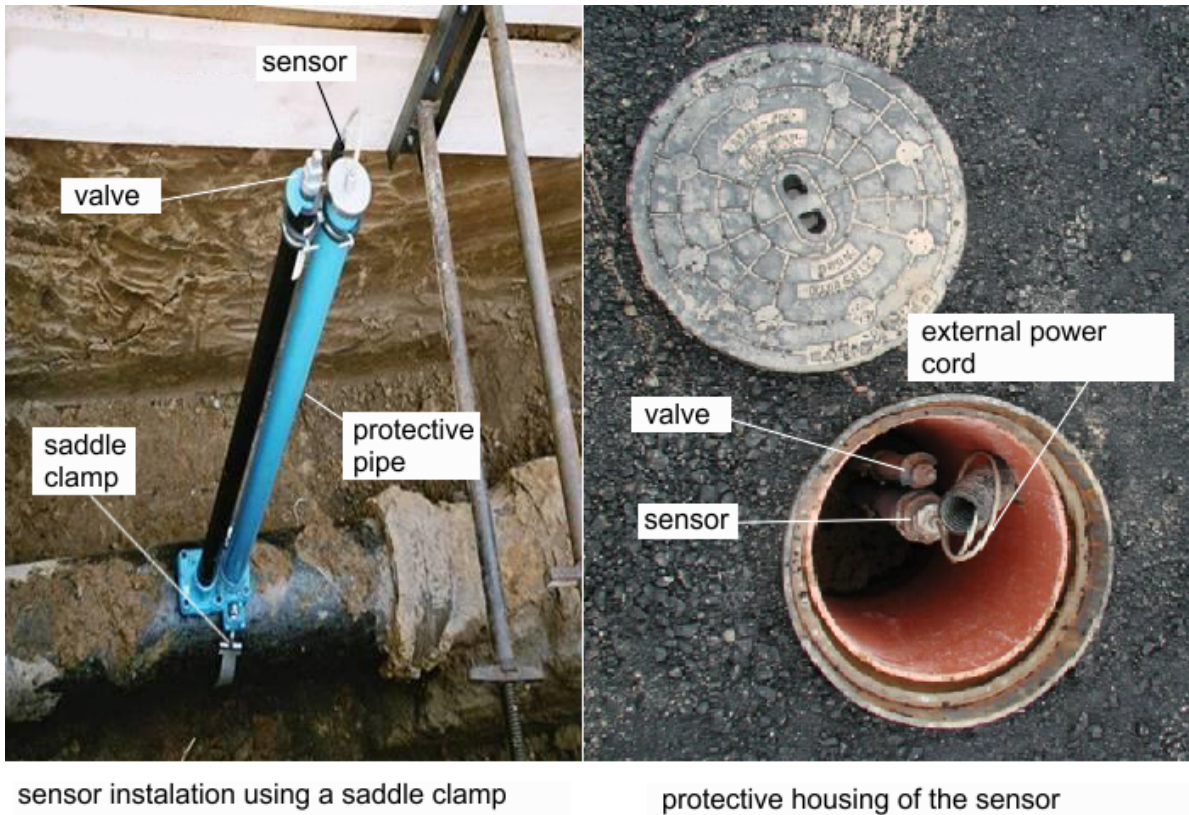
Figure 6: Installation of the WLM sensor.

identified damages were carried out. A very quick analysis of a large amount of data was obtained, and the important role of an extensive monitoring network in the leak reduction strategy was confirmed [Fido-Tech, 2021b].

3.3 WLM system

The basis of this system also includes highly sensitive combined sensors simultaneously registering flow and velocity together with flow direction, pressure, noise intensity and water temperature. The system includes the software controlling sensors, calculations and remote transmission of measurement data to the control panel. The sensors are installed directly on pipes with a saddle clamp, similar to the indoor plumbing connection to the network (Fig. 6) [Martinek, 2019].

Measurements are carried out continuously, with particular emphasis on the night hours when water consumption is the lowest. High accuracy and wide measurement ranges (v = 0.01–9999 m/s with a resolution of 0.001 m/s; pressure 0–16 and even 30 bar; noise intensity 8–3500 Hz with an amplification of 5000

Hz) allow detecting even the smallest water leaks. The dedicated AQUALYS software analyses the measurement data and, in cooperation with GIS, allows for a clear presentation of the results at individual sensor location points on the network map. Fig. 7 shows an example of changes in the measured parameters when a water leak is detected [Materials WLM, 2020].

WLM sensors can be equipped with interfaces for direct communication with any SCADA (*Supervisory Control And Data Acquisition*). The system demonstrates the possibility of learning based on the previous measurement results. Programmable standard parameters, that is, pressure, flow and noise, are the baseline for further monitoring. Correlation of the above measurement data allows establishing the relationship between pressure changes, recorded noise, as well as flow changes, which is the basis for estimating the size of the leak. This solution has already been used in many companies in Germany, Austria, Estonia and Latvia. In Tallinn (Estonia), after installing the first six sensors, the return on investment was achieved just after 3 months [Martinek, 2019].
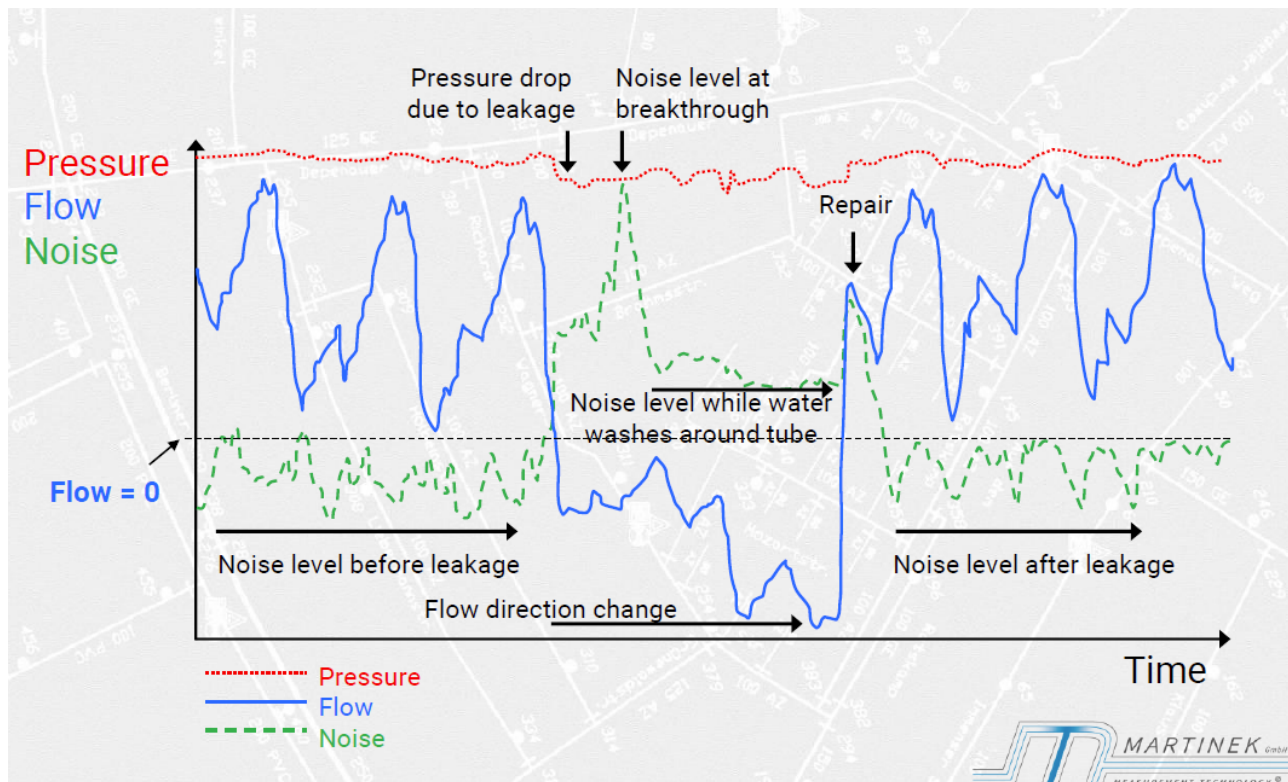
Figure 7: Variability of the tested parameters in the event of a leak – AQUALYS software.

3.4 PermaNET system

Like the previous systems, it is based on a network of acoustic sensors and telemetry modems. The noise recorders are installed on the network pipelines in 200–400 m intervals. Each device has a specific position using GPS, owing to which it is easily located on a map background. The devices record pipe noise, then the data is converted using the Permalog algorithm and sent via cellular telemetry to the PermaNET Web software. The installed modems enable transferring data via GPRS (General Packet Radio Service) in real time, which allows for quick leak detection. The data is also transferred in the form of sound (audio file), so one can listen to leaks remotely and perform remote correlation if necessary. A detailed noise histogram (Aqualog) and re-verification help remove false alarms and pinpoint the leak accurately. The PermaNET Web platform enables bi-directional communication, which enables data to be received and processed, as well as to remotely set the recorder parameters. The platform can be accessed using a web browser. The processed measurement results are presented in various forms (charts, diagrams, tables), but in conjunction with the map background, making it easy to locate a specific device. The ability to connect to Google Maps and StreetView makes it easy to locate the detected leaks in the field. Additionally, a mobile application is available, allowing the geolocation of each recorder and its automatic placement on the map and in the database immediately after installation in the field. The information from the recorders can be easily linked with the data from the flow meters in the network, owing to which it is possible to determine the amount of water lost due to leakage. This solution was applied on a large scale by the UK company Affinity Water, which is struggling with the problem of leakage reaching 181,000 m³ per day. Owing to the implementation of the leak reduction plan, the installation of at least 20,000 sensors, the combination of various technologies and appropriate investments in new equipment, the leakage was reduced to the level of 15% [WWT, 2021; Domagalski, 2020].

3.5 SmartFlow system

This system was created by Future Processing in cooperation with Municipal Water and Sewerage Company (MWSC) in Wrocław (Poland) and Microsoft Azure (cloud solution) [Future Processing, 2018a]. SmartFlow covers four main areas of activity, namely balancing of District

Metered Areas (DMAs) created on the water network; study of night flows in zones between 1:00 am and 5:00 am, when water consumption is the smallest; monitoring measuring points recording flow, velocities along with the flow direction, pressure and temperature; and the use of various methods of direct localisation of the leakage site [Future Processing, 2018b].

SmartFlow collects the data from sensors located throughout the city. These include flow meters and water meters that provide measurement data via radio to the system management centre. The readings are performed every 10 minutes, and the data is transferred once a day. The analysis is performed automatically by means of specially programmed algorithms adapted to the network operation. Division into DMA zones and a rich package of data provided enable to test nine parameters describing the current state of the water supply network. As part of zone balancing, the system analyses several parameters simultaneously, comparing the latest data with historical records. On the basis of iterative calculations, it indicates the places where water consumption is higher than normal by displaying an alarm. The 'diagnostician' module found in the management centre verifies the validity of the alert and examines its cause, as the increased consumption may also be caused by the use of water for the company's own purposes or fire-fighting purposes or resulting from other needs. After assessing the situation, it makes an appropriate decision whether or not to initiate service activities. The results of analyses and calculations are visualised in a convenient and legible way in the form of tables, charts or infographics. In addition, the system is connected to the GIS, where the location of measuring points is visualised on the water supply infrastructure network, and in the case of detection of irregularities, the probable places of leakage. SmartFlow allows determining the leak location with an accuracy of several dozen metres. A service team is sent to the place selected by the system, which diagnoses the water supply network using the acoustic method, locating the place of the hidden leak with an accuracy of 1 m. Then, the repair team removes the defect. Owing to the use of the Microsoft Azure cloud solution in SmartFlow, technical services can log into the system from anywhere, both on a mobile and stationary device. The SmartFlow solution enabled MWSC in Wrocław to reduce water losses by 9%, which in 2016 resulted in saving almost half a million cubic metres of water. Altogether, detection and elimination leakage takes up to 72 hours, on average. The system is still being developed. Appropriate failure prediction algorithms are being developed as well [Future Processing, 2018b].

3.6 Leakfrog system

In addition to the above-mentioned monitoring systems for water supply networks, an interesting, innovative system for detecting and estimating the size of water leaks within internal water installations is presented here as well. Internal installations are also responsible for water losses in the entire distribution system, from the power source to the consumer. Therefore, when designing a long-term water loss reduction program, attention is additionally paid to this aspect. The Leakfrog system, developed at Thames Water in England, is mainly a special device (sensor) with appropriate software installed on water meters, which allows monitoring the minimum flow rate and indirectly recording the amount of leakage (Fig. 8).

The device is installed on the water meter in several seconds and its start-up is performed by holding down one button, without the need for programming. After displaying the value '0000 – no flow', the device is ready for operation. Measurements are carried out at night, that is, when household water consumption should be zero, and the presence of flow through the meter indicates a potential leakage. The principle of Leakfrog operation is to detect, store and display the maximum time between successive water meter impulses signalling the presence of flow. The displayed value on the counter indicates how many seconds it takes for 1 l of water to flow. The maximum time between impulses is the reverse of the minimum flow. This means that the higher the displayed value, the smaller the leakage. For example, the displayed value '0001' means that 1 l of water flows through the meter every 1 second. This corresponds to a minimum flow of approx. 60 l/min, indicating a large leak. When set to '0010', a litre of water flows through the meter every 10 seconds, which is 6 l/min, indicating a minor leak, albeit still significant. The value '9999' means the interval between impulses every 9999 seconds or more, that is, almost 3 hours, which can be considered as confirmation that there is no leakage. Upon reaching this indication, the metering is paused and the device enters the battery saving mode. The data collected by the sensors can be collected and transferred to the analysis centre in the Remote Reading Water Metering system [User Guide, 2011; Materials Leakfrog, 2011]

Figure 8: Leakfrog device installed on a water meter.

4 Strengths and weaknesses of particular systems

The strengths and weaknesses of the systems discussed above (excluding Leakfrog) are presented below from the point of view of the effectiveness of detecting and creating the possibilities of estimating the size of leakages from water supply networks.

Table 1 showing the most important strengths and weaknesses characterising the systems discussed in the article was not intended to compare them, but to draw attention to the most important features of these systems. Nevertheless, it seems that the FIDO system stands out due to the learning algorithm, based on artificial intelligence and constantly increasing its effectiveness by expanding the library of noise patterns, which provides this system with high accuracy of leak location and size. The ASQ-SYS system also exhibits similar features.

5 Conclusions

The issues related to limiting water losses are very extensive. The article focused on the leading element of the loss reduction strategy, that is, detection and location of water leaks in its distribution systems with the possibility of estimating the size of these leaks. Selected latest solutions in this field have been presented. In line

with the current trends, these are usually integrated on-line monitoring systems, mainly controlling pressure, flow and noise accompanying the flow of water in pipes and using the latest achievements of information technologies, including GIS, GPS, GSM and software based on a cloud platform. The monitoring system is a basic element of modern operation of water supply networks, where network modelling and integrated management systems on the GIS platform are also important. It is worth noting that some of the presented systems are still in the implementation testing phase, for example, the ASQ-SYS system. However, it should be noted that the operation of most systems almost completely eliminates the influence of the human factor on the obtained results. The role of the operator is often limited to the introduction and removal of measuring devices from the network along with their supervision, as well as to the control and interpretation of the results.

All the presented monitoring systems, although differing in their individual features, are in line with the current direction of a modern approach to planning and implementing a water loss reduction strategy in water distribution systems. From a water network management perspective, the systems enabling continuous monitoring should be considered the best. They allow achieving high automation of the water loss reduction process. Measuring devices equipped with batteries with a very long operation time and data transmission modems are virtually maintenance-free after their installation. The acquired data is continuously processed using complex algorithms and in the event of inaccuracies, they are immediately signalled. All this, combined with GIS systems, ensures high transparency and effective monitoring. Sensors and software play a major role in these systems. Among the leakage monitoring systems discussed above, the FIDO system stands out, which, owing to the use of a learning algorithm, continuously increases its effectiveness in locating and creating possibilities of estimating the size of leaks.

Currently, there are no universal legal regulations regarding the maximum value of the allowable losses in the water supply system. This is probably due to the specificity of each water system and the economic profitability of its operation. These activities will now also be supported by the new Drinking Water Directive (2020/2184), according to which all EU Member States should quantify leakages in the next 5 years and reduce them if they exceed a certain threshold. This threshold will be established as a standard by all Member States. Hence, there is a strong need to intensify work on limiting leakages in water distribution systems. The current trends

Table 1: Strengths and weaknesses of the systems.

Strengths	Weaknesses
ASQ-SYS system	
• Regularity and consistency of readings • Automatic data analysis and alarm display • High accuracy of determining the leak location (<2% of the distance between the sensors) • GIS integration • Automatic data transfer via GSM • Adaptive filtering of external disturbances and noises • Automatic noise correlation with the use of algorithms based on artificial intelligence enables the classification of the probability of the size of a leak • Dedicated application also for mobile devices supporting the work of field teams	• Significant uncertainty in estimating the size of the leak • Necessary access to a large number of fittings in order to achieve high accuracy of leak detection • Sensitive to sound attenuation in pipes, which is not always predictable • High implementation costs
FIDO system	
• Automatic data analysis and alarm display • Very accurate algorithm with high accuracy of filtering noise leakage (92% efficiency) • Learning algorithm – constantly increasing its effectiveness by expanding the library of leak patterns • High frequency of FIDO bugs readings (15-minute interval) • High accuracy of leak location (exact correlation between sensors) • Detection of even very small leaks	• A solution that mainly supports other acoustic systems (conducting noise analysis), but it can also operate independently • Necessary access to a large number of fittings in order to achieve high accuracy of leak detection • Data transmission from FIDO bugs sensors takes place via bluetooth (the sensor must be approached with a mobile device) • High implementation costs
WLM system	
• Ability to monitor several parameters with one recorder (pressure, flow, noise, temperature) • Automatic data analysis and alarm display • Automatic data transfer via GSM • High accuracy of the leak location (several metres) • Detection of even very small leaks • Ability to remotely set the recorder parameters and force the measurement • GIS integration • Ability to automatically send an alarm via SMS	• The sensor is installed directly on the pipe – direct access to the pipeline is required (excavation required) • High implementation costs
PermaNET system	
• Automatic data analysis and alarm display • Automatic data transfer via GSM • High accuracy of the leak location (several metres) • Integration with Google Maps and StreetView • Two-way communication – the ability to remotely set the parameters of the recorders • Dedicated application for mobile devices supporting the work of field teams	• In order to achieve high accuracy in determining the amount of leakage, it must be linked to data from the flow meters • Necessary access to a large number of fittings in order to achieve high accuracy of leak location • High implementation costs
SmartFlow system	
• A comprehensive multi-functional system that locates leaks, balances the water in the network and determines the size of the leaks • Pressure, flow, speed and direction of flow and temperature are monitored simultaneously • It can also be accessed via mobile devices • Automatic analysis of multiple data and alarm display	• Determining the exact location of leaks has to be supplemented with acoustic methods • High implementation costs

in scientific research and the development of innovative technologies, the examples of which are shown in the article, already meet this challenge. These technical solutions not only enable leak detection, but also control the operation of measuring devices and provide the basis for network control. Visualisation and animation of technological diagrams enables better management of the network infrastructure. It is possible to adjust the parameters at the operator station, depending on the current needs, without the need to travel to the field, which significantly reduces the operating costs.

The systems allow collecting and storing the data from measuring devices located on the network. Thus, the access to archived data is simple. It also enables creating statements and reports showing the trends in the operation of devices or changes taking place. The ability to immediately compare the latest measurements with stabilised characteristics enables to quickly detect irregularities in the network operation (in this case, a leakage). The systems allow quickly assessing the changes in network parameters, such as increased flows, pressure drops and determining whether they are caused by changing demand for water or a failure. This, in turn, enables to minimise the reaction time to the damage occurring in the network and to remove it faster.

While appreciating the enormous possibilities and undeniable advantages of modern leak detection and location systems, it should be borne in mind that the use of such an extensive system is not always possible or economically justified in a given enterprise. In such a case, there are other methods, which are simpler and cheaper, allowing single tests to be carried out on a smaller area, over a longer period of time, enabling to detect leaks as well. As shown by examples from various waterworks around the world (e.g. Yorkshire Water, Thames Water, United Utilities), sometimes combination of several solutions yields very good results. First of all, this includes a rough detection of potential leaks over a large area using inexpensive and automatic technology, and then verification in the field using accurate mobile methods.

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