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WATER 4.0 - DIGITALISATION IN THE WATER SUPPLY AND SEWERAGE SECTOR

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Abstract: Digitization enables companies in the water supply and wastewater treatment sector to adapt to climate, demographic and structural changes. Water 4.0 is the interaction of innovative, current and future network technologies, in which water is viewed as a natural resource, product or raw material with the aim of sustainable management, use and risk reduction, taking into account the interests of all direct and indirect users and stakeholders. Networking of management and measurement systems with solutions for data analysis and modeling leads to obtaining information that supports or provides a basis for decision-making, implementation of measures and monitoring of their functioning in the water supply system. In addition, information gathered over time can provide new ways to ensure more efficient use of water in different application areas. This makes Water 4.0 a holistic approach that evaluates digital data and uses it for predictions, drawing on data from other technical fields, thus enabling sustainable decision-making. The concept of Water 4.0 is not static, but follows technical development and uses new opportunities that are provided. An important feature of the current stage of development of both Industry 4.0 and Water 4.0 is the merging of real and virtual models into cyber-physical systems. This is reflected in the real-time connection of sensors, computer models and controllers to real water systems using smart grids and intranets/internets. The integration of processes, measures and technologies into the IT system is taking place, including classical, proven methods, as well as new, innovative approaches.
Key words: Internet of Things, digital twin, water purification, water supply

INTRODUCTION

The cliché-sounding phrase - life is impossible without water could soon become a gloomy forecast if current statistical trends hold true. Today, 3.6 billion people face insufficient access to water for at least one month of the year. Water scarcity is not only a problem in arid, rural or underdeveloped regions, but is increasingly affecting wealthy nations and urban areas. According to UN-Water, the number of urban residents without safe drinking water has increased by more than 50% since 2000 [1]. Climate change, urbanization, and pollution from agriculture and industry threaten water quality in lakes, rivers, and aquifers in many regions around the world, making clean water an increasingly scarce and valuable resource. According to the Global Water Intelligence White Paper, water networks are responsible for 135 million tons of CO_2 emissions. Reducing this figure by 30% by avoiding leaks would significantly reduce the carbon footprint of water infrastructure. Investing in leak detection technologies often pays off through reduced water losses and energy savings [10]. New technologies can help detect and locate leaks of all types and sizes. Digital solutions provide improved monitoring of water and sewage infrastructure systems and optimized operation of systems and installations. They can ensure compliance with increasingly stringent regulatory requirements for drinking water and wastewater quality, as well as for the safety and quality of supply. By networking and integrating process, engineering and operational data, the entire technical and organizational process and value chain of the water industry can be represented in the form of a digital model. This is the so-called digital twin – a data-driven model that includes all design and operational data for the entire life cycle of the plant. The digital twin supports continuous optimization of design, operation and maintenance procedures. Intelligently linking plant performance data with global data such as weather reports, combined with advanced analysis methods such as machine learning, enables water utilities to optimize day-to-day plant operations and better respond to unusual events (eg heavy rainfall, network leaks, etc.). Such solutions are already available today [11, 12]. One of the applications of digital solutions is the optimization of the electricity consumption of pumping plants. Pumping water during transport or treatment often requires high-power pumping units that are responsible for a large part of the energy consumed in the water sector. Therefore, optimizing the energy consumption of pumps can help significantly reduce the costs and carbon footprint of water and sewage systems. In addition, the optimized operation of the installations reduces the load on the equipment and increases the availability and service life of the pumps and related components. However, energy-efficient operation should not come at the expense of safety. That is why data must be analyzed in real time, both from installations and from other sources. Intelligent applications such as SIWA Optim collects data from process management systems and links them to utility data, consumption forecasts and other sources. The application integrates all analysis parameters using advanced algorithms, which results in a reduction of operating costs with supply protection and greater resource security [13, 14]. One of the most common causes of water loss around the world is leakage or theft, which represents a major problem for water management. This not only affects the economic performance of water utilities, but also increases pressure on natural water resources. In addition, unreported wastewater leaks are often a major source of pollution and can affect water quality and the state of the environment. For this reason, water utilities must be able to detect and locate leaks quickly and with great accuracy. Using technology similar to that used to detect water on other planets, satellites can provide images that help identify leaks in water systems on Earth. Advanced tools such as the SIWA Leak app use data from existing measurement and automation systems and combine different measurement methods (flow, mass balance, pressure analysis, pressure drops) to detect leaks with minimal delay and high accuracy. In addition, cloud applications such as SIWA LeakPlus combine data from the water distribution network with cloud computing, artificial intelligence and hydraulic simulations to detect hidden anomalies that indicate leaks. Using these digital tools, leaks can be detected faster and more accurately than before, reducing the time and percentage of leaks by up to 50% [11, 12, 15, 16]. Digitization also offers benefits in terms of capacity management, e.g. for sewage systems. These systems are already affected by the effects of climate change. When the surface swelling and sewage are collected in a combined sewerage system, abundant precipitation (for which it is expected to occur due to climate change, especially in Europe) can lead to an uncontrolled discharge of contaminated water into natural water surfaces. Dried, in turn, lead to "dry" pipes in which sedimentation arises, with unpleasant odors from the sewer system. In order to cope with abundant precipitation and insufficient cleansing of the sewer system, the water supply system needs optimized control of pumping plants and adequate capacity of the tank. The intelligently centralized solution for sewage management and control can enable that capacity in the sewer network is used to relieve pipes and flow leveling to wastewater treatment plants. Applications such as Siwa Sewer enable dynamic online optimization of sewerage operation based on current levels in pipes, collected and overflow tanks. Valves and pumps can be managed based on current precipitation forecasts to optimize sewage management and increased wastewater treatment efficiency, preventing uncontrolled sewage discharge in the environment [2, 3, 17]. As these examples show, digitization can contribute to safer drinking water supply and wastewater disposal, reduced energy consumption and lower operating costs. By integrating advanced solutions and services such as digital twins and machine learning, the industry can benefit from applications and digital services that enable greater transparency throughout the plant lifecycle and value chain. In this way, utility companies increase efficiency and savings potential in many areas, while at the same time ensuring a reliable supply. To support these efforts, Siemens has developed a package for the water supply and wastewater industry. Through full application interoperability and comprehensive and flexible plant data analysis in a virtual environment, the MindSphere application increases the availability of information throughout the entire life cycle. The package also includes Siemens Water Applications (SIWA), developed specifically for the water and wastewater industry, combining digitization with engineering expertise [17].

IoT TECHNOLOGIES IN THE WATER AND SEWAGE SYSTEM

The need to adopt innovative technologies such as the Internet of Things (IoT), cloud-based virtualization and modeling are becoming increasingly important, especially in the field of wastewater treatment. Water management is a responsible process in which the margin for error is small. If even one monitoring device in the communication protocol loses connectivity, it can lead to significant water loss or failure of the water network. Reliability and durability of components are of utmost importance, as well as interoperability between sensors and communication transmitters. All these factors must be present for the implementation of remote monitoring to be effective. In the field of water purification, industrial IoT systems find application, e.g. in monitoring chlorine content in water supply networks in real time, monitoring pressure changes in pipes and using ultrasonic sensors for early warning of water supply and sewage operators about upcoming events [2, 3]. Currently, organizations in the water sector depend heavily on Supervisory Control and Data Acquisition (SCADA) systems to monitor certain parts of the water distribution system. However, the practical placement of monitoring points often limits the application of these solutions. IoT advancements in the water sector are helping to improve water management by providing wireless system automation throughout the water network. IoT connects all objects and devices equipped with electronic sensors in a network and allows them to communicate with each other and issue commands to actuators to perform various functions. Implementing Internet connectivity in industrial facilities with dispersed distribution is a particularly challenging endeavor. Industrial IoT (IIoT) devices are typically deployed in remote locations to reach physically inaccessible locations and provide real-time information (e.g., sensors located in remote reservoirs or underground shafts) [4]. These devices must be robust enough to withstand corrosive chemicals, aggressive gases and liquids. In addition, hundreds of sensors may be required in a water system for operators to receive real-time information. Each sensor requires a reliable power supply and communication network to operate continuously. Accessibility is also a challenge in many cases – e.g. in order to build a network to monitor hydrogen sulfide (H_2S) in the sewage system, the sensors must be powered by long-life batteries. Failure to do so will result in increased maintenance costs. The physical presence of personnel responsible for monitoring activities in wastewater treatment plants will always be necessary, but this accounts for 30% of the operating costs of a treatment plant. New IoT technologies take advantage of automation to reduce the need for operator involvement. Water management uses the concept of smart sensors installed at various points in the water supply system. They can collect data and send it back to tracking systems. With the help of smart IoT technology implemented in multiple components of the water network, it can also be ensured that losses are reduced. The implementation of this new technological approach is in some cases conditioned by regulatory requirements. The concept of IoT technologies in water purification is based on a reliable communication system that is used to wirelessly send data from physical objects to a computer connected to the cloud, which has the appropriate software to analyze this information. Through smartphone and tablet apps that connect to the cloud, water utilities can access real-time data from IoT sensors. These mobile devices can, e.g. provide useful information about the entire network to technicians, engineers and other personnel responsible for managing water treatment plants [4, 5]. With smart leak detection sensors, faults such as burst pipes can be located quickly and easily. When a leak is detected, the sensors generate an immediate warning and send it to the remote control panel. Thanks to timely corrective measures, damage can be prevented and limited, thereby reducing losses. IoT technologies are also used in wastewater treatment through smart sensors to measure the amount of chemicals remaining after treatment. The information they provide can be used to calculate the effectiveness of the selected treatment process and ensure that the amount of chemicals released remains within acceptable limits. This network of sensors and communication technologies for smart water management enables companies to take advantage of big data analytics, cloud storage and mobile computing, contributing to practical improvements and cost reductions. The introduction of IoT in the water sector allows the operational centers of water management and monitoring systems to be located anywhere [11, 12]. Water management costs can be reduced by improving equipment utilization, process efficiency and productivity, as well as improving services. Monitoring the pressure in water supply networks enables the prevention of accidents and the limitation of losses and damages in the event of bursting and leaking pipelines. Water utilities can use pressure monitoring to ensure that the pressure value in the water supply system is as low as possible. In addition, optimized pressure helps optimize the operation of pumping stations, which leads to a reduction in energy consumption. On the other hand, pressure monitoring ensures efficient water flow management and prevents a possible increase in the amount of water discharged into the sewer, bringing the water supply system in line with the requirements of regulatory authorities. Also, modern remote monitoring solutions based on IoT technology are significantly cheaper than their predecessors. Other benefits of IoT technologies for the water sector are more efficient maintenance and improved service. Appropriate data analysis programs can significantly help companies in making decisions and developing preventive and predictive maintenance strategies. This can include e.g. measuring total chlorine content in remote tanks to facilitate timely mixing or dosing of chemicals to prevent nitrification, or determining groundwater levels and conductivity to properly model underground aquifers and prevent potential disasters. These benefits further improve network performance and help achieve additional cost savings. A more efficiently managed water network provides better service to customers by ensuring consistent system pressure, fewer interruptions in water supply, and proper chlorination.

CONCEPT OF WATER 4.0 IN LIGHT OF INDUSTRY 4.

The importance of digitalization is constantly growing, with popularization of terms such as big data, Internet of Things (IoT), industrial IIoT and cyber-physical systems (CPS) [4]. The water industry is constantly looking for opportunities to adapt to changing boundary conditions, as well as to find effective solutions to face global challenges in this area. Climate change and urbanization, just two of the important driving forces in the water sector around the world, are continuously increasing the demand for water resources that are diminishing. Water 4.0 is a concept that has recently been accepted as the future of the water industry. But in order to explain the essence of this concept, the principles of Industry 4.0 must first be considered. Industry 4.0 is a collective term for technologies and concepts related to organizing value chains. Based on the technological concepts of cyber-physical systems, the Internet of Things and the Internet of Services, Industry 4.0 helps realize the vision of a smart factory. Within modularly structured smart factories, cyber-physical systems monitor ongoing processes, create virtual copies of the physical world and make decentralized decisions. These systems communicate and collaborate with each other as well as with people in real time via IIoT. The concept of Industry 4.0 is based on six principles:

• interoperability – the ability of cyber-physical systems (ie devices that participate in the production of certain elements, assembly lines and products), people and smart factories to connect and communicate with each other through the Internet of Things and the Internet of Services;
• virtualization – a virtual copy of a smart factory, created by connecting data from sensors that detect physical process parameters with virtual and simulation models;
• decentralization – the ability of cyber-physical systems to make decisions on their own;
• real-time monitoring – the ability to acquire and analyze data and provide immediate conclusions;
• service orientation – offering services (cyber-physical systems, people and smart factories) through Internet services;
• modularity – flexible adaptation of smart factories to the changing requirements of individual modules [7, 8]. All concepts from Industry 1.0 to 4.0 refer to the manufacturing industry, which is relatively simple: something is made and assembled using separate parts. At the forefront of the concept of Water 4.0 are digitization and automation, and the goal is efficient, flexible and competitive management of water resources. Water 4.0 provides a high degree

of transparency for users, thereby covering current needs and providing opportunities for sustainable activities in water management. The implementation of Water 4.0 through cyber-physical systems achieves the optimal connection of virtual and real water systems, where planning, construction and operation are largely done by software.

REALIZATION OF THE WATER 4.0 CONCEPT

The realization of the Water 4.0 concept (intelligent water management or simply efficient exploitation of water resources), which is necessary for the future of the sector, can be achieved by applying the basic principles of Industry 4.0. Figure 1 shows the configuration of the water supply system according to the concept of Water 4.0 [18].

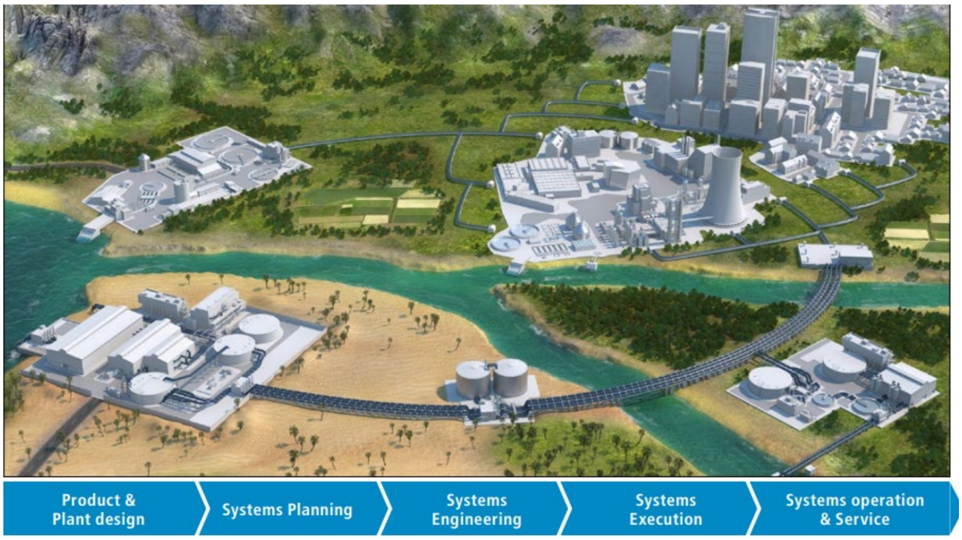

Fig. 1. *Water 4.0 - Sketch of a complex water supply system (source Siemens)*

There are several barriers to successful implementation of the approach that need to be considered not at the company level, but at the industry level as a whole. The first of these obstacles is related to communication protocols - until now, water and sewage systems have mainly worked with analog signals and Profibus protocol in larger installations, and future concepts are more focused on Ethernet [7, 8]. A large number of technical and technological units that are part of a water supply system (sources, dams, river intakes, well plants, reservoirs, pumping plants, transport pipelines, etc., often distributed over large areas and distant locations from each other) have sensors for measuring various process variables and parameters (level, pressure, flow, temperature, concentration of harmful elements such as manganese, iron, arsenic, etc., chemicals - chlorine, fluorine, aluminum sulfate). Advances in sensor technology and wireless communication protocols have enabled the application of IoT in various industries. This is also the case with the water supply and sewerage sector. Data from the sensors are sent via wireless networks to base stations. In recent times, the LoRa (Long-Range) protocol has gained increasing popularity and application. Hundreds of millions of IoT devices in more than a hundred countries are connected in the LoRa network communication system, which enables data transmission over long distances (up to 10 km) with low energy consumption. According to forecasts, over 50% of IoT devices will use the LoRa protocol by 2026. LoRa works with a spectrum of frequency bands. In our country, the frequency bands 433 MHz and 868 MHz are used, and no special licenses are required if the maximum permitted transmission power is not exceeded. LoRa supports the use of different bandwidths starting from (7.8 kHz to 500 kHz), which enables the operation of a larger number of independent networks in different parts of the frequency band. The data transfer speed is proportional to the bandwidth. The highest transmission speeds are achieved by using a bandwidth of 500 kHz, but in this case, a maximum of two to three independent networks per frequency band is possible. The range of wireless communication between the transmitter and receiver depends on the loss in the signal propagation path. These losses increase with the square of the distance in a clear space, while in mountainous or urban areas due to various obstacles the losses increase significantly faster, with an exponent ranging from 3 to 5 [4]. Cybersecurity as a problem is becoming a very serious issue in the water industry. Ensuring complete security is an absolute necessity for anyone using a cloud or IoT environment. The problem becomes even more important and relevant in view of hacker attacks. Such attacks related to e.g. chemical dosing can have a serious impact on water service users or the environment [9]. The third challenge for implementing the concept is the quality of the tools and data and eliminating the situation in which there is a lot of available data, but no useful information is extracted. Water utilities have a variety of equipment and devices that generate a huge amount of data, which does not always provide a basis for taking the necessary actions. Therefore, it is necessary to move to an approach that ensures the availability of rich and accurate information, but in an understandable and easily accessible format. This of course requires the investment, installation, management and proper maintenance of appropriate equipment. Water 4.0 offers enormous potential for optimizing the management of water infrastructure systems and achieving rational and more efficient use of resources (eg energy, water, manpower), combined with improved security of water supply and wastewater treatment. Studies show that the key point in networking and automating the water infrastructure is related to the education, training and skills of all employees involved in the creation of value. In order to meet the new requirements, it should be determined exactly what skills are needed and how to improve the knowledge of the subjects involved. In the future, both experienced and newly hired staff will have to deal with the new situation, with the need for education and training to focus on current challenges. The implementation of Water 4.0 is an evolutionary process – existing basic technologies and expertise must be adapted to the special needs of the water industry, especially in an international context.

DIGITAL TWINS IN WATER SUPPLY AND SEWAGE SECTOR

In their efforts to provide reliable, stable and affordable systems, water supply and sewerage companies face problems such as rising electricity prices, depreciating infrastructure, water shortages and losses, natural disasters related to climate change, etc. The solutions to these problems are equally numerous and diverse – from public-private partnerships to awareness of the need to preserve water resources and the application of smart technologies. The availability of quality data is of fundamental importance for making optimal decisions. Companies in the water supply and sanitation sector are striving to find an efficient way to use the data they already have and that is collected regularly, often isolated in disjointed IT solutions, spreadsheets and paper records. Digitization of data and the business processes it supports can help the mentioned companies to make maximum use of data when making decisions, increase the efficiency and quality of the services they offer. One of the most powerful tools in this area is digital twin technology. Figure 2 shows the role of a digital twin in the creation of a modern water supply system [19]. A digital twin is a virtual representation of physical equipment, processes or systems. Creating a digital twin of the water supply and sewerage system involves the integration of virtual engineering models with real models and GIS data. In addition, digital twins are continuously updated with operational data from SCADA systems, sensors, meters, etc. This is what distinguishes digital twins from static 3D models. The end result is an intelligent and connected digital infrastructure model that supports the planning, design, construction and operation of smart water and sewer networks. Digital twins of water and wastewater systems provide accurate and reliable data that businesses can use for "what-if" analyzes and decision-making throughout the system's lifecycle – from long-term forecasting e.g. capacity to direct monitoring of operational parameters and response in the event of an accident. By introducing a model of the system's hydraulic characteristics and water quality that reflects existing conditions, digital twins enable the simulation of events such as pipeline failures, power outages, fires, pollution, etc.

As a result, water companies can analyze the resilience of their systems and assess the corresponding risks.

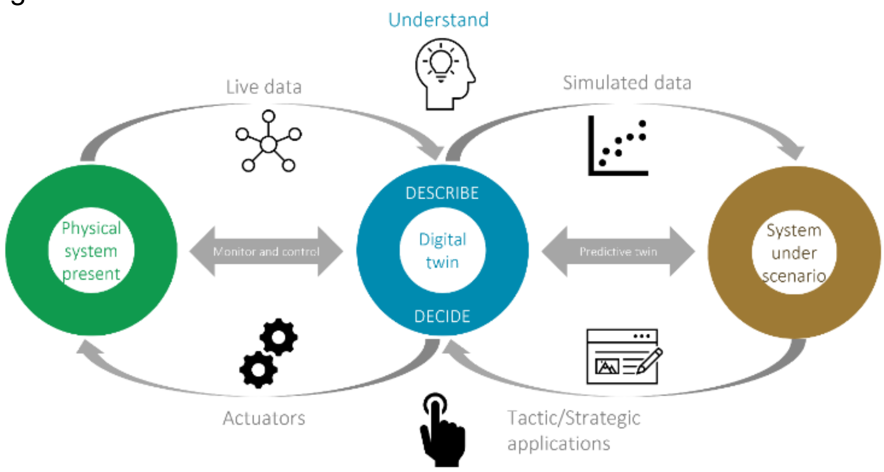

Fig. 2. *Digital twin diagram, with the left side representing operational applications (present) and the right side tactical and strategic applications (what if and future scenarios)*

Digital twins effectively use data from different management systems, thereby supporting strategic management of equipment based on risk assessment. These advantages contribute to optimizing costs, extending the life of equipment and prioritizing certain projects in order to improve performance [7, 8]. Continuously updating digital twins with the latest operational data helps utilities locate potential leaks and reduce water loss. Most water utilities already have a hydraulic model of their system, which is used for planning and design. By integrating hydraulic models with data from the SCADA system, digital twins enable the determination of properties of the water supply system that cannot be directly measured. This provides a more complete view of the system, which can help increase safety and reduce breakdowns (eg pipeline bursts).

CONCLUSION

With the advent of digitization, more and more procedures, tools and other resources are becoming available, contributing to a new era in water management. Like other industries, the water industry is able to further improve its future competitiveness with modern automation. Through the increased implementation of IT technologies, sensors and modeling applications, opportunities are created for a better understanding of water management systems in terms of their complexity. The integration of planning and work processes with the help of intelligent hardware, software and independent exchange of information (from consumers to individual components to water supply and sewage companies) is becoming increasingly necessary to achieve high productivity and efficient use of resources. IoT and services also play an important role in these real-time systems, making data about water-related processes and characteristics more durable, accessible and usable whenever and wherever needed. It is also possible to further network other data (eg short-term and long-term weather information) to prepare forecasts that can be fed into control algorithms for processes in the water sector. Choosing the right communication network is also not easy, due to the number of competing networks available in the market. Although modern IIoT technologies make remote monitoring of remote locations more affordable compared to legacy telemetry solutions, the investment in them is significant. A positive fact is that the investment return period is approximately one year. However, the online infrastructure itself poses a threat to the security of water companies' equipment and is associated with the risk of misuse. The Internet of Things can be one of the most important approaches in the development of management of utility systems, which will contribute to a more efficient use of water resources. IoT solutions for water monitoring and management provide the ability to collect data from a large number of devices, analyze and send data or processed results to different applications or other devices, which enables optimization of the management process and prevention or limitation of possible accidents.

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