REPUBLIQUE ALGERIENNE DEMOCRATIQUE ET POPULAIRE

MINISTERE DE L'ENSEIGNEMENT SUPERIEUR ET DE LA RECHERCHE SCIENTIFIQUE

UNIVERSITE YAHIA FARES DE MEDEA



Faculté de Technologie

Département du Génie Electrique

Mémoire de fin d'études de Master

Filière : Automatique

Spécialité : Automatique et systemes

Implementation of a Digital Twin: application to the management of a domestic water distribution network

---

Présentés par :

ABED Mohamed houssem elddine

BELKHEIR Nihal

Proposés et Dirigés par :

Dr.KARA Reda

Mr.ELMOHRI Mohamed Abdessalam

Promotion 2022-2023

Dedication

We would like to express our heartfelt appreciation to our family. Their love, support, and encouragement have been the foundation of our achievements. They have been our rock, offering guidance and believing in us even during the most challenging times. We are blessed to have such a loving and supportive family by our side.

To our friends and family, words cannot adequately express the depth of ourgratitude. Thank you for your unwavering belief in us, for inspiring us to reach new heights, and for always being there with your unwavering support. We are forever indebted to you all.

Acknowledgement

we want to extend our deepest gratitude to our professors

Dr.KARA REDA

Dr.ELMOHRI ABDESLAM

for their invaluable knowledge, mentorship, and unwavering dedication to our education.

Their expertise, passion, and willingness to go the extra mile have had a profound impact on our intellectual growth and personal development. We are truly grateful for the opportunities they provided us and the wisdom they imparted.

ملخص :

تؤدي إدارة المياه دورا حاسما في كفالة الاستخدام المستدام للموارد المائية وحفظها. مع التقدم التكنولوجي، أحدث تكامل التوأم الرقمي، وإنترنت الأشياء، والذكاء الاصطناعي، والخدمات السحابية ثورة في طريقة مراقبة أنظمة إدارة المياه وتحليلها وتحسينها. من خلال الاستفادة من قدرات التوأم الرقمي، إنترنت الأشياء، الذكاء الاصطناعي، الخدمات سحابية أمازون، يمكن لأنظمة إدارة المياه تحقيق كفاءة محسنة، وتقليل فقدان المياه، والصيانة الاستباقية، والإدارة المستدامة لموارد المياه.

الكلمات الرئيسية : إدارة المياه ,التوأم الرقمي ,إنترنت الأشياء ,الذكاء الاصطناعي ,الخدمة السحابية,البيانات في الوقت الفعلي, التحليلات التنبؤية,الكفاءة ,الصيانة الاستباقية والاستدامة.

Résume :

La gestion de l’eau joue un rôle crucial pour assurer l’utilisation durable et la conservation des ressources en eau. Grâce aux progrès technologiques, l’intégration des jumeaux numériques, de l’Internet des objets, de l’intelligence artificielle et des services infonuagiques a révolutionné la façon dont les systèmes de gestion de l’eau sont surveillés, analysés et améliorés. En tirant parti des capacités des jumeaux numériques, de l’IdO, de l’intelligence artificielle, du nuage Amazon et de la visualisation, les systèmes de gestion de l’eau peuvent améliorer l’efficacité, réduire les pertes d’eau, assurer un entretien proactif et gérer les ressources en eau de façon durable.

Les mots clés : la gestion de l’eau, les jumeaux numériques, l’IdO, l’intelligence artificielle, Amazon, la visualisation, le service infonuagique, les données en temps réel, l’analyse prédictive, l’efficacité, la maintenance proactive et la durabilité.

Abstract :

Water management plays a crucial role in ensuring the sustainable use and conservation of water resources. With the advancements in technology, the integration of a digital twin, Internet of Things (IoT), artificial intelligence (AI), and Amazon cloud services (AWS) has revolutionized the way water management systems are monitored, analyzed, and optimized.By leveraging the capabilities of the digital twin, IoT, AI, Amazon cloud, and visualization, water management systems can achieve improved efficiency, reduced water losses, proactive maintenance, and sustainable water resource management.

Key words : water management, digital twin, IoT, AI, Amazon, visualization,cloud service, real-time data, predictive analytics, efficiency, proactive maintenance, and sustainability

Table of Contents

List of Figure VIII

List of Table X

List of abrevation XI

GENERAL INTRODUCTION 1

I. Chapter 1: Water management system 2

Introduction: 2

I.1 .Water Management: 3

I.1.1 Statistics on Water: 3

I.1.2 The importance of water management: 5

I.1.3 Types of water management systems: 6

I.1.4 Challenges and opportunities for improving water management systems: 10

I.2 Overview of water in Algeria (source, problem...): 12

I.2.1 Source of water in Algeria: 12

I.2.1.1 Surface water: 12

I.3 Importance of real-time monitoring and control for water management: 14

I.4 Smart meters: 15

I.4.1 Benefits of smart meter: 16

Conclusion: 17

II. Chapter 2: Digital Twin Technology and Proposed Solution 18

Introduction: 18

II.1 DIGITAL TWIN: 19

II.1.1 DEFINITIONS of Digital twin: 19

II.1.2 Literature Review: 20

II.1.3 Integration Levels: 21

II.1.4 DIGITAL TWIN APPLICATIONS: 22

II.1.5 Digital twin technologies: 23

II.1.6 Deep learning techniques: 25

II.2 Suggested solution: 30

II.2.1 System Architecture and Components: 30

II.2.2 Features and capabilities of the proposed solution: 31

II.3 .Case studies of Digital Twin implementations in water management systems: 32

Conclusion: 34

III. Chapter 3 Internet of things and Cloud service 36

Introduction: 36

III.1 Definition of IoT: 36

III.2 Importance of IoT: 37

III.3 Key Technologies Empowering the Internet of Things (IoT): 37

III.4 Example of iot application: 38

III.4.1 IoT Sensor: 38

III.4.2 esp8266 : 39

III.4.3 YF-S201: 39

III.5 Cloud service: 40

III.5.1 AWS IoT Core : 40

III.5.2 MQTT components: 42

III.5.3 AWS Timestream: 42

III.5.4 Aws Grafana: 44

III.5.5 Aws TwinMaker: 45

III.5.6 Aws Sage maker: 45

III.6 Example of Creating an AWS IoT thing: 46

Conclusion: 49

IV. Chapter 4: Results and Discussion 50
Introduction: 50
IV.1 The hardware-cloud setup 50
IV.2 Presentation of visualisation: 55
IV.3 Future Demand Prediction: 59
IV.3.1 Presenting the dataset used for training: 62
IV.4 Discussng the result: 62
IV.4.1 LSTM Model Architecture: 63
Conclusion: 64
General Conclusion 65

List of Figure

Figure I-1 percent of water to land on earth surface 3
Figure I-2 percent of fresh water and salt 4
Figure I-3 water usage 4
Figure I-4 sea water supply 6
Figure I-5 storm water runoff 7
Figure I-6 wastewater treatment on industrial 8
Figure I-7 Water recycling 9
Figure I-8 importance of water conservation 10
Figure I-9 map for surface water in Algeria 13
Figure I-10 map of ground water in Algeria 14
Figure I-11 architecture of smart water meter 16
Figure II-1 integration level 22
Figure II-2 technologies on DT 24
Figure II-3 ARIMA parameters 26
Figure II-4 example of perdiction value from sequence of data 28
Figure II-5 architecture of LSTM and RNN 28
Figure III-1 microcontroller esp8266 39
Figure III-2 water sensor YF-S201 39
Figure III-3 Amazon web service 40
Figure III-4 sevice used in iot application 40
Figure III-5 AWS iot core 41
Figure III-6 MQTT component 42
Figure III-7 Aws grafana 44
Figure III-8 Aws twin maker 45
Figure III-9 AWS sage maker 45
Figure III-10 Aws iot core 46

Figure III-11 Creating thing 46
Figure III-12 thing name 46
Figure III-13 configure of certificate 47
Figure III-14 Downloading thecertificate 47
Figure III-15 Policies 48
Figure III-16 example of message 48
Figure IV-1 Cloud-Hardeware diagram 50
Figure IV-2 Aws iot core 51
Figure IV-3 certificates 52
Figure IV-4 Mqtt host 52
Figure IV-5 example of MQTT message 53
Figure IV-6 : Rule to trigger and store data 53
Figure IV-7 Table and database name 54
Figure IV-8 timestream table name and dimention 54
Figure IV-9 example of data 55
Figure IV-10 Dashboard 56
Figure IV-11 dashboard 57
Figure IV-12 adding new user 58
Figure IV-13 invitation 58
Figure IV-14 diagram of training and deploy model 61
Figure IV-15 training and validation loss on LSTM model 62

List of Table

Table I-1 Water resource availability in Algeria 12

Table II-1 Advantages and disadvantages of RNN and LSTM 29

Table IV-1 comparaison between deffirents models 60

List of abrevation

Dt: digital twin

WDS: water distribution system

WMS:water management system

AMR:automatic meter reading

RF:radio frequence

LSTM:long short term memory

ARIMA:autoregressive integrated moving average

IoT:internet of things

AI:artificial intelegence

XR: extended reality

AR:augmented reality

MR:mixed reality

VR:virtual reality

AWS:amazon web service

MSE:mean square error

MQTT:messaging queuning telemetry transport

TLS/SSL:transport layer security/secure socket layer

CMK: customer-managed key

KMS:key management service

GENERAL INTRODUCTION

Water management is indeed a critical global issue[1], and the application of advanced technologies like digital twin models can greatly help in addressing the challenges we face. Companies like Amazon, with their expertise in technology and data analytics, can play a significant role in developing and implementing such solutions for water systems. By leveraging their resources, Amazon can contribute to more effective and sustainable water management practices, helping to ensure the efficient utilization of water resources.

Digital twin models, which are virtual replicas of real-world water systems, can simulate and optimize water management strategies. Amazon can support the development of these models by providing the necessary computing power, cloud infrastructure, and data storage capabilities. These digital twins can integrate real-time data from sensors placed in water infrastructure, enabling better monitoring and predictive analysis of water usage, distribution, and quality[2].

Amazon can also collaborate with water management authorities, research institutions, and technology partners to enhance the accuracy and reliability of these digital twin models. By harnessing machine learning and artificial intelligence algorithms, these models can identify patterns, optimize resource allocation, and forecast potential water stress or crises.

Furthermore, Amazon's logistical expertise and global reach can facilitate the implementation of digital twin solutions across various regions, ensuring widespread adoption and impact. They can work with local communities, governments, and organizations to deploy sensor networks, establish data-sharing protocols, and provide training and support for operating and maintaining these systems.

Through these efforts, Amazon can contribute to more sustainable water management practices, promoting water conservation, mitigating risks of water scarcity, and improving overall efficiency in water resource utilization.

I. Chapter 1: Water management system

Introduction:

Water management systems are crucial for facilitating the sustainable utilization and safeguarding of water resources. Water management systems encompass an array of technological, policy, and procedural measures employed to regulate the caliber, amount, and dispersion of water for multifarious objectives, encompassing but not limited to potable consumption, agricultural utilization, industrial requisites, and recreational activities. The implementation of robust water management systems is of paramount importance in guaranteeing a consistent provision of potable water for societal requirements, safeguarding public welfare alongside the biosphere, and promoting economic progress.

Water management systems are confronted with an array of challenges, comprising the effects of climate change, population expansion, deteriorating infrastructure, and limited availability of water. The aforementioned challenges necessitate inventive remedies and novel methodologies for the effective management of water resources, with a view to optimizing the efficiency, efficacy, and durability of water systems. In contemporary water management systems, real-time monitoring and control serve as crucial elements, facilitating the prompt detection of water quality complications, leakage, and other issues, while concurrently supporting the optimization of water resource utilization.

Algeria, akin to numerous nations worldwide, encounters noteworthy obstacles in regulating its water reservoirs. Algeria's water resources encompass several vital sources, such as surface water, groundwater, and desalination facilities. The nation, notwithstanding, encounters a myriad of issues pertaining to water resource management. These issues include meager precipitation levels, augmented evaporation rates and water sources pollution emanating from farming practices, industrial undertakings as well as inadequate treatment provisions for wastewater. The aforementioned matters necessitate ingenious resolutions and efficient management tactics that are capable of tackling the intricate and manifold predicaments that confront Algeria's water reserves.

This chapter presents a comprehensive examination of water management systems by elucidating their varied typologies, functionalities, obstacles, and avenues for amelioration. The present study emphasizes the significance of real-time monitoring and control in contemporary water management systems, as a means to promptly identify complications and encourage effective utilization of water resources. Furthermore, an in-depth examination of

Algeria's water crisis has been undertaken, encompassing the origins, challenges and feasible remedies towards optimal water governance.

I.1 **Water Management**:

Water Resources Management (WRM) is the process of planning, developing, and managing water resources, in terms of both water quantity and quality, across all water uses. It includes the institutions, infrastructure, incentives, and information systems that support and guide water management. Water resources management seeks to harness the benefits of water by ensuring there is sufficient water of adequate quality for drinking water and sanitation services, food production, energy generation, inland water transport, and water-based recreational, as well as sustaining healthy water-dependent ecosystems and protecting the aesthetic and spiritual values of lakes, rivers, and estuaries. Water resource management also entails managing water-related risks, including floods, drought, and contamination. The complexity of relationships between water and households, economies, and ecosystems, requires integrated management that accounts for the synergies and tradeoffs of water's great number uses and values.[3]

I.1.1 Statistics on Water:

Water covers 70% of the earth’s surface but only 3% of this is fresh water. Of this, 2% is in polar ice caps and only 1% is usable water in rivers, lakes and subsoil aquifers. Only a fraction of this can be actually used.[4]

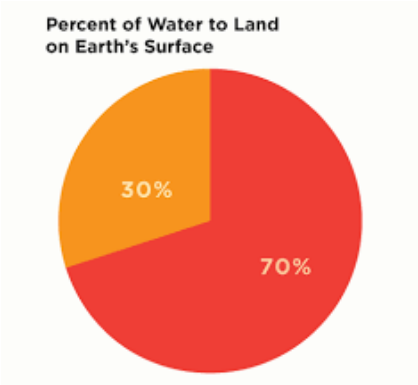


Figure I-1 percent of water to land on earth surface



Figure I-2 percent of fresh water and salt

At a global level 70% of water is used for agriculture about 25% for industry and only 6% for domestic use. However, this varies in different countries and industrialized countries use a greater percentage for industry.

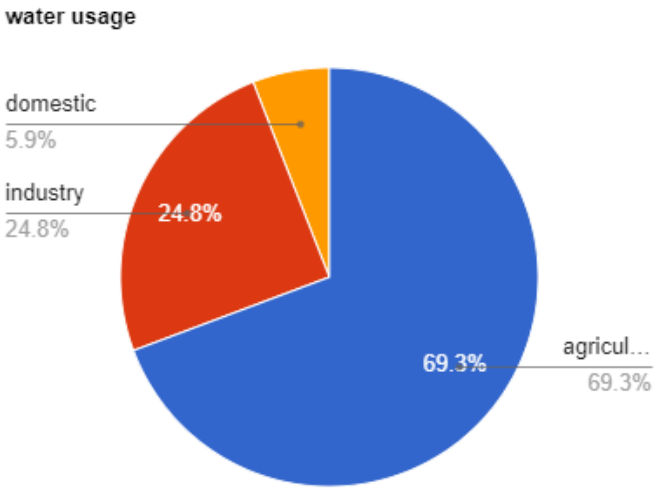


Figure I-3 water usage

Studies indicate that a person needs a minimum of 20 to 40 liters of water per day for drinking and sanitation. More than one billion people worldwide have no access to clean water.[4]

The UN has estimated that by the year 2050, 4 billion people will be seriously affected by water shortages. This will lead to multiple conflicts between countries over the sharing of water; there are 100 countries that share the waters of 13 large rivers and lakes. International accords that will look at a fair distribution of water in such areas will become critical to world peace.[4]

I.1.2 The importance of water management:

Water management is the management of the water resources available on earth. Authorities establish systems and regulations that deal with water for a variety of uses, including agriculture and sanitation. Why is this so important? Water is a renewable resource, but only when it's managed well[1], If it isn't, the world faces serious consequences. Here are ten reasons why water management matters so much:

1. When it comes to water management, we`re working with a very limited amount for all our needs.
2. Water management addresses complex issues: Managing water resources involves a lot of moving parts. The parties responsible must know how much water is available, how it needs to be used, and what needs to happen to make the water usable. They also need to be aware of competing demands, processes, and policies. The fact that water sources often cross national borders adds another layer. Good management helps streamline this complex task.
3. Combined with a growing demand for water, those responsible for water management face an uphill battle.
4. Water management and food production are linked: At 70%, agriculture uses the majority of the world`s freshwater.
5. 40% of the global population will live in water-stressed areas. At the 2019 World Economic Forum, water scarcity was named as one of the most serious global risks going into the next decade.
6. More than 2 billion people lack reliable water services: According to a report released by the WHO and UNICEF in 2019, over 2 billion people lack access to a safely managed drinking water service.
7. Poorly managed water resources are deadly: Waterborne illnesses like cholera cause millions of deaths each year. Children under the age of five who live in developing countries are especially at risk. In addition to possible death, contaminated water leads to diarrhea, dehydration, vomiting, infections, and more. Disease is not the only threat to water safety. Heavy metals and chemicals like pesticides can contaminate drinking water. Strict policies regarding impurity levels are essential to any water management system. Good water management saves lives.
8. Water management is a local and national issue: Local authorities are best equipped to handle top priority issues within a community. This makes a strong local water

management system essential. However, there still needs to be excellent communication between the local and national levels. If this communication breaks down, competing local and national water interests can throw a region into chaos. National regulations and laws are also necessary so water resources are consistently protected and managed.

9. Good water management benefits everyone: When water resources are managed well, communities and the government benefit. Water management allows for reduced water and sewer costs, better irrigation controls during summer, and less energy waste. Good management also ensures that water is clean and safe, which protects public health.

I.1.3 Types of water management systems:

To regulate, safeguard, and conserve water resources, varieties of water management methods are utilized. The following are some of the popular kinds of water management systems:

I.1.3.1 Water supply systems:

Infrastructure for the collection, transmission, treatment, storage, and distribution of water for homes, commercial establishments, industry, and irrigation, as well as for such public needs as firefighting and street flushing. Of all municipal services, provision of potable water is perhaps the most vital. People depend on water for drinking, cooking, washing, carrying away wastes, and other domestic needs. Water supply systems must also meet requirements for public, commercial, and industrial activities. In all cases, the water must fulfill both quality and quantity requirements.[5]

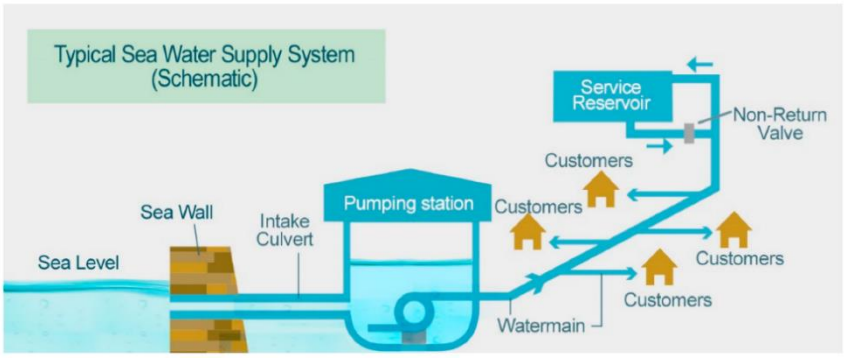


Figure I-4 sea water supply

I.1.3.2 Storm water Management:

Storm water management is the effort to reduce runoff of rainwater or melted snow into streets, lawns and other sites and the improvement of water quality, according to the United States Environmental Protection Agency (EPA). When storm water is absorbed into the soil, it is filtered and ultimately replenishes aquifers or flows into streams and rivers. However, when heavy rainwater hits, ground saturated by water creates excess moisture that runs across the surface and into storm sewers and road ditches. This water often carries debris, chemicals, bacteria, eroded soil, and other pollutants, and carries them into streams, rivers, lakes, or wetlands.[6]

In urban and developed areas, impervious surfaces such as pavement and roofs prevent precipitation from naturally soaking into the ground. Instead, water runs rapidly into storm drains, sewer systems and drainage ditches and can cause flooding, erosion, turbidity (or muddiness), storm and sanitary sewer system overflow, and infrastructure damage. However, storm water design and "green infrastructure" capture and reuse storm water to maintain or restore natural hydrologist. Detaining storm water and removing pollutants is the primary purpose of storm water management. Pervious Surfaces that are porous and allow rainfall and snowmelt to soak into the soil, Gray infrastructure, such as culverts, gutters, storm sewers, conventional piped drainage, and Blue/Green infrastructure that protect, restore, or mimic the natural water cycle, all play a part in storm water management.

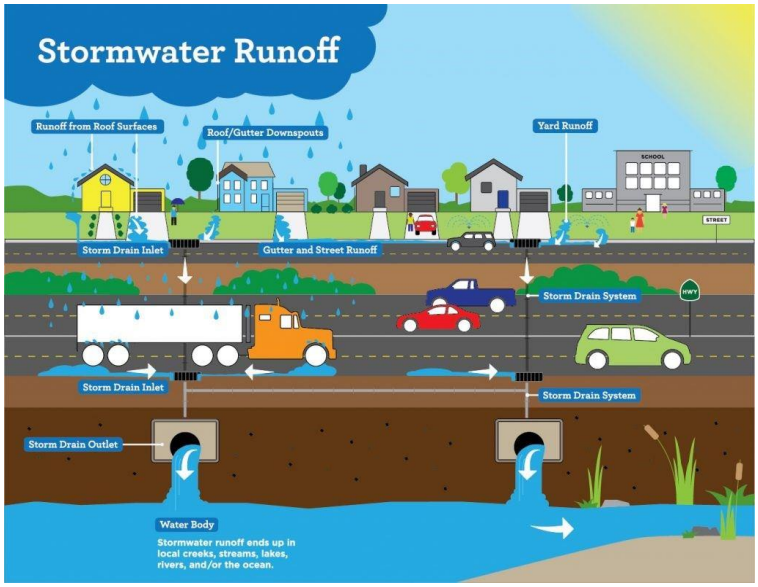


Figure I-5 storm water runoff

I.1.3.3 Wastewater treatment:

The ultimate objective of a wastewater treatment system is to supply effective treatment methods that purifies water and returns the recycled water back into the ecosystem safely. However, the amount of energy it takes for a wastewater treatment system to accomplish this task is herculean. [7]

To put things into more perspective, industrial plants are compelled to follow effluent regulations, which brings a general set of issues to the production of wastewater treatment systems, which include:

Every community produces both liquid and solids waste and air emissions. Wastewater collected from municipalities and communities ought to be ultimately returned to receiving waters, land, or potentially reused. Wastewater contains numerous pathogenic microorganisms that dwell in the human intestinal tract. Other contaminants include biodegradable organics (measured as biochemical oxygen demand "BOD" and Chemical oxygen demand "COD") which can lead to depletion of natural oxygen resources, nutrients (such as nitrogen and phosphorous) which can stimulate the growth of undesirable aquatic life, and may contain toxic compounds that may be mutagenic or carcinogenic. For the aforementioned reasons, the immediate removal of wastewater from its source of generation, followed by treatment, reuse, or disposal into environment is necessary to protect public health and the environment.[7]

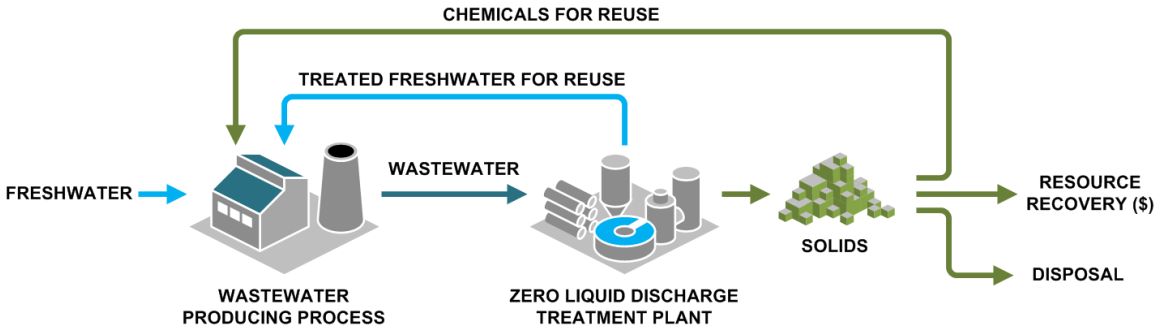


Figure I-6 wastewater treatment on industrial

I.1.3.4 Water reuse and recycling systems:

Water recycling is the process of treating wastewater and reusing it. Recycled water can be reused for the same process, for irrigation or as an alternative to mains water in wash-down applications. Water recycling systems will vary according to the quality of wastewater to be treated and the intended application of the water.[8]

Recycling water allows us to continually reuse one of our most vital resources. Water recycling removes contaminants from wastewater and allows it to be reused on a wash bay several times. Recycling water systems ensure that the water is safe for washing plant and equipment, and other practical uses.[8]

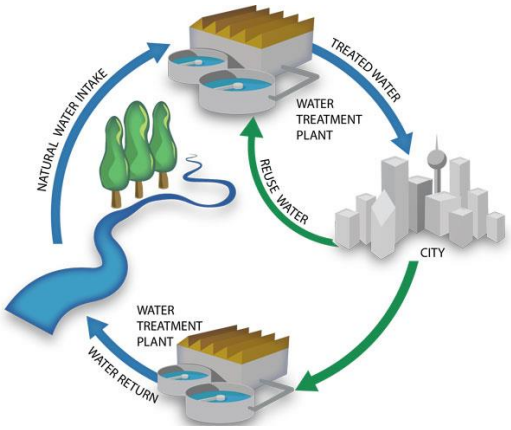


Figure I-7 Water recycling

I.1.3.5 Water conservation:

Water conservation can be defined as any beneficial deduction in water loss, use, or waste. A reduction in water use accomplished by implementation of water conservation or water efficiency measures improved water management practices that reduce or enhance the beneficial use of water a water conservation measure is an action, behavioral change, device, technology, or improved design or process implemented to reduce water loss, waste, or use. Water efficiency is a tool of water conservation. That results in more efficient water use and thus reduces water demand. The value and cost-effectiveness of a water efficiency measure must be evaluated in relation to its effects on the use and cost of other natural resources. (e.g., energy or chemicals)[9]

The goals of water conservation efforts include:

1. Sustainability to ensure availability for future generations, the withdrawal of fresh water from an ecosystem should not exceed its natural replacement rate.
2. Energy conservation Water pumping, delivery, and wastewater treatment facilities consume a significant amount of energy.
3. In some regions (e.g. California2) of the world over 15% of total electricity consumption is devoted to water management Habitat conservation- Minimizing human water use helps to preserve fresh water habitats for local wildlife and migrating waterfowl, as well as reducing the need to build new dams and other water diversion infrastructure.[9]



Figure I-8 importance of water conservation

I.1.4 Challenges and opportunities for improving water management systems:

Water management systems face several challenges and opportunities for improvement. Some of the challenges include poor governance of water systems and programs, increasing demand, water scarcity, growing uncertainty, greater extremes, and fragmentation challenges. To address these challenges, investments in institutional strengthening, information management, and infrastructure development are needed Institutional tools such as legal and regulatory frameworks, water pricing, and incentives are also needed to better allocate, regulate, and conserve water resources ,On the other hand, opportunities for improvement include research, development, and deployment of clean water technologies, promoting reuse opportunities, and investments in innovative technologies for enhancing productivity,

conserving and protecting resources, recycling storm water and wastewater, and developing non-conventional water sources.[3]

Technology can help address water management challenges in several ways. Investments in innovative technologies for enhancing productivity, conserving and protecting resources, recycling storm water and wastewater, and developing non-conventional water sources can be explored .Digital water instruments with built-in software can improve efficiency and reduce downtime, allowing water utilities to dial into devices and discover their operational status [10].

Smart Water Monitoring and Management Systems, based on the combination of sensors, big data, and AI technologies, can provide water utility operators with real-time data to make more reasonable and sustainable usage of water resources. Innovative solutions such as carbon paper evaporators and filtration systems can be used to improve the performance and efficiency of water purification devices. Smart water management systems can also help address the growing lack of available fresh water by planning, developing, distributing, and managing the use of water resources using an array of IoT technologies. Overall, technology can play a significant role in addressing water management challenges by improving efficiency, reducing downtime, providing real-time data, and developing innovative solutions.

There are several innovative technologies for water management. Smart Water Monitoring and Management Systems based on the combination of sensors, big data, and AI technologies can provide water utility operators with transparency and improved control over water resources[11] . Innovative Water Technologies is dedicated to researching and developing products for water treatment and purification[12] . Advanced filtration and innovative materials such as modular adsorbents, electrode-based reactors, photocatalysts, and nanoparticles are key technologies that are advancing the trend of water recovery and reuse. Decentralized water infrastructure is also improving access to drinking water in remote areas. Furthermore, water management solutions combine flood prevention with water safety and reuse. Investments in innovative technologies for enhancing productivity, conserving and protecting resources, recycling storm water and wastewater, and developing non-conventional water sources should be explored. Therefore, innovative technologies can play a significant role in addressing water management challenges.

I.2 Overview of water in Algeria (source, problem...):

Algeria is one of the driest countries in the world with less than 600 cubic meters of water per person per year. Algeria's territory is her 2.4 million km², but most of it (87%) is desert and receives very little rain. In fact, more than 90% of the surface water is in the north (Tell region), which occupies about 4% of the territory and is home to more than two-thirds of the country's estimated population of 45 million. Algeria also suffers from severe hydro-climatic conditions, such as chronic droughts and devastating floods, which have become more frequent in recent years. Furthermore, demographics and economic growth have significantly increased the demand for drinking, industrial and agricultural water, making it very difficult to meet water demand both quantitatively and qualitatively. In recent years, serious water shortages have been observed, especially in large cities, and social unrest has arisen in some areas. This situation should be viewed as a chronic crisis requiring long-term solutions rather than a temporary problem caused by low rainfall.

I.2.1 Source of water in Algeria:

Algeria's renewable water resources are estimated at about 19 billion cubic meters (BCM/year) per year (Table 1), or about 450 cubic meters (m3) per person per year. This is below the recommended water crisis threshold of 500 cubic meters per person per year. Water resources are characterized by high variability.

Water resource	Volume (BCM)	Region
Renewable surface water	11	North and south
Renewable groundwater	2.5	North
Non-renewable groundwater	6.1	South

Table I-1 Water resource availability in Algeria

I.2.1.1 Surface water:

Algeria is divided into five major river basins comprising 17 catchments and concentrated mainly in the north (Map 1). The renewable surface water resources are estimated to total 11 BCM. Surface water inflows are low in the Saharan basin, with 0.5 BCM per year. In contrast, the north relies mainly on surface water, since a number of medium and large dams captures almost 7 BCM. Runoff occurs as rapid and powerful floods that replenish the dams during the short rainy season, which typically runs from December to February.

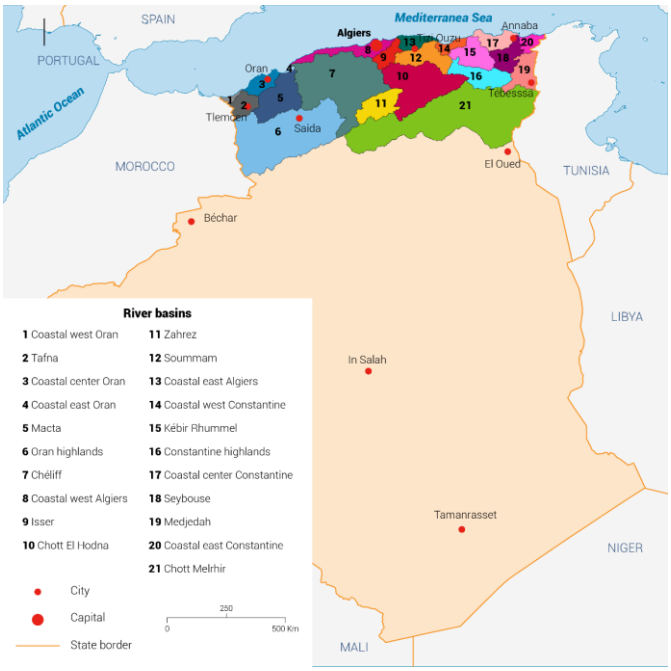


Figure I-9 map for surface water in Algeria

I.2.1.2 Groundwater:

Groundwater resources are estimated to total 7.6 BCM, but demand is much higher in the north of the country. Important aquifers in the Sahara meet 96% of water demand in the south. In the mountainous region in the north, the aquifers are shallow and exploited using wells and springs. While these aquifers are naturally recharged with 1.9 BCM/yr., the total withdrawals are estimated at 2.4 BCM/yr. The deficit is mainly due to a lack of effective groundwater management, linked to poor knowledge of the resource, an increase in the number of illegal wells and a lack of coordination between the water authorities.

Groundwater in the south is mainly fossil with very low renewability. The water resources are contained within two major overlapping aquifers, the Complex Terminal and the Continental Interlayer, which form the transboundary North-Western Sahara Aquifer System (NWSAS). The Complex Terminal (100-400 meters deep) and the Continental Interlayer (1,000-1,500 meters deep) contain significant reserves of 30,000-40,000 BCM (Map 2). The deep aquifers are exploited mainly using deep boreholes, whereas the shallow ones are exploited using the traditional foggara system. [10]

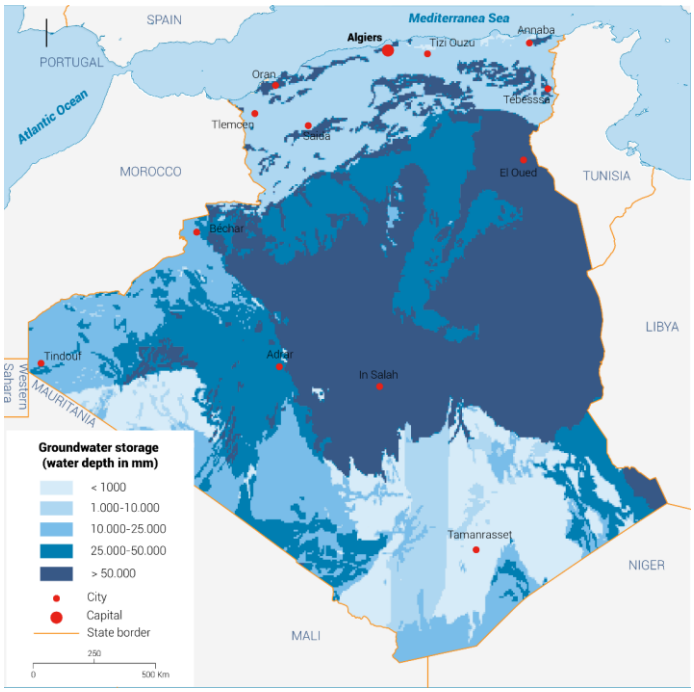


Figure I-10 map of ground water in Algeria

I.3 Importance of real-time monitoring and control for water management:

Real-time monitoring and control play an important role in water management. Real-time monitoring (RTM) can be used to control water quality and quantity, which is essential for the management of water distribution systems (WDSs) and protection of consumers' health1. The objective of water management companies is to have a centralized and single monitoring system for all their assets that encompasses equipment and operations. Real-time wireless communications can be used to improve the management of physical assets and personnel. Real-time monitoring and control can also be used for fault measurement detection in an urban water supply network. A generic tool for real-time operational predictive optimal control of water networks can also be used to improve water management. Therefore, real-time monitoring and control are essential for water management and can be used to improve the efficiency and reliability of water systems.

Real-time monitoring and control in water management can be achieved through various technologies. These include real-time monitoring systems, supervisory control and data acquisition (SCADA) software, industrial radio with messaging queuing telemetry transport (MQTT), and Barbara's Edge Platform. Real-time monitoring systems can help to detect and respond to changes in water quality and quantity in real-time. SCADA software can be used

for improved management of physical assets and better decision-making. Industrial radio with MQTT can provide faster communication and improved reliability and reporting. Barbara's Edge Platform can help water management companies to have a centralized and single monitoring system for all their assets that encompasses equipment and infrastructure. Therefore, real-time monitoring and control in water management can be achieved through various technologies.

Real-time monitoring and control technologies offer several benefits for water management. Control of water quality and quantity by real-time monitoring plays an important role in the management of water distribution systems and protection of consumers' health[13]. Real-time monitoring and control can help to detect and respond to changes in water quality and quantity in real-time, which can help to prevent water loss, reduce energy consumption, and improve water management efficiency. Real-time monitoring and control can also help to ensure the suitability of water for drinking and warn operators to stop water supply to save water and minimize risks when needed. Real-time monitoring and control technologies can also help water management operators to monitor all components that make up the OT and industrial automation architectures in a unified and comprehensive way, which can help to operate more efficiently. Therefore, real-time monitoring and control technologies offer several benefits for water management.

I.4 **Smart meters:**

A smart meter is an electronic device that records information such as electricity consumption, voltage level, current and power factor. Smart meters send information to consumers for better visibility into consumption behavior, and information to electricity suppliers for system monitoring and customer billing. Smart meters provide a way to measure electricity consumption in near real time, allowing utilities to charge different electricity rates depending on the time of day and year. Smart meters are not the same as automatic meter reading (AMR); they have additional features such as real-time or near-real-time sensors, outage notifications, and power quality monitoring. Smart meters typically use low power radio frequencies (RF) that are much lower than the RF used by devices already in the home such as baby monitors, cell phones, microwave ovens, televisions and wireless routers. . Smart meters are safe, with about 100 million smart meters already installed in over 70% of households nationwide.

Smart meters for water supply work similarly to those for electricity, recording information such as consumption and communicating it to the consumer for greater clarity of consumption behavior, and to the water supplier for system monitoring and customer billing

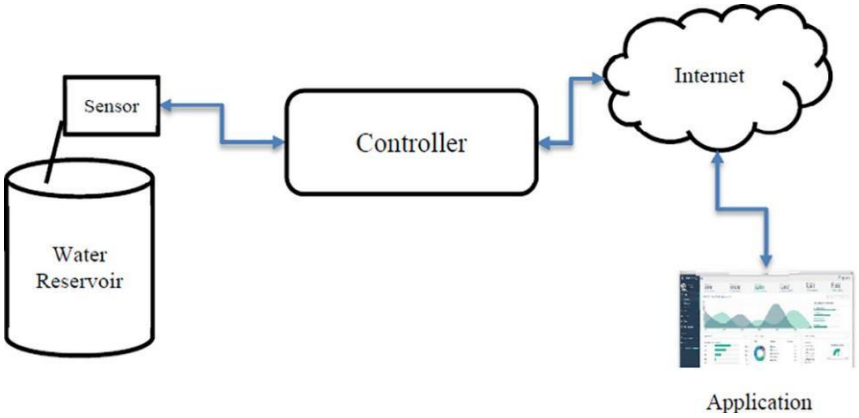


Figure I-11 architecture of smart water meter

I.4.1 Benefits of smart meter:

Smart water meters have several benefits, including water conservation, water leak detection, and reduction of non-revenue water. Smart water metering systems capture and share water consumption data more frequently, monitor the rate of flow, identify reverse flows, and send alerts at the first sign of a problem. Smart water meters can also capture additional flow through their extended low flow accuracy. Smart meter-based water consumption feedback and digital user engagement can effectively promote durable conservation behaviors. Smart water meters can track consumption and catch leaks as soon as possible, providing homeowners with information on how to improve efficiency. Smart water meters can also set water usage and flow rate alerts to stay on budget and reduce water waste.

Conclusion:

Water management systems are essential for sustainable water resource utilization and conservation. They involve various practices and technologies to optimize water allocation, treatment, storage, and distribution. Despite challenges such as population growth and limited infrastructure, there are opportunities for innovation and resilience. Real-time monitoring and control play a vital role in detecting issues and improving efficiency. In the context of Algeria, which faces water scarcity, comprehensive strategies focusing on conservation, efficiency, and community engagement are crucial. By implementing these measures, countries can ensure water security and create a sustainable future.

II. Chapter 2: Digital Twin Technology and Proposed Solution

Introduction:

In today's world, effective water management is of utmost importance due to increasing water scarcity and the need for sustainable resource allocation. Addressing the challenges faced by water infrastructure and consumption requires innovative approaches that leverage advanced technologies. This chapter focuses on the exploration of Digital Twin technology and its application in water management systems.

To begin, the chapter provides a comprehensive overview of Digital Twin technology, offering a clear definition and understanding of its principles. A Digital Twin refers to a virtual replica of a physical system, encompassing its structure, behavior, and characteristics. It serves as a powerful tool that enables real-time monitoring, simulation, and analysis of complex systems, including water management infrastructure.

The chapter then delves into the advantages and applications of Digital Twins in the context of water management systems. By utilizing Digital Twins, water managers can monitor and optimize water infrastructure in real-time, leading to increased efficiency, reduced waste, and improved resource allocation. Furthermore, the predictive analytics capabilities of Digital Twins empower decision-makers to proactively address maintenance needs, assess risks, and make informed choices to optimize water management practices.

A literature review is conducted to examine existing studies and research related to Digital Twin implementations in water management systems. This review aims to identify successful case studies, lessons learned, and best practices that can inform the proposed solution. By drawing upon previous work in the field, the chapter gains valuable insights into the potential and challenges associated with Digital Twin technology in water management.

We delve into the application of deep learning techniques for time series prediction. Specifically, we explore LSTM (Long Short-Term Memory), ARIMA (Autoregressive Integrated Moving Average), and exponential smoothing. These techniques allow us to analyze historical water consumption data and make accurate forecasts for future usage patterns.

In conclusion, Chapter 3 provides a comprehensive introduction to Digital Twin technology and its proposed application in water management systems. By offering an overview,

exploring the advantages and applications, and conducting a literature review, this chapter sets the stage for further exploration of the potential of Digital Twins in revolutionizing water management practices.

II.1 DIGITAL TWIN:

Formal ideas around Digital Twins have been around since the early 2000s. That said, it might have been possible to define Digital Twins earlier owing to the ever-changing definitions. [14]

II.1.1 DEFINITIONS of Digital twin:

The first terminology was given by Grieves in a 2003 presentation and later documented in a white paper setting a foundation for the developments of Digital Twins .The National Aeronautical Space Administration (NASA) released a paper in 2012 entitled ‘‘The Digital Twin Paradigm for Future NASA and U.S. Air Force Vehicles’’, setting a key milestone for defining Digital Twins.

a: NASA 2012: ‘‘A Digital Twin is an integrated Multiphysics, multiscale, probabilistic simulation of an as-built vehicle or system that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its corresponding flying twin.’’ [15]

b: CHEN 2017: ‘‘A digital twin is a computerized model of a physical device or system that represents all functional features and links with the working elements.’’

c: LIU et al. 2018 :‘‘The digital twin is actually a living model of the physical asset or system, which continually adapts to operational changes based on the collected online data and information, and can forecast the future of the corresponding physical counterpart.’’

d: ZHENG et al. 2018: ‘‘A Digital Twin is a set of virtual information that fully describes a potential or actual physical production from the micro atomic level to the macro geometrical level.’’

e: VRABIČ et al. 2018: ‘‘A digital twin is a digital representation of a physical item or assembly using integrated simulations and service data. The digital representation holds information from multiple sources across the product life cycle. This information is continuously updated and is visualized in a variety of ways to predict current and future conditions, in both design and operational environments, to enhance decision-making.’’

f: MADNI 2019 : ‘‘A Digital Twin is a virtual instance of a physical system (twin) that is continually updated with the latter’s performance, maintenance, and health status data throughout the physical system’s life cycle.’’

Definition a) is a common fuzzy definition NASA interplanetary vehicle development and one in the first documents describing Digital Twins. There, too with more than six years between books a) and f, there is still one idea that is neither original nor plausible change. Both academia and industry have not contributed to the distinction between DT’s and conventional computer models and simulations. Future work a. requires clarification for Digital Twins of Worms. The aim of this research is. The revised definition is likewise helpful in related research work and identifies unrepresented digital twins[14].

II.1.2 Literature Review:

The authors conducted a structured literature review to identify and analyze existing research on Digital Twins. They followed a five-step process recommended by Vom Brocke et al. (2009), which included defining the scope of the review, conceptualizing the topic, conducting a search process, analyzing the literature, and revising the research agenda. [16]

In the first step, the authors defined the scope of their literature review to consider only peer-reviewed publications dealing with the topic of Digital Twins. They also identified key search terms and databases to use in their search process.

In the second step, they conceptualized the topic of Digital Twins by defining its characteristics and distinguishing it from related concepts such as cyber-physical systems and digital models.

In the third step, they conducted a search process using their identified search terms and databases. They screened articles based on inclusion criteria such as relevance to Digital Twins and publication in peer-reviewed journals.

In the fourth step, they analyzed the literature by extracting data on key themes related to Digital Twins such as their definition and characteristics, their applications in various industries, and their potential benefits for businesses. They also identified gaps in the literature related to Digital Twins and proposed research questions to address these gaps.

Finally, in the fifth step, they revised their research agenda based on insights gained from their analysis of the literature. They proposed further research on topics such as developing a taxonomy for Digital Twins and exploring ethical considerations related to their use.

Overall, this literature review provided a foundation for subsequent analysis of archetypes of Digital Twins for individual use cases. It also highlighted areas where further research is needed to advance understanding of this emerging technology.

II.1.3 Integration Levels:

1) DIGITAL MODEL A digital model is described as a digital version of a pre-existing or planned physical object, to correctly define a digital model there is to be no automatic data exchange between the physical model and digital model. Examples of a digital model could be but not limited to plans for buildings, product designs and development. The important defining feature is there is no form of automatic data exchange between the physical system and digital model. This means once the digital model is created a change made to the physical object has no impact on the digital model either way. [17].

2) DIGITAL SHADOW A digital shadow is a digital representation of an object that has a one-way flow between the physical and digital object. A change in the state of the physical object leads to a change in the digital object and not vice versus.

3) DIGITAL TWIN If the data flows between an existing physical object and a digital object, and they are fully integrated in both directions, this constituted the reference ‘‘Digital Twin’’. A change made to the physical object automatically leads to a change in the digital object and vice versa.

These three definitions help to identify the common misconceptions seen in the literature. However, there are several misconceptions seen but they are not limited to just these specific examples. Amongst the misconceptions, is the Digital Twins have to be an exact 3D model of a physical thing. On the other hand, some individuals that think a Digital Twin is just a 3D model. Figure below and their definitions present the different levels of integration for a Digital Twin. The definitions and figures should help in the development and identification of future Digital Twins.

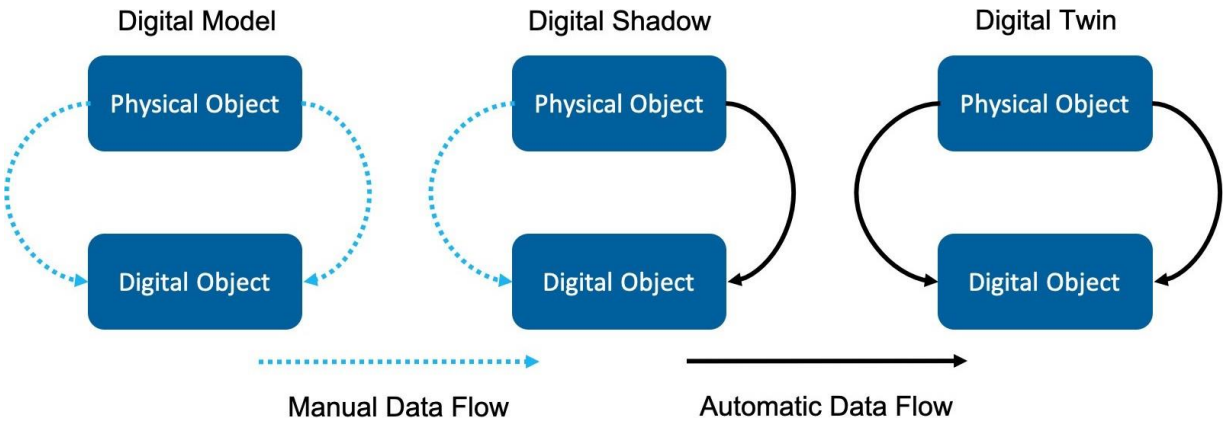


Figure II-1 integration level

II.1.4 DIGITAL TWIN APPLICATIONS:

II.1.4.1 SMART CITIES:

With an increasing number of smart cities developed, the more connected communities are, with this comes more Digital Twins use. Not only this, the more data we gather from IoT sensors embedded into our core services within a city, but it will also pave the way for research aimed at the creation of advanced AI algorithms The ability of services and infrastructures within a smart city to have sensors and to be monitored with IoT devices is of great value for all kinds of future-proofing. It can be used to help in the planning and development of current smart cities and help with the ongoing developments of other smart cities. As well as the benefits of planning, there are also benefits within the energy saving world.

II.1.4.2 MANUFACTURING:

highlights that the usage of DTs may allow to develop a computerized system supervising each step of manufacturing through a modular approach. This can be obtained by using faithful virtual replica of the physical entities, in the depicted scenario; DTs also allow a continuous communication between the system and the physical asset. seems referring to the DT as a realistic model or simulation with the ability of continuously communicating with its physical twin, which is a too simplistic way for describing it.

what makes a simulated model or Avatar a DT is the artificial intelligence and the continuous real-time data exchange between the physical model and its virtual counterpart. Such data are required not only to describe the physical twin’s behavior but also to derive solutions relevant for the real system. Essentially, DTs are particular

simulations, specifically designed for their intended purpose, which evolve along with the real system, during its whole life cycle. [18]

II.1.4.3 HEALTHCARE

The increased connectivity is only growing the potential application of Digital Twin use within the healthcare sector. One future application is a Digital Twin of a human, giving a real-time analysis of the body. Twin used for simulating the effects of certain drugs.

Likewise with other applications within a healthcare setting the use of a Digital Twin gives researchers, doctors, hospitals and healthcare providers the ability to simulate environments specific to their needs whether it be real-time or looking to future developments and uses. As well as this, the Digital Twin can be used simultaneously with AI algorithms to make smarter predictions and decisions. Many applications within healthcare do not directly include the patient but are beneficial for the ongoing care and treatment, hence the key role such systems have on patient care. Digital Twin for healthcare is in its infancy, but the potential is vast from using it for bed management to large-scale wards and hospital management. [17]

Having the ability to simulate and act in real-time is even more paramount within healthcare as it can be the difference between life and death. The Digital Twin could also assist with predictive maintenance and ongoing repair of medical equipment. The Digital Twin within the medical environment has the potential along with AI to make life saving decisions based on real-time and historical data.

II.1.5 Digital twin technologies:

Digital Twin uses four technologies to collect and store real-time data, obtain information to provide valuable insights, and create a digital representation of a physical object. These technologies include the Internet of Things, Artificial Intelligence, Extended Reality, and Cloud [14]

1. Internet of Things: IoT refers to a giant network of connected «things». The connection is between things–things, people–things, or people–people. By 2027, more than 90 percent of all IoT platforms will have Digital Twinning capability. The digital version then can then be analyzed, manipulated, and optimized. IoT constantly updates data and helps Digital Twin applications create a real-time virtual representation of a physical object.
2. Cloud Computing: Cloud computing refers to delivering hosted services over the

Internet. Cloud computing provides Digital Twins with data computing technology and cloud data storage technology. Cloud computing enables Digital Twins to effectively reduce the computation time of complex systems and overcome the difficulties of storing large amounts of data.

3. Artificial Intelligence (AI): As a discipline of computer science, AI seeks to mimic the basis of intelligence to create a new intelligent machine capable of responding like human-to-human intelligence. Areas of AI study include Robotics, image recognition, and language recognition. Neural Networks, Machine Learning, Deep Learning, and expert systems , AI can assist Digital Twins by providing an advanced analytical tool capable of automatically analyzing obtained data and providing valuable insights, making predictions about outcomes, and giving suggestions as to how to avoid potential problems
4. Extended Reality (XR) is an umbrella term used to describe immersive technologies like Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR). These technologies can merge the physical and virtual worlds and extend the reality we experience. XR creates digital representations of objects where digital and real-world objects co-exist and interact in real-time. Digital Twins utilize XR capabilities to digitally model physical objects, allowing users to interact with digital content.

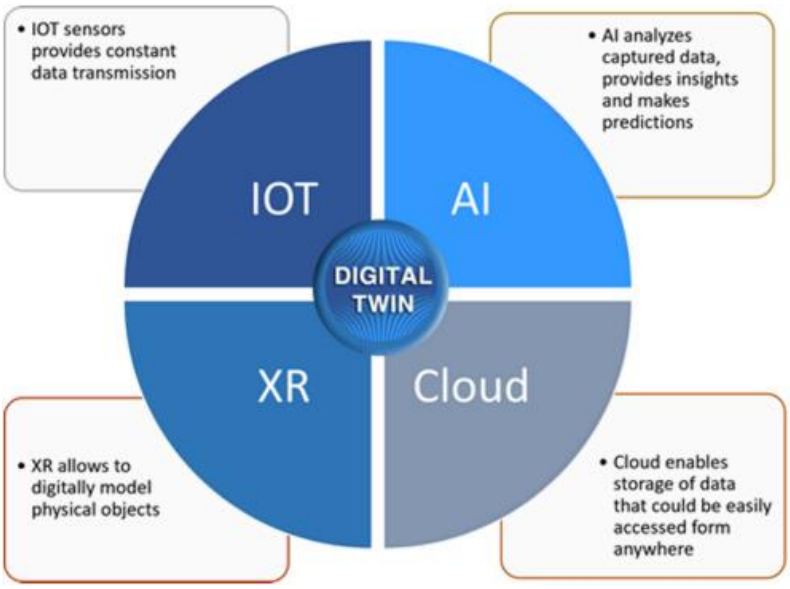


Figure II-2 technologies on DT

II.1.6 Deep learning techniques:

Deep learning is a subset of device studying that focuses on education artificial neural networks to imitate the human mind's ability to examine and make decisions. By leveraging deep mastering strategies inclusive of LSTM, ARIMA, and exponential smoothing, we can seize tricky styles, temporal dependencies, and nonlinear relationships in the water intake facts.

By utilizing deep getting to know, we will make more informed selections concerning water resource management, conservation efforts, and infrastructure making plans.

The significance of deep learning in our assignment lies in its potential to address complex and dynamic time collection records, providing accurate and reliable predictions.

II.1.6.1 ARIMA:

An autoregressive integrated moving average, or ARIMA, is a statistical analysis model that uses time series data to either better understand the data set or to predict future trends. [19]

A statistical model is autoregressive if it predicts future values based on past values. For example, an ARIMA model might seek to predict a stock's future prices based on its past performance or forecast a company's earnings based on past periods. [19]

An autoregressive integrated moving average model is a form of regression analysis that gauges the strength of one dependent variable relative to other changing variables. The model's goal is to predict future securities or financial market moves by examining the differences between values in the series instead of through actual values. [19]

An ARIMA model can be understood by outlining each of its components as follows:

Autoregression (AR): refers to a model that shows a changing variable that regresses on its own lagged, or prior, values.

Integrated (I): represents the differencing of raw observations to allow the time series to become stationary (i.e., data values are replaced by the difference between the data values and the previous values).

Moving average (MA): incorporates the dependency between an observation and a residual error from a moving average model applied to lagged observations.

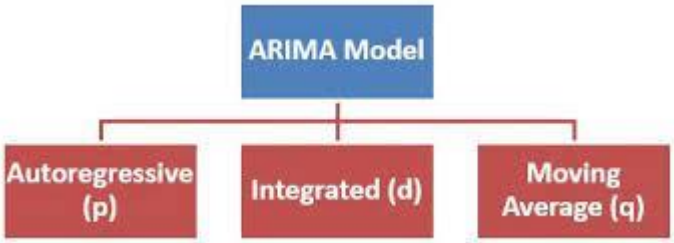


Figure II-3 ARIMA parameters

Advantage:

- Good for short-term forecasting
- Only needs historical data
- Model non-stationary data

Disadvantage :

- Not built for long-term forecasting
- Poor at predicting turning points
- Parameters are subjective

II.1.6.2 Exponential Smoothing:

A Powerful Forecasting Technique for Time Series Data[20] Exponential smoothing is a widely employed forecasting method specifically designed for univariate time series data. This approach generates forecasts by computing weighted averages of past observations, with older observations receiving exponentially decreasing weights. By incorporating various forms of exponential smoothing, this method can effectively model time series data with trends and seasonal components.

Originating in the 1950s, exponential smoothing has emerged as a highly successful tool embraced by statisticians and analysts alike. Its ability to swiftly generate accurate forecasts has found applications across diverse fields, particularly in industry. Additionally, the technique has proven valuable in signal processing, where it is employed to smooth signals by filtering out high-frequency noise, further expanding its utility.

Overall, exponential smoothing continues to be a valuable and versatile forecasting technique, empowering analysts to make informed predictions in time series analysis while finding utility in signal processing applications.

The Principe of working:

- Exponential smoothing assigns exponentially decreasing weights to past observations.
- The weights reflect the importance of recent data points.
- The forecasted values are updated iteratively based on the weighted average of past observations and the previous forecast.
- The specific formula for updating the forecast depends on the variant of exponential smoothing being used (e.g., SES, Holt's, Holt-Winters').
- Exponential smoothing captures the overall level, trend, and seasonality in the time series.
- By adapting to changing patterns in the data, exponential smoothing generates smoothed estimates for future time periods.

Advantage of Exponential Smoothing:

- Simple and easy to implement.
- Computationally efficient, making it suitable for large datasets.
- Provides reliable forecasts for time series data without significant trends or seasonality.
- Adapts quickly to recent changes in the data due to the emphasis on recent observations.
- Can handle irregularly spaced time intervals.

Disadvantage of Exponential Smoothing:

- Limited ability to capture complex or nonlinear trends in the data.
- May not perform well with time series that exhibit strong seasonality or irregular patterns.
- Relies heavily on recent observations, potentially overlooking long-term patterns.
- Can be sensitive to the initial forecast or parameter selection.
- Not suitable for time series with missing data points or outliers.

II.1.6.3 LSTM (long short-term memory):

- Recurrent Neural Network (RNN) is used to process sequence data, Compared with the general neural network, it can process sequential changes in the data. [21]

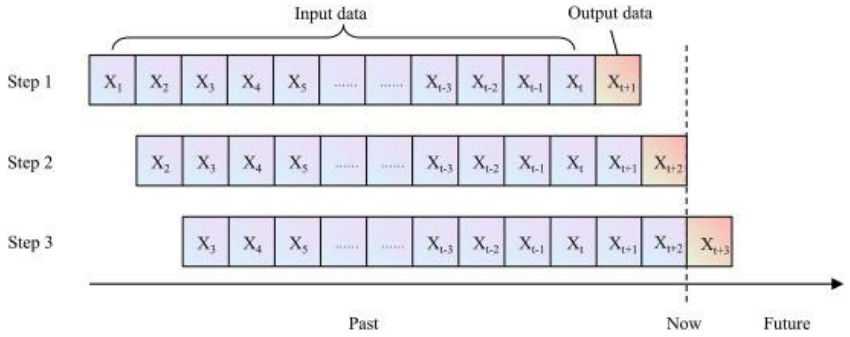


Figure II-4 example of perdiction value from sequence of data

For example, a word can have different meanings depending on the content mentioned above, and RNN is skilled in solving these kinds of problems. The structure of RNN is illustrated in figure.1.a, A is a hidden layer, X_t and h_t are the input and output of the current state, this loop allows information to be passed from one step to the next. One of the appeals of RNN is that the output of the present hidden layer is transformed to an input of next hidden layer, in other words, present information is connected to the next task. RNN can handle inputs of any length, but RNN is only sensitive to short-term information, making it difficult to solve problems of "long-term dependencies".

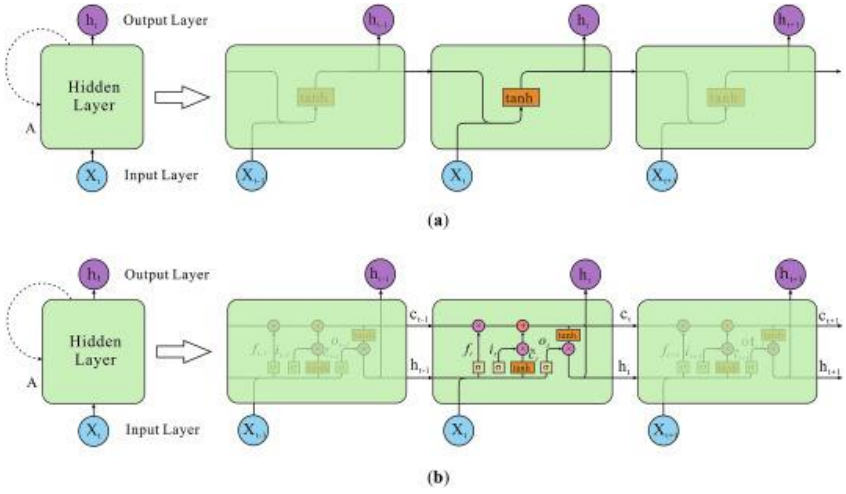


Figure II-5 architecture of LSTM and RNN

LSTM is a special kind of RNN that can handle “long-term dependencies” and was first introduced by Hochreiter & Schmidhuber in 1997. The structure of standard RNN repeating module is very simple, with only a single tanh layer. Compared with RNN, the internal structure of LSTM is more complex, and consists of cell state, input gate, forget gate, and output gate. The LSTM is regulated carefully by these three gates to remove or add information to cell state, as shown in part b of the figure 16.

The advantages and limitations of RNN and LSTM are listed in the Table 2.

	RNN	LSTM
Advantages	1. RNN can model sequence of data (i.e., time series data). 2. Simple to implement.	1. Capable of learning long-term dependencies. 2. Remembering information from a long period of time is its default behavior. 3. Gradient vanishing and exploding can be overcome in the long sequence training process. 4. Simple to implement.
Limitations	1. It cannot process very long sequence data. 2. Gradient vanishing and exploding problems.	1. High-performance computing equipment (i.e., high memory-bandwidth and large-memory graphics card) are required, because of large amount of calculation.

Table II-1 Advantages and disadvantages of RNN and LSTM

II.2 Suggested solution:

The proposed Digital Twin solution for water management systems aims to improve water management efficiency, improve efficiency and enable informed decision-making regarding water usage IoT, cloud computing, data analysis to create a comprehensive digital representation of water use and practices and other advanced technologies.

II.2.1 System Architecture and Components:

The Digital Twin solution for water management systems consists of the following components:

- Data acquisition and integration: Real-time data on water consumption, such as flow, usage patterns, and meter readings, are collected from IoT devices, including smart water meters and sensor is included This information in the Digital Twin Is integrated, making it a central repository for controller data.

- IoT devices and connectivity: IoT devices, such as smart water meters, are deployed at convenient locations in water distribution networks or individual customers These devices capture consumption data and transmit it to the cloud environment by cable or wire connections.

- Cloud Infrastructure: Digital Twin solutions are offered on a cloud platform, such as Amazon Web Services (AWS), which provide scalability, reliability, and secure data storage Cloud infrastructure provides the data processing, analytics, and storage capabilities needed to run it the power of the Digital Twin function.

- Data analysis and modeling: Advanced analytical techniques including machine learning algorithms and predictive models are applied to resource consumption data collected These analytical models analyze patterns, identify anomalies, and gain insights though understand the behavior of materials and provide efficient water management.

- Visualization and Reporting: Digital Twin includes visualization tools and reporting techniques that deliver real-time and historical consumption data in an easy-to-understand format. These tools enable consumers, supply chain providers, and decision makers to understand supply chain characteristics, patterns, and anomalies.

II.2.2 Features and capabilities of the proposed solution:

The proposed Digital Twin solution for water management systems offers the following features and capabilities.

- Real-time analytics: Digital Twin continuously monitors real-time water consumption data, providing up-to-date information on usage patterns, flows and trends This empowers customers and suppliers monitor users and make adjustments as needed.

- Predictive analytics: Using advanced analytics algorithms, the digital pair can predict future usage patterns and behaviors. Predictive models enable forecasting water use, identifying peak usage periods, and estimating future demand.

- Consumption optimization: Digital coupling incorporates optimization algorithms that analyze consumption data and make recommendations to optimize water use. This includes identifying high-use areas, identifying leaks or malfunctions, and proposing conservation strategies.

- Anomaly Detection: Digital Twin uses anomaly detection techniques to identify usage patterns that are unusual or suddenly deviate from expected behavior. This helps detect leaks, unauthorized use, or mechanical malfunctions, allowing for timely intervention and repair.

- Customer engagement: The Digital Twin solution has features to engage customers through customer insights, feedback and personalized recommendations. This allows customers to proactively manage their water use, promote conservation, and make informed decisions about their water use.

- Reporting and Compliance: Digital Twin creates reporting and analysis summaries that help users, regulators, and stakeholders understand, evaluate, and ensure water conservation efforts water use regulations.

The proposed Digital Twin solution for water management systems provides a comprehensive and data-driven approach to optimizing water management, encouraging conservation, and improving decision-making. Utilizing real-time analytics, predictive analytics and visualization capabilities, the solution enables customers, utilities and decision makers to actively manage water consumption, identifying areas they must improve and implement effective water conservation measures.

II.3 .Case studies of Digital Twin implementations in water management systems:

Here are some details of how Digital Twin will be used in water management systems:

1. A research paper describes how to effectively apply Digital Twin expertise in water distribution. The study showed that identifying rapid flow rates with the setting of the optimal pressure control valves using Digital Twin with optimization process can ensure water savings of up to 28%, contributing to overall system performance increases significantly.

   In EPAL, water distribution network in Lisbon, the measures in terms of flow, demand and pressure are recorded in District Metering Areas (DMAs). Leakage detection and WDN efficiency are significantly improved when DMAs are supported by electronic devices and AI model (DT + Optimization).

   This study relies on specific data available for a DMA in Lisbon, with the aim of studying the behavior of the water system. Among the possible analyses, the following ones are:

   - Evolution of the water network throughout the day
   - Differences between consumptions, depending on the time of the day
   - Peaks of consumption along the day and further periods (e.g., workdays or weekends)
   - Segregation of water consumptions (real and apparent losses);
   - Flow and pressure in the WDN along the time.

   The analysis of water losses was carried out with reference to DMA 320 of Lisbon in 2005, and the related measures are used in this study to support the proposed research. Although there has been an improvement in terms of water losses since 2005, the leakage trend is considered and still represents an interesting example of study. The data based on real measurements recorded by EPAL are used in this study to explore the benefits of DT implementation .[22]

2. **WaterWise in Singapore:**

As a platform, WaterWiSe allows water utilities to better understand the behavior of their distribution network and thus improve its operation. This includes reduced response time to events, improved operational planning potential and associated efficiency savings. WaterWiSe also helps bridge the "experience gap" between senior and junior engineers, helping encapsulate expert knowledge into easy-to-run simulation/operational tools. To

better illustrate the benefits of the WaterWiSe platform, this section gives a case study of WaterWise's operation in Singapore.

At present, a 25-node wireless sensor network is deployed in the City area of Singapore (in collaboration with the Public Utilities Board of Singapore, PUB). The WaterWiSe platform is linked in to PUB's SCADA system to exchange sensor data, and operates remotely with a stand-alone browser-based interface. WaterWiSe provides PUB's water supply network operations and planning teams with decision support services including event detection (leaks, bursts), system modeling, demand prediction and operational simulation. [23]

a. As a platform, WaterWiSe allows water utilities to better understand the behavior of their distribution network and thus improve its operation. This includes reduced response time to events, improved operational planning potential and associated efficiency savings
b. At present, a 25-node wireless sensor network is deployed in the City area of Singapore (in collaboration with the Public Utilities Board of Singapore, PUB). The WaterWiSe platform is linked in to PUB's SCADA system to exchange sensor data, and operates remotely with a stand-alone browser-based interface. WaterWiSe provides PUB's water supply network operations and planning teams with decision support services including event detection (leaks, bursts), system modeling, demand prediction and operational simulation.

3.Sydney Water implements IoT wastewater monitoring devices:

Sydney Water is rolling out a large-scale online wastewater monitoring system, with the company spending $15 million by June 2024 to install more than 26,000 detectors across a 4,600km wastewater network. Sydney Water has already installed 9,000 devices into Sydney's wastewater networks generating 70 per cent of flows. On average, the sensors detect about 20 gravity sewer blockages per month, saving about $400,000 in incident costs. Sensors are placed on top of existing wastewater systems, and many data readings are sent back. These alarms allow Sydney Water to act on the issue before a sewage overflow. Because the system detects obstructions in sewage pipes to dump wastewater into customers' property and the environment, incidents can be avoided that could pose a public health risk and result in high cleanup costs and reputation as they are wasted results « We lead the industry in some of these new applications, as a result They are through significant savings through early

detection of blockages in our sewer lines» Mr. Earl said. The installation of the devices will allow Sydney Water to operate its highly successful wastewater project. It provides for the digitization of its existing wastewater infrastructure and allows for proactive management of incidents of interruptions in the infrastructure. [24]

Conclusion:

In conclusion, Chapter 2 has provided a comprehensive exploration of Digital Twin technology and its potential application in water management systems. The chapter began by introducing Digital Twins as virtual replicas of physical systems, highlighting their ability to monitor, simulate, and analyze complex systems in real-time. The advantages and applications of Digital Twins in water management were then discussed, emphasizing their potential to enhance efficiency, reduce waste, and optimize resource allocation.

A literature review was conducted to examine previous studies and research on Digital Twin implementations in water management systems. This review helped identify successful case studies, lessons learned, and best practices, which provided valuable insights for the proposed solution. By drawing upon the existing knowledge in the field, the chapter gained a deeper understanding of the potential and challenges associated with Digital Twin technology in water management.

Building upon the insights from the literature review, the chapter presented a detailed description of the proposed Digital Twin solution for water management systems. The system architecture, components, and features were discussed, highlighting the importance of real-time monitoring, predictive analytics, and optimization. The proposed solution aims to empower water managers and operators with the necessary tools and insights to make informed decisions, improve system performance, and ensure sustainable water resource management.

Overall, Chapter 2 sets the foundation for further exploration of Digital Twin technology and its potential impact on water management systems. By leveraging the capabilities of Digital Twins, water managers can gain real-time visibility into their infrastructure, predict future trends, and optimize resource allocation. However, further research and development are needed to address challenges such as data integration, scalability, and interoperability.

In conclusion, Digital Twin technology holds great promise for transforming water management practices by providing data-driven insights, proactive decision-making, and

enhanced efficiency. By embracing this innovative approach, we can pave the way for a sustainable and resilient water future.

III. Chapter 3 Internet of things and Cloud service

Introduction:

This chapter introduces the concept of the Internet of Things (IoT) and its importance in our interconnected world. It discusses key technologies that enable IoT, such as wireless connectivity protocols, sensors, and embedded systems. An example of an IoT application, such as a smart grid system, is provided to illustrate its practical implications.

The chapter also highlights the role of cloud services in supporting IoT deployments. It explains how cloud computing provides the necessary infrastructure and resources for managing the vast amount of data generated by IoT devices. Specifically, it focuses on AWS IoT as a leading cloud platform and presents an example of creating an AWS IoT thing, showcasing the features and functionalities available.

By the end of the chapter, readers will have a solid understanding of IoT, its significance, and the role of cloud services in enabling its potential. They will also be familiar with the process of setting up an AWS IoT thing, empowering them to explore and develop innovative IoT applications.

III.1 Definition of IoT:

The concept of IOT is quite simple, it means taking all the things in the world and connecting them to the internet. Connecting things to the internet provides many amazing benefits. When a device is connected to the internet, it has the ability to send information or receive information or do both the things. The ability to send information and/or receive information makes devices Smart. When the devices are smart, it is an amazing thing[25]. In the Internet of things, the devices that are connected to the internet fall under the three categories mentioned below:

1. Devices that collect information and then send it.
2. Devices that receive the information then act accordingly.
3. Devices that can do both

2.1.Devices that collect Information and then send it:

The devices that are used to collect or gather the information from the surroundings are called as sensors. Sensors could be temperature sensor, motion sensor, moisture sensors, proximity sensors, light sensors and many more. The sensors with the help of a medium allows us to collect information from the environment which allows us to take smarter decisions

2.2.Receiving and Acting on Information:

We are aware of the devices that act on the information that it receives. The printer prints the document after receiving it through Bluetooth, WIFI or in a network. The car receives a signal from the car keys and then the doors open. We have the ability to tell machines what to do from far away. So, we come to know that we have devices that collect information and send the information. We also have devices that receive information and act on the information. This ability gives real power to the Internet of Things.

2.3.Doing Both:

for example, in farming, the sensor can collect information about the soil moisture to tell the farmer how much water the crops need, there can also be a scenario where the farmer is not needed at all. The irrigation system mentioned can also be turned on or off automatically depending on the moisture present in the soil.

III.2 Importance of IoT:

In recent years, the Internet of Things (IoT) has emerged as a pivotal technology in the 21st century. The ability to connect everyday items such as kitchen appliances, cars, thermostats, and baby monitors to the internet through embedded devices has revolutionized communication, enabling seamless interaction among individuals, processes, and objects. Through the integration of affordable computing, cloud computing, big data, analytics, and mobile technologies, physical objects can now effortlessly share and gather data with minimal human involvement. This interconnected landscape allows digital systems to meticulously record, monitor, and adjust every interaction between connected objects. It marks a harmonious convergence between the physical and digital realms, enabling them to collaborate effectively. [26]

III.3 Key Technologies Empowering the Internet of Things (IoT):

1. Accessibility to low-cost, low-power sensor technology: The availability of affordable and reliable sensors plays a crucial role in enabling a wide range of manufacturers to implement IoT technology effectively.
2. Connectivity: The existence of diverse network protocols for the internet has simplified the process of connecting sensors to the cloud and other interconnected devices. This facilitates efficient data transfer within IoT systems.
3. Cloud computing platforms: The proliferation of cloud platforms has provided businesses and consumers with convenient access to scalable infrastructure without

the need for extensive management. This accessibility has fueled the growth and expansion of IoT applications.

4. Machine learning and analytics: Advancements in machine learning and analytics, combined with the vast and diverse data stored in the cloud, have accelerated the ability of businesses to gather insights quickly and efficiently. These allied technologies continually push the boundaries of IoT and benefit from the valuable data produced by IoT devices.
5. Conversational artificial intelligence (AI): Breakthroughs in neural networks have introduced natural-language processing (NLP) capabilities to IoT devices, such as popular digital personal assistants like Alexa, Cortana, and Siri. These advancements have made conversational AI more appealing, affordable, and viable for home use, enhancing the overall IoT experience. [2]

IoT devices, such as smart water meters and sensors, are integral components of modern water management systems. Equipped with sensors, these devices capture water consumption data at regular intervals, providing accurate and real-time information. By automating data collection and transmission to cloud-based platforms, IoT devices eliminate manual efforts and enable continuous monitoring. The granularity of data collection allows for the identification of consumption patterns, peak usage periods, and potential inefficiencies. The integration of IoT devices revolutionizes water management by providing real-time, accurate, and detailed data, which serves as the foundation for advanced analytics, decision-making, and the development of predictive models. Ultimately, this integration enhances the efficiency, sustainability, and proactive management of water resources.

III.4 Example of iot application:

In our project we are making IOT application in water management system to gather consummation data of water, and to realize this we need:

1. IOT sensor (esp8266 with water flow sensor)
2. Cloud service (amazon web service)
3. Ai model to predict future demand (many models and we will choose the best)

III.4.1 IoT Sensor:

Our circuit comprises an ESP8266 microcontroller and a YF-S201 water flow sensor. The ESP8266 processes data from the sensor, which detects water flow through a pipe. This integration enables real-time monitoring of water flow, facilitating insights into consumption

patterns and system performance. It offers a cost-effective solution for efficient water management.

III.4.2 esp8266 :

Module based on 80 MHz ESP8266 running open-source firmware NodeMCU. This board is programmed via the Arduino IDE. This microcontroller has a Wi-Fi interface ideal for connected objects. Male and female side connectors fit the module onto a quick mounting plate. The wireless WIFI interface allows the creation of wireless access points, the hosting of a server, the connection to the internet and the sharing of data for example. The module programs directly from the Arduino IDE (installation of an extension required) and requires a micro an USB cord[27].



Figure III-1 microcontroller esp8266

III.4.3 YF-S201:

This sensor is aligned with your water line and contains a rotary sensor to measure the amount of liquid that has moved there. There is an integrated magnetic effect sensor that produces an electrical pulse at each revolution. The Hall effect sensor is waterproof to the water hose and allows the sensor to stay dry and safe.

The sensor comes with three wires: red (5-24VDC power supply), black (ground) and yellow (Hall impulse output). By counting the pulses from the sensor output, you can easily calculate the water flow rate It will need careful calibration to get good mesures.[28]



Figure III-2 water sensor YF-S201

III.5 Cloud service:

We chose the AWS cloud for our water management system due to its reliable infrastructure, scalable services, comprehensive IoT support, AI and machine learning capabilities, secure data storage options, and global presence. AWS provides the necessary tools and resources to effectively manage and analyze water consumption data, ensuring the sustainability and efficiency of our system.

Figure III-3 Amazon web service

this figure represent the service we need from connecting iot device to make visualisation of data or analysis:

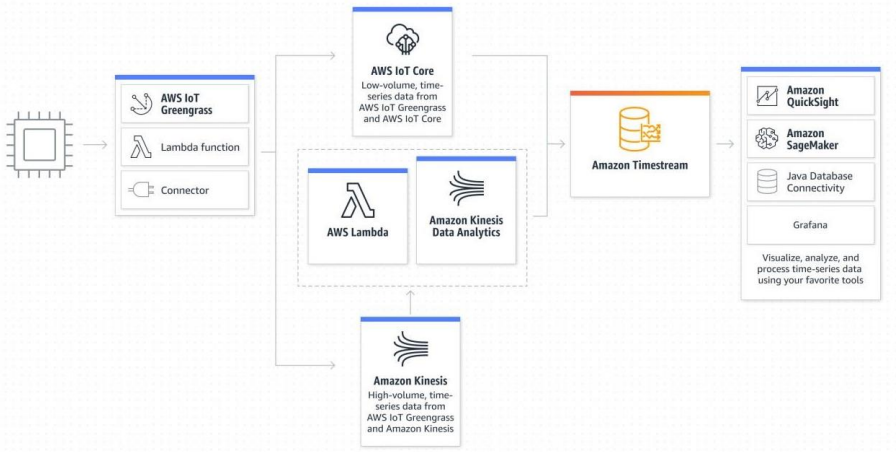


Figure III-4 sevice used in iot application

First, we need IOT device (sensor medium that can send or receive message from/to cloud) then we need connector to assure connection between device and cloud service (communication protocol), we will represent the services that we are using in our project:

III.5.1 AWS IoT Core :

AWS IoT Core is a managed cloud service that enables connected devices to securely interact with cloud applications and other devices. AWS IoT Core can support many devices and messages, and it can process and route those messages to AWS IoT endpoints and other devices. With AWS IoT Core, your applications can interact with all of your devices even when they aren't connected.



Figure III-5 AWS iot core

By leveraging AWS IoT Core, applications gain continuous tracking and communication capabilities with all connected devices, even in offline scenarios. This eliminates the limitations posed by device disconnection.

Furthermore, AWS IoT Core seamlessly integrates with various AWS services, including AWS Lambda, Amazon Kinesis, Amazon S3, Amazon SageMaker, Amazon DynamoDB, Amazon CloudWatch, AWS CloudTrail, and Amazon QuickSight. This integration empowers the development of IoT applications that effortlessly gather, process, analyze, and respond to data generated by connected devices. Importantly, users can leverage these capabilities without the burden of managing underlying infrastructure.

Using MQTT as the messaging protocol allows for lightweight and efficient communication, minimizing the bandwidth and power consumption of the IoT devices. MQTT's publish-subscribe model ensures that data is delivered to the appropriate subscribers in a reliable and scalable manner.

III.5.1.1 MQTT: Message Queuing Telemetry Transport

MQTT is a standards-based messaging protocol, or set of rules, used for machine-to-machine communication. Smart sensors, wearables, and other Internet of Things (IoT) devices typically have to transmit and receive data over a resource-constrained network with limited bandwidth. These IoT devices use MQTT for data transmission, as it is easy to implement and can communicate IoT data efficiently. MQTT supports messaging between devices to the cloud and the cloud to the device. [29]

Why MQTT:

1. Lightweight and efficient, minimizing resource consumption.
2. Publish-subscribe model enables flexible and scalable communication.
3. Ensures reliable communication with different Quality of Service levels.
4. Supports asynchronous communication, improving system responsiveness.

5. Scalable and flexible, accommodating a large number of devices and data volume.
6. Provides security through encryption and authentication mechanisms.

III.5.2 MQTT components:

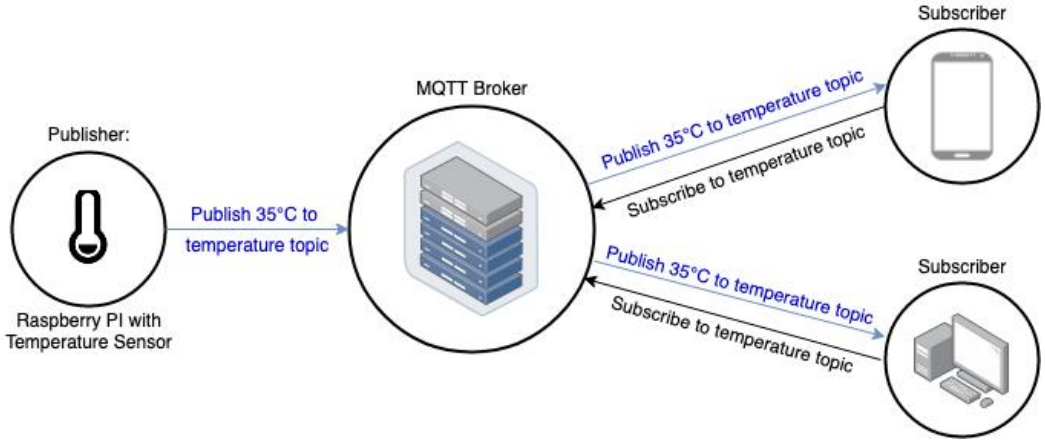


Figure III-6 MQTT component

- MQTT Broker: The MQTT broker acts as a server that receives messages published by MQTT clients and distributes them to subscribers based on topics. It manages connections, handles message delivery, and ensures reliable communication in the MQTT network.
- MQTT Client: An MQTT client is an application or device that connects to the MQTT broker to publish or subscribe to topics. Clients can send messages, subscribe to topics for receiving messages, and establish bidirectional communication with the broker.
- The MQTT broker-client architecture enables scalable and flexible communication between devices and applications, optimizing data exchange and facilitating real-time monitoring and control. It follows a publish-subscribe model, ensuring efficient and targeted message delivery.

III.5.3 AWS Timestream:

Aws timestream is a fast, scalable, and serverless time series database service for IoT and operational applications that makes it easy to store and analyze trillions of events per day up to 1,000 times faster and at as little as 1/10th the cost of relational databases. Amazon TimeStream has built-in time series analytics functions, helping you identify trends and patterns in your data in near real-time. Amazon TimeStream is serverless and automatically scales up or down to adjust capacity and performance, so you don’t need to manage the underlying infrastructure, freeing you to focus on building your applications.[30]

III.5.3.1 Characteristics of Amazon Timestream:

The characteristics of the time stream are as follows[31]:

1. Because you cannot delete or update data in the Timestream, all data sent to it is an append-only table. The data is not deleted until the retention period expires.

2. A Timestamp, one or more dimensions, a measurement name, and a value are all required for all records.

3. Records are not editable or deletable. Records are only removed when their retention limit within the magnetic tier is exceeded (infinite storage is an option).

4. Multiple measures can be represented logically as multiple individual records (one step per record).

5. Scales automatically to handle real-time data ingestion at high speeds.

III.5.3.2 **Benefits of Timestream[31]**:

1. High performance at low cost– It is intended to enable interactive and affordable real-time analytics, with query performance that is up to 1,000 times faster and costs as little as one-tenth the price of relational databases.
2. Serverless with auto-scaling- It is serverless, which means there are no servers to manage or capacity to provision, allowing you to focus on developing your applications.
3. Data lifecycle management- It simplifies the complex process of managing data throughout its lifecycle. Storage tiering is available, with a memory store for recent data and a magnetic store for historical data.
4. Simplified data access- You no longer need to utilize many tools to access recent and previous data thanks to Amazon Timestream.
5. Purpose-built for time series- SQL has built-in time series functions for smoothing, approximation, and interpolation that make it easy to swiftly evaluate time series data.
6. Always Encrypted- For the purpose of encrypting data in the magnetic store, Amazon Timestream additionally lets you provide an AWS KMS customer-managed key (CMK).

III.5.3.3 Use cases of Amazon Timestream:

1. IoT applications, Amazon Timestream enables you to easily evaluate time series data produced by IoT applications.
2. Analytics applications- The incoming and outgoing web traffic for your apps can be stored and processed using Amazon Timestream when you have clickstream data. Additionally, it offers aggregate capabilities to examine this data and gain insights into things like path-to-purchase and cart abandonment rates.
3. DevOps applications- DevOps systems that track usage and health metrics and analyze data in real-time to boost performance and availability are best suited for Amazon Timestream. [31]

III.5.4 Aws Grafana:

Amazon Managed Grafana is a fully managed and secure data visualization service that you can use to instantly query, correlate, and visualize operational metrics, logs, and traces from multiple sources. With Amazon Managed Grafana, you create logically isolated Grafana servers called workspaces. Then, you can create Grafana dashboards and visualizations to analyze your metrics, logs, and traces without having to build, package.



Figure III-7 Aws grafana

III.5.4.1 Features of AWS Grafana:

- Amazon Managed Grafana offers a unified observability tool for tracking metrics, logs, and traces from various data sources.
- The user-friendly interface allows customization of pre-built dashboards or creating new ones from scratch.
- It is highly scalable and can handle large volumes of data without performance issues, making it suitable for enterprises of all sizes.
- Native integration with AWS service[32]

III.5.5 Aws TwinMaker:

AWS IoT TwinMaker is an AWS IoT service that you can use to build operational digital twins of physical and digital systems. IoT TwinMaker creates digital visualizations using measurements and analysis from a variety of real-world sensors, cameras, and enterprise applications to help you keep track of your physical factory, building, or industrial plant. You can use this real-world data to monitor operations, diagnose and correct errors, and optimize operations. [33]



Figure III-8 Aws twin maker

III.5.6 Aws Sage maker:

Sage Maker is a fully managed service that enables you to quickly and easily integrate machine learning based models into your applications, With Sage Maker, data scientists and developers can quickly and easily build and train machine learning models, and then directly deploy them into a production-ready hosted environment[34]. It provides an integrated Jupyter authoring notebook instance for easy access to your data sources for exploration and analysis, so you do not have to manage servers. It also provides common machine learning algorithms that are optimized to run efficiently against extremely large data in a distributed environment.



Figure III-9 AWS sage maker

III.6 Example of Creating an AWS IoT thing:

1. In the AWS IoT Core console, navigate to "Manage" in the left navigation panel.

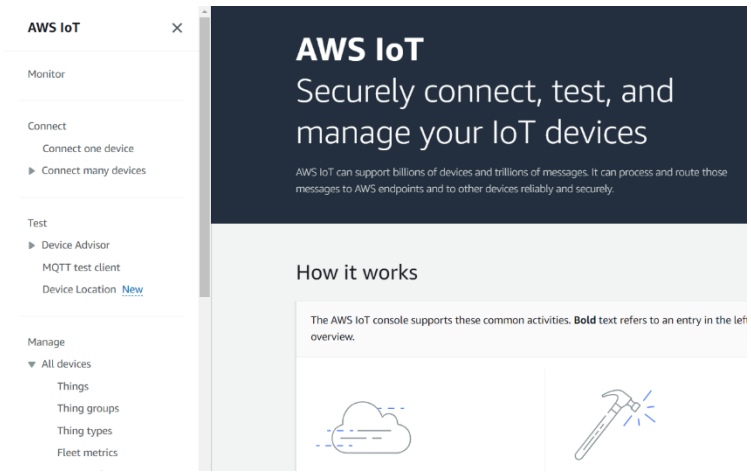


Figure III-10 Aws iot core

2. If you have existing things, choose "Create" to create a new thing. Otherwise, select "Register a thing" on the "You don't have any things yet" page.

3. On the "Creating AWS IoT things" page, choose "Create a single thing".

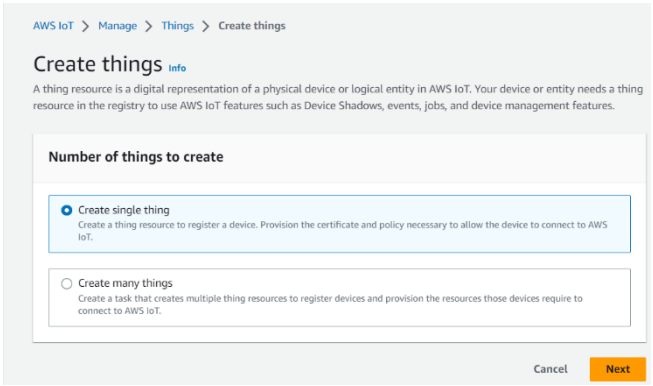


Figure III-11 Creating thing

4. On the "Add your device to the thing registry" page, provide a Name for your thing (e.g., TestDevice). Optionally, you can add a thing type, assign it to a group, or set searchable attributes. Click "Next".

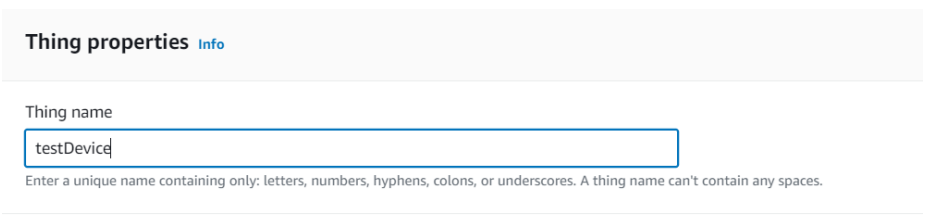


Figure III-12 thing name

5. On the "Add a certificate for your thing" page, choose "Create certificate" and save the generated certificate, public key, and private key files to the previously created certificates sub-directory.

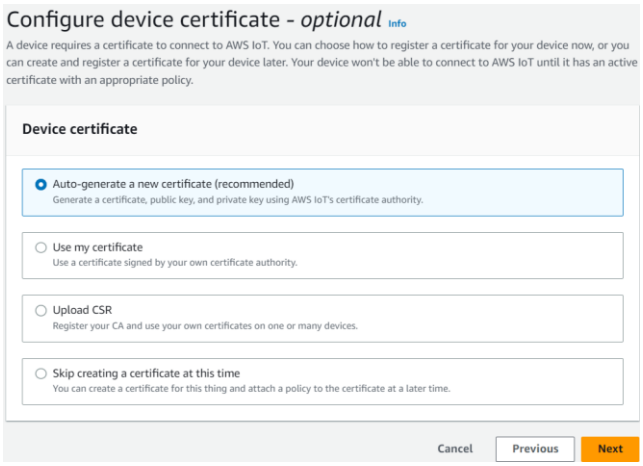


Figure III-13 configure of certificate

6. Download the root CA certificate for AWS IoT by selecting "Download" under "You also need to download a root CA for AWS IoT". Save the certificate and open it in a browser.

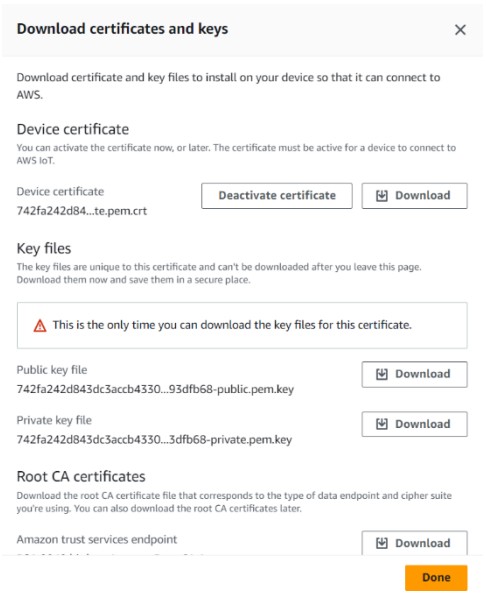


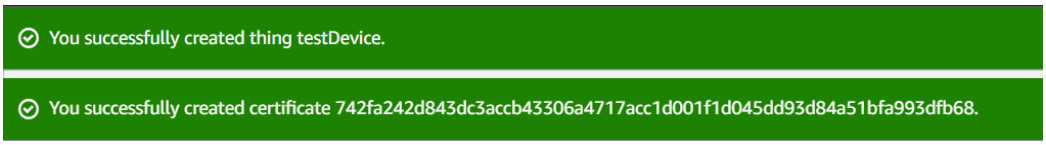
Figure III-14 Downloading thecertificate

7. Attach policies to certificate: AWS IoT policies grant or deny access to AWS IoT resources.



Figure III-15 Policies

8. Back in the Certificate created page of the AWS IoT Core console, choose "Done" to activate the certificate.
9. Finally, click "Register Thing" to complete the creation of the AWS IoT thing.



here is an example of message we received to the cloud:

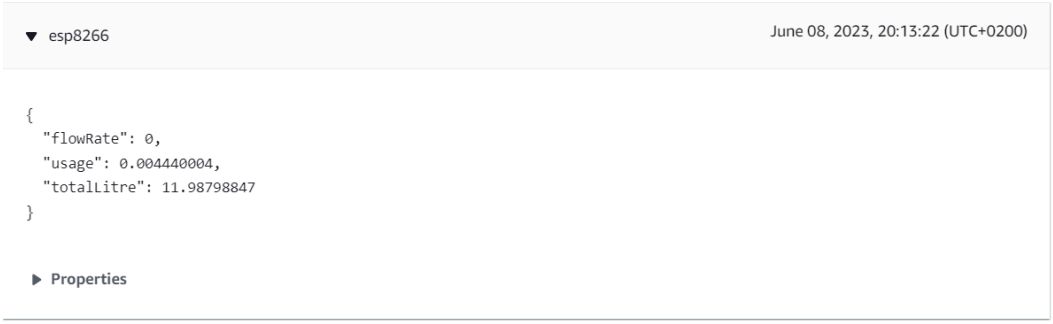


Figure III-16 example of message

Conclusion:

In conclusion, this chapter has explored the transformative nature of the Internet of Things (IoT) and the critical role of cloud services in enabling its potential. IoT has revolutionized how we interact with technology, offering efficiency, automation, and connectivity across various sectors.

The chapter covered the definition and importance of IoT, emphasizing its ability to connect physical devices and enhance our lives. Key enabling technologies such as wireless connectivity, sensors, and embedded systems were discussed in detail.

An example of an IoT application, the smart grid system, demonstrated the practical implications of IoT in optimizing energy consumption and promoting sustainability.

Cloud services, particularly AWS IoT, were highlighted as crucial for supporting IoT deployments. These services provide the necessary infrastructure, storage, processing power, and analytics capabilities to manage the vast amount of data generated by IoT devices.

By understanding the fundamentals of IoT, key technologies, and the role of cloud services, readers are empowered to explore and develop their own innovative IoT applications. The potential of IoT is vast, and by leveraging cloud services, we can unlock new levels of efficiency, productivity, and connectivity.

As technology continues to evolve, IoT and cloud services will play an increasingly significant role in shaping our future. Embracing these technologies enables us to create a more connected, intelligent, and sustainable world for generations to come

IV. Chapter 4: Results and Discussion

Introduction:

In this chapter, we explore the relationship between hardware-cloud configuration, model visualization, and the process of choosing the best model. Hardware-cloud configuration is crucial for efficient data processing and visualization. We also delve into the presentation of visualizations through dashboards, highlighting their role in communicating complex data relationships. Additionally, we cover the mean square error (MSE) as an evaluation metric for model comparison. The chapter provides insights and techniques to create effective visualizations, and evaluate models using MSE. These concepts are valuable for practitioners looking to make informed decisions and select the best model for their specific requirements.

IV.1 The hardware-cloud setup

The hardware-cloud setup involves an ESP8266 microcontroller connected to the AWS Cloud using MQTT protocol. The ESP8266, along with a water sensor, detects and sends real-time water-related data to the AWS Cloud. The MQTT protocol ensures efficient and secure communication between the ESP8266 and the cloud. The data is received by an MQTT broker in the AWS Cloud, which routes it to subscribed services or applications for analysis, storage. This integration enables seamless transmission of water sensor data for IoT applications.

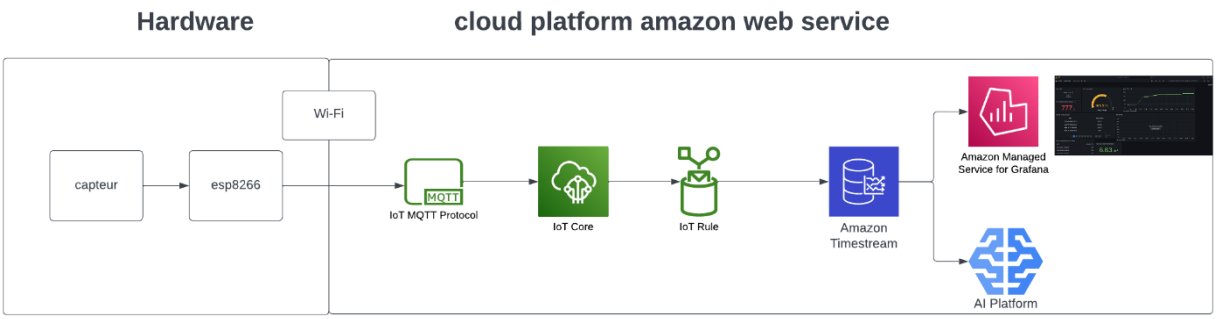


Figure IV-1 Cloud-Hardeware diagram

To set up the circuit and send data to AWS IoT Core for storage using AWS Timestream, we follow these instructions:

1. Circuit Setup: Begin by building the circuit using an ESP8266 microcontroller and a YSF201 water flow sensor. Connect the appropriate pins of the sensor to

the microcontroller according to the sensor's specifications. Ensure the circuit is properly powered and connected.

2. Program the ESP8266: Develop the firmware for the ESP8266 microcontroller to read data from the water flow sensor. Utilize the appropriate programming language and libraries to interface with the sensor and retrieve water consumption data.
3. Configure AWS IoT Core: Create an AWS IoT Core account and set up a Thing to represent your IoT device. Generate security certificates (TLS/SSL) and download them for authentication purposes.(all devices>things>create thing)

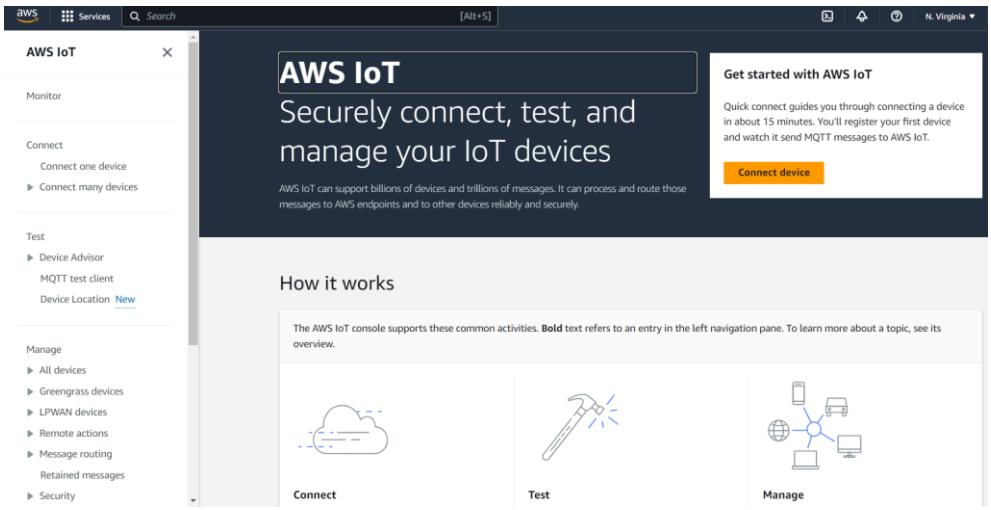


Figure IV-2 Aws iot core

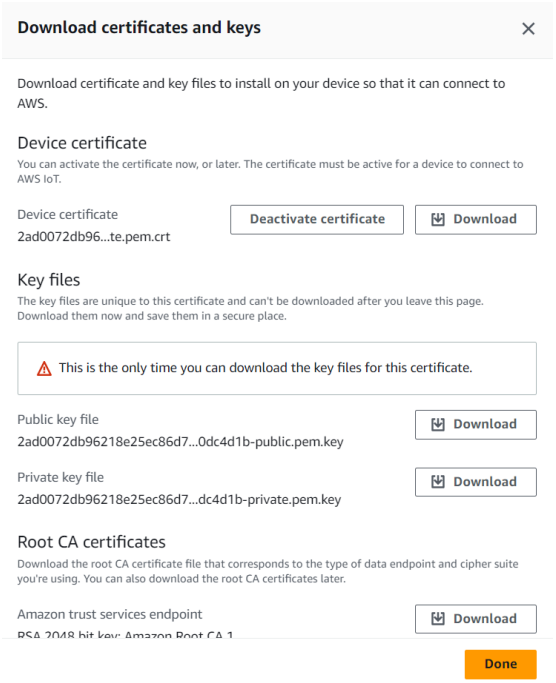


Figure IV-3 certificates

4. Establish MQTT Connection: In the firmware code running on the ESP8266, establish an MQTT connection with AWS IoT Core using the security certificates. Use the appropriate MQTT library to connect to the MQTT broker, specifying the correct AWS IoT Core endpoint, client ID, and authentication details.

```
const char MQTT_HOST[] = [redacted]-east-1.amazonaws.com";

static const char cacert[] PROGMEM = R"EOF(
-----BEGIN CERTIFICATE-----
MIIDQTCCAimgAwIBAgITBmyfz5m/jAo54vB4ikPmljZbyjANBgkqhkiG9w0BAQsF
ADA5MQswCQYDVQQGEwJVUzEPMA0GA1UEChMGQW1hem9uMRkwFwYDVQQDExBBbWF6
b24gUm9vdCBDQSAxMB4XDTE1MDUyNjAwMDAwMFoXDTM4MDExNzAwMDAwMFowOTEL
MAkGA1UEBhMCVVMxDzANBgNVBAoTBkFtYXpvbjEZMBcGA1UEAxMQQW1hem9uIFJv
b3QgQ0EgMTCCASIwDQYJKoZIhvcNAQEBBQADggEPADCCAQoCggEBALJ4gHHKeNXj
ca9HgFB0fW7Y14h29Jlo91ghYPl0hAEvrAIthtOgQ3pOsqTQNroBvo3bSMgHFzZM
9O6II8c+6zf1tRn4SWiw3te5djgdYZ6k/oI2peVKVuRF4fn9tBb6dNqcmzU5L/qw
IFAGbHrQgLKm+a/sRxmPUDgH3KKHOVj4utWp+UhnMJbulHheb4mjUcAwhmahRWa6
VOujw5H5SNz/0egwLX0tdHA114gk957EWW67c4cX8jJGKLhD+rcdqsq08p8kDi1L
93FcXmn/6pUCyziKrlA4b9v7LWIbxcceVOF34GfID5yHI9Y/QCB/IIDEgEw+OyQm
```

Figure IV-4 Mqtt host

5. Publish Data to AWS IoT Core: Within the firmware code, publish the water consumption data obtained from the sensor as MQTT messages to a specific

MQTT topic in AWS IoT Core. Define the appropriate topic structure that best suits your data organization and management needs.

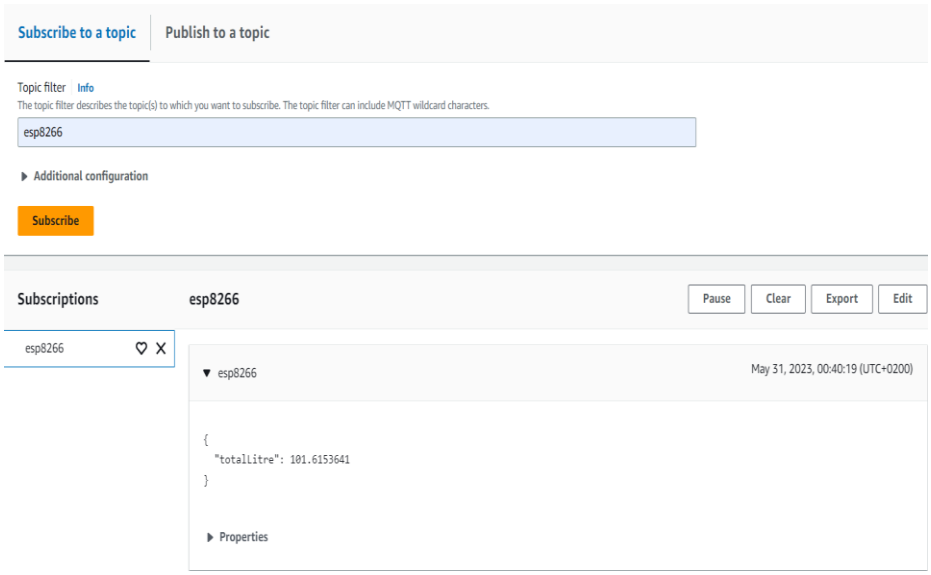


Figure IV-5 example of MQTT message

6. Configure AWS IoT Core Rule: In AWS IoT Core, set up an MQTT rule to capture the published messages from the specified topic. Configure the rule to transform and forward the messages to AWS Timestream.(message routing>rules).

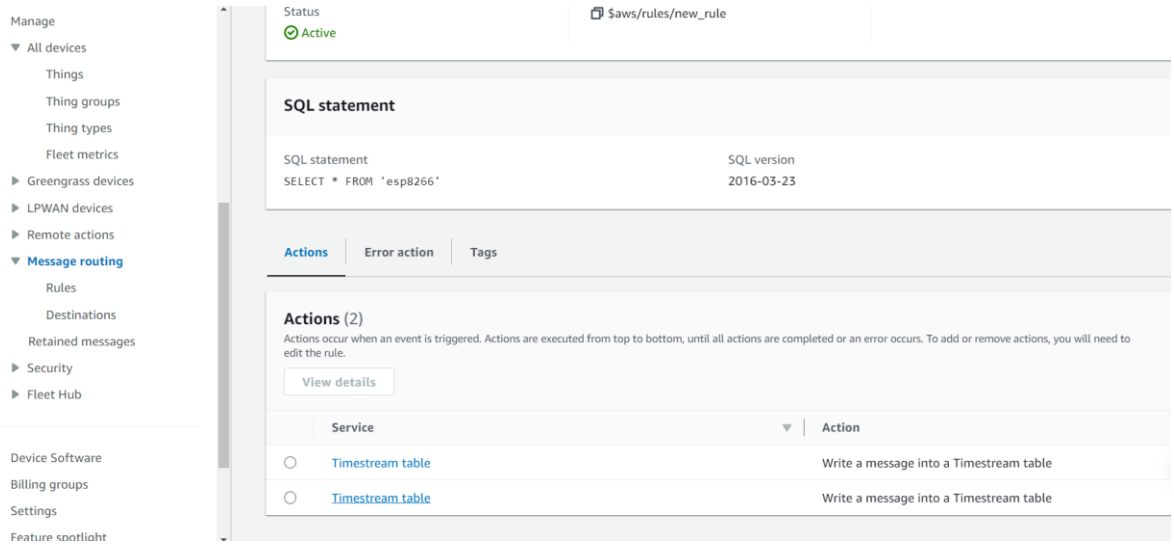


Figure IV-6 : Rule to trigger and store data

7. Create AWS Timestream Database and Table: Set up an AWS Timestream database and create a table to store the incoming water consumption data. Define the appropriate schema to capture the required data fields and ensure compatibility with the data being published.

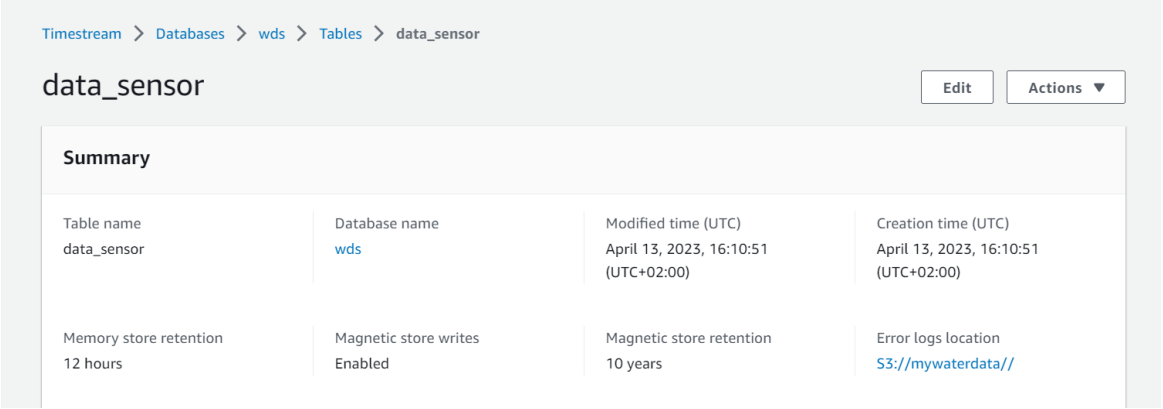


Figure IV-7 Table and database name

8. Ingest Data into AWS Timestream: Configure the MQTT rule to forward the received messages to AWS Timestream. Map the MQTT message fields to the corresponding fields in the Timestream table. This ensures the data is properly ingested into the specified database and table.

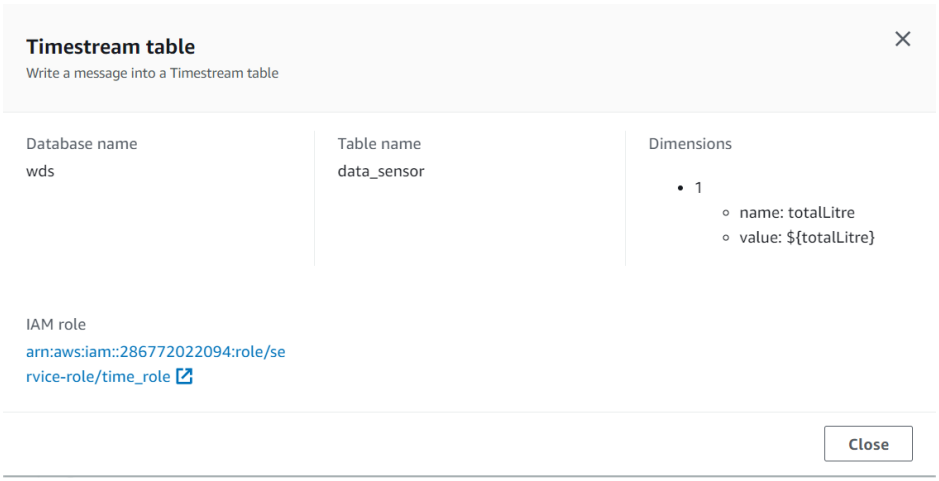


Figure IV-8 timestream table name and dimention

9. Analyze Data in AWS Timestream: Utilize the analytical capabilities of AWS Timestream to query, analyze, and visualize the stored water consumption data. Leverage the built-in functions and tools provided by AWS Timestream to gain insights, identify patterns, and make data-driven decisions for effective water resource management.

date	day_consume
2023-04-13	78.5235672
2023-04-14	207.6098785
2023-04-15	99.90497589
2023-04-16	124.8045273
2023-04-17	36.54454803

Figure IV-9 example of data

By following these instructions, we successfully set up the circuit, establish a connection to AWS IoT Core, publish the water consumption data, configure an MQTT rule to route the data to AWS Timestream, and utilize AWS Timestream's capabilities to store and analyze the data efficiently.

IV.2 Presentation of visualisation:

Once the connection between the hardware and cloud service is established and data is successfully stored, we leverage AWS Grafana service to construct a comprehensive dashboard. This dashboard encompasses essential information that facilitates a clear understanding of consumption behavior and provides easy access to consumption history. By utilizing the powerful visualization capabilities of Grafana, we can create visually appealing and interactive charts, graphs, and widgets that showcase real-time and historical data. This empowers users to gain insights into patterns, trends, and anomalies in consumption,

.



Figure IV-10 Dashboard

The dashboard includes various components to provide comprehensive information and facilitate easy access to consumption data:

1. A gauge, named "Current Day Consumption Gauge," displays consumption for the current day, ranging from 0 to 300L. It features a visual alert system with colors (green, orange, red) to indicate consumption levels. Green represents low consumption(0-100L), orange represents moderate consumption(100-200L), and red indicates high consumption.(>200).
2. A table, named "Historical Consumption Data Table," offers convenient access to historical data, allowing users to explore consumption records easily.
3. Another table, named "Top Daily Consumption Table," displays the top three consumption values for each day over a specified period, enabling users to identify days with the highest consumption.
4. Numerical displays, named "Weekly Total Consumption" and "Monthly Total Consumption," present the total consumption over the last 7 days (week) and the last 30 days (month), providing an overview of consumption trends within these time frames.

5. A line chart, named "Real-time Consumption Trend Chart," showcases real-time water consumption, allowing users to observe the evolution of consumption over time and gain insights into patterns and trends.
6. Another line chart, named "Daily Consumption Overview Chart," depicts daily consumption, enabling users to quickly identify days with higher consumption levels.

The dashboard automatically refreshes at regular intervals, defined by an "Auto-refresh Timer." Additionally, users can select a specific time range using the "Data Range Selector" to view data on the first line chart, providing flexibility in analyzing consumption patterns within desired intervals.



Figure IV-11 dashboard

In addition to the described features of the dashboard, an important capability is the ability to grant access to individual users or teams to view and modify their own personalized dashboards. This feature ensures that users have control over their data and enables collaboration and customization based on specific needs.

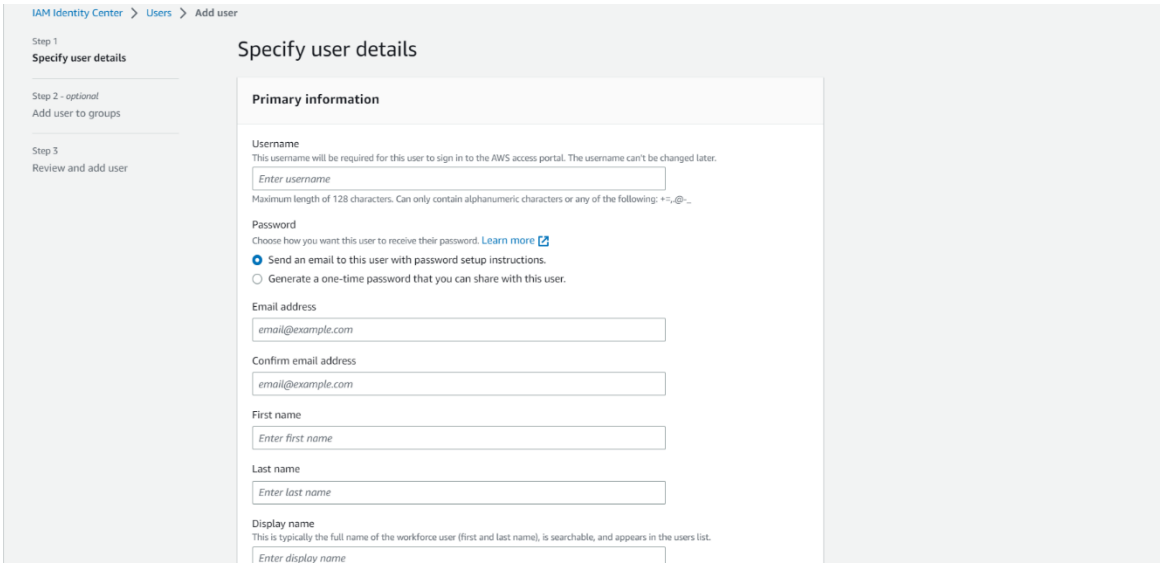


Figure IV-12 adding new user

You need to invite them by adding their email and they will complete registration prossesse.

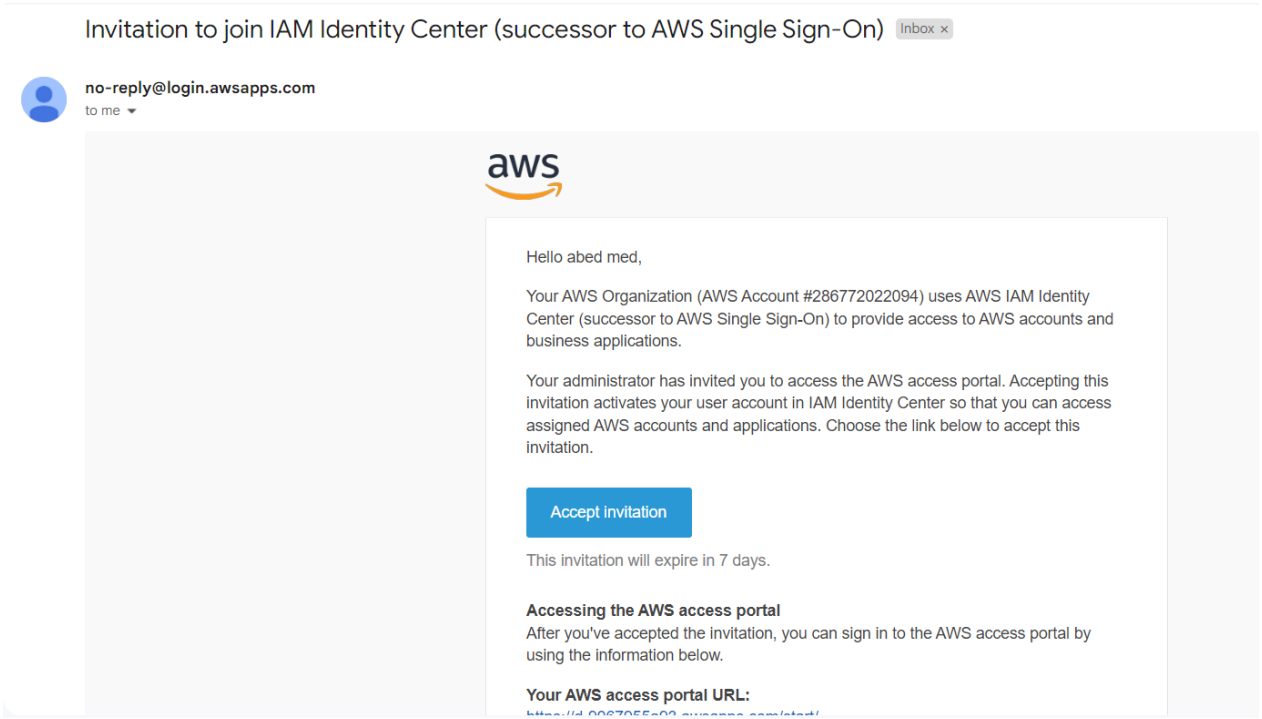


Figure IV-13 invitation

With access control and user management features, administrators can assign permissions to different users, granting them the ability to view and edit their own dashboards. This allows

individuals or teams to have ownership over their consumption data and tailor the dashboard to their specific requirements.

By providing the flexibility for users to make changes to their dashboards, they can personalize the visualizations, add or remove specific metrics, and customize the layout to align with their preferences. This empowers users to explore and analyze the consumption data in ways that are most relevant and meaningful to their specific roles or objectives.

Furthermore, this collaborative aspect fosters teamwork and knowledge sharing within an organization. Different stakeholders can collaborate on the same dashboard, share insights, and make collective decisions based on the information presented. This enhances communication and collaboration, leading to more effective analysis and decision-making processes.

Overall, the ability to grant access and allow users to make changes to their own dashboards promotes user engagement, customization, and collaboration, resulting in a more personalized and powerful tool for consumption data analysis.

IV.3 **Future Demand Prediction:**

In our work, we conduct a comparative analysis between LSTM, ARIMA, and exponential smoothing techniques for demand forecasting. These techniques are widely recognized and have their unique strengths in capturing patterns and predicting future demand in different contexts.

Through our comparative analysis, we aim to determine which technique or combination of techniques yields the most accurate and reliable demand predictions. This analysis will provide valuable insights into the strengths and limitations of each method and enable us to recommend the most suitable approach for your specific demand forecasting needs.

Technique	Data Patterns	Model Complexity	Flexibility	Training Time	Sensitivity	Accuracy
LSTM	Complex, non-linear	High	Many data types	Longer	High	High
ARIMA	Seasonality, trends, stationary	Moderate	Suitable for univariate data	Moderate	Medium	Medium
Exponential Smoothing	Short-term trends, noise smoothing	Low	Versatile	Quick	Low	Medium

Table IV-1 comparaison between deffirents models

The table provides a comparative overview of LSTM, ARIMA, and Exponential Smoothing techniques for demand forecasting, considering factors such as data patterns, model complexity, flexibility, training time, long-term forecasting capability, sensitivity, accuracy, and interpretability.

- LSTM stands out with its ability to capture complex, non-linear data patterns, making it suitable for handling various data types and long-term forecasting. However, it requires a longer training time and may have lower interpretability.
- ARIMA is well-suited for capturing seasonality, trends, and stationary patterns, making it a good choice for univariate data and long-term forecasting. It offers a balance between model complexity and interpretability.

- Exponential Smoothing excels at short-term trend capturing and noise smoothing, providing quick and simple forecasts. It has lower complexity but may lack long-term forecasting capability and has lower sensitivity and medium accuracy.

We will proceed by training our forecasting models using the selected techniques, namely LSTM, ARIMA, and Exponential Smoothing. During the training phase, we will assess the performance of our forecasting models by utilizing the Mean Squared Error (MSE) metric. MSE is a commonly used evaluation metric for regression tasks, including demand forecasting. It measures the average squared difference between the predicted values and the actual values of our demand data. To evaluate the models, we will calculate the MSE for each technique by comparing the predicted demand values against the actual demand values from a validation dataset. The model with the lowest MSE will be considered the best-performing model in terms of minimizing the prediction errors. By using MSE as our evaluation metric, we can effectively compare the accuracy of different models and select the one that provides the most precise and reliable forecasts. This approach ensures that we choose the model that best captures the underlying patterns and fluctuations in the demand data, enabling us to make more informed decisions regarding future demand projections.

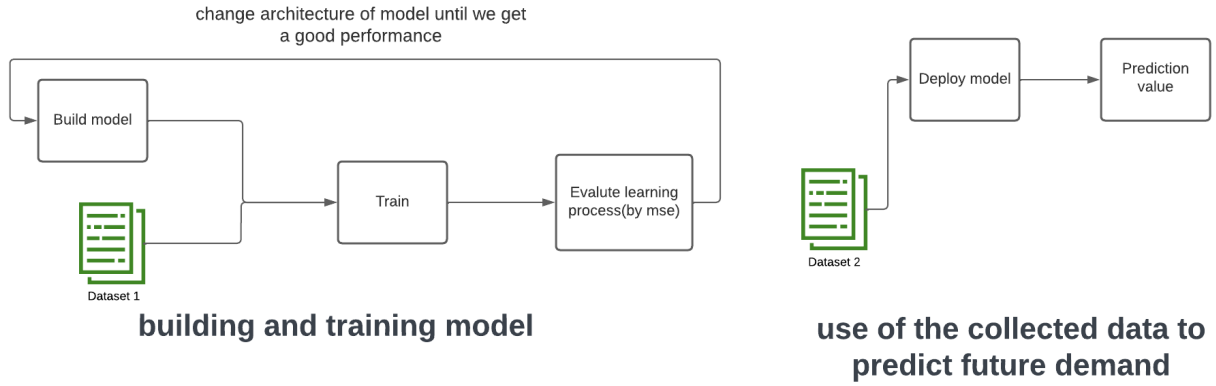


Figure IV-14 diagram of training and deploy model

IV.3.1 Presenting the dataset used for training:

The dataset was obtained from DAIAD, a platform for monitoring real-time water consumption in different cities. It consists of water consumption records from smart water meters, providing daily data on total water usage in liters for a year. A subset of 50 random user records was selected after thorough data cleaning. The chosen dataset focuses on daily water consumption and considers factors such as day-to-day activities, weekends, seasons (with emphasis on summer and winter), and individual perspectives in a smart city. The data has been carefully prepared to enable accurate results through suitable preprocessing and analysis methods. This dataset presents an opportunity to conduct experiments and gain insights into water usage patterns and behaviors by considering the various criteria and factors that were taken into account during its selection.[35]

IV.4 Discussng the result:

The lstm model shows a better performance on learning and has the lowest mse than the others model.



Figure IV-15 training and validation loss on LSTM model

Based on learning results and advantage of every model,we found that lstm model is suitable for our needs and standards:

1. Ability to capture complex, non-linear data patterns.

2. Remembering information from a long period of time

IV.4.1 LSTM Model Architecture:

- The model begins with a Bidirectional LSTM layer, which processes the input sequence in both forward and backward directions. This layer has 70 LSTM units and takes input of shape (sequence_length, input_features).
- A Dense layer follows the Bidirectional LSTM layer with 32 units and a ReLU activation function.
- Dropout regularization is applied after the Dense layer to prevent overfitting. It randomly drops 15% of the inputs.
- The final layer is a Dense layer with a single unit and a sigmoid activation function, suitable for binary classification tasks.

Model Compilation:

- The model is compiled using the Adam optimizer with a learning rate of 0.001.
- The loss function is set to mean squared error (MSE), commonly used for regression tasks.

Model Training:

- The model is trained on the training data using the fit() method.
- Training is performed for 25 epochs with a batch size of 32.
- The training data is split into a validation set using a 20% validation split.
- The ModelCheckpoint callback is used to save the best model based on the validation loss.

Overall, this LSTM model with bidirectional architecture and two Dense layers aims to capture long-term dependencies in sequential data. It utilizes dropout regularization to avoid overfitting. The model is trained using the Adam optimizer with MSE loss, and the best model is saved during training based on validation loss.

Conclusion:

this chapter has highlighted the importance of hardware-cloud configuration, model visualization, and model comparison in the process of choosing the best model. Optimizing hardware resources is crucial for efficient data processing and visualization. Dashboards provide an interactive means of presenting visualizations, aiding in understanding complex data relationships. The mean square error (MSE) serves as an evaluation metric for comparing models in regression tasks. By leveraging these concepts, practitioners can make informed decisions and select the most suitable model for their specific needs. This chapter equips readers with practical knowledge to optimize hardware resources, create impactful visualizations, and evaluate models effectively, ultimately enhancing data analysis and decision-making processes.

General Conclusion

In conclusion, our project of Implementation of a Digital Twin: application to the management of a domestic water distribution network , by developing a real-time water consumption dashboard and incorporating future predictive demand has been a significant achievement. We set out with the goal of empowering homeowners to visualize their water usage and make informed decisions to promote conservation. Through our efforts, we have successfully provided users with a powerful tool to monitor and manage their water consumption effectively.This not only contributes to water conservation but also helps users save on their water bills and reduce their environmental footprint.

Looking ahead, we anticipate exciting changes in our work. As technology continues to advance and data availability improves, we can enhance our predictive models and provide even more accurate insights to users. Additionally, we can explore incorporating smart home devices and Internet of Things (IoT) connectivity to further automate and optimize water usage in households.

Moreover, as awareness about environmental sustainability and the importance of water conservation grows, our work will likely become even more relevant and impactful. We should continue to adapt our solution to meet the evolving needs of users, ensuring that it remains user-friendly, scalable, and aligned with the latest advancements in technology.

By staying committed to our goals and embracing future changes, we have the opportunity to make a lasting positive impact on water conservation efforts in homes. we can contribute to a more sustainable future and inspire others to take action towards responsible water consumption.

Reference Bibliographic:

[1] '10 Reasons Why Water Management is Important - The Important Site'. https://theimportantsite.com/10-reasons-why-water-management-is-important/ (accessed Jun. 13, 2023).

[2] 'What is Digital Twin Technology? - Digital Twin Technology Explained - AWS', *Amazon Web Services, Inc.* https://aws.amazon.com/what-is/digital-twin/ (accessed May 22, 2023).

[3] 'Water Resources Management', *World Bank*. https://www.worldbank.org/en/topic/waterresourcesmanagement (accessed Jun. 13, 2023).

[4] 'Water Management: Meaning, Statistics and Solutions', *Jagranjosh.com*, Sep. 07, 2019. https://www.jagranjosh.com/general-knowledge/watermanagement-1440753457-1 (accessed Jun. 13, 2023).

[5] 'Water supply system | Description, Purification, Distribution, & Water Quality | Britannica', May 29, 2023. https://www.britannica.com/technology/water-supply-system (accessed Jun. 13, 2023).

[6] 'What Is Stormwater Management and Why Is It Important? - Expert Environmental Consulting', *https://eecenvironmental.com/*, Jan. 31, 2018. https://eecenvironmental.com/what-is-stormwater-management/, https://eecenvironmental.com/what-is-stormwater-management/ (accessed Jun. 14, 2023).

[7] 'Wastewater Treatment Systems - Pure Aqua, Inc.' https://pureaqua.com/waste-water-treatment/ (accessed Jun. 14, 2023).

[8] 'how water recycling systems work'. Water recycling is the process of treating wastewater and reusing it. Recycled water can be reused for the same process, for irrigation or as an alternative to mains water in wash-down applications. Water recycling systems will vary according to the quality of wastewater to be treated and the intended application of the water.

[9] Dr. M. Kumari and J. Singh, 'WATER CONSERVATION: STRATEGIES AND SOLUTIONS', *Int. J. Adv. Res. Rev.*, vol. 1, pp. 75–79, Jan. 2016.

[10] 'Disruptive technology: The answer to water challenges?', *Innovation News Network*, Apr. 17, 2023. https://www.innovationnewsnetwork.com/will-disruptive-technology-solve-challenges-faced-water-utilities/30000/ (accessed Jun. 14, 2023).

[11] 'Smart water management: 5 innovative solutions to water scarcity offered by the IoT', *Saft | Batteries to energize the world*, Mar. 22, 2022. https://www.saft.com/energizing-iot/smart-water-management-5-innovative-solutions-water-scarcity-offered-iot (accessed Jun. 14, 2023).

[12] admin, 'Home', *Innovative Water Technologies*. https://innovativeh2o.com/ (accessed Jun. 14, 2023).

[13] S. Kara, I. E. Karadirek, A. Muhammetoglu, and H. Muhammetoglu, 'Real time monitoring and control in water distribution systems for improving operational efficiency', *Desalination Water Treat.*, vol. 57, Jul. 2015, doi: 10.1080/19443994.2015.1069224.

[14] M. Attaran and B. G. Celik, 'Digital Twin: Benefits, use cases, challenges, and opportunities', *Decis. Anal. J.*, vol. 6, p. 100165, Mar. 2023, doi: 10.1016/j.dajour.2023.100165.

[15] E. Glaessgen and D. Stargel, ‘The Digital Twin Paradigm for Future NASA and U.S. Air Force Vehicles’, in *53rd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference
20th AIAA/ASME/AHS Adaptive Structures Conference
14th AIAA*, Honolulu, Hawaii: American Institute of Aeronautics and Astronautics, Apr. 2012. doi: 10.2514/6.2012-1818.
[16] H. Van Der Valk, H. Haße, F. Möller, and B. Otto, ‘Archetypes of Digital Twins’, *Bus. Inf. Syst. Eng.*, vol. 64, no. 3, pp. 375–391, Jun. 2022, doi: 10.1007/s12599-021-00727-7.
[17] A. Fuller, Z. Fan, C. Day, and C. Barlow, ‘Digital Twin: Enabling Technologies, Challenges and Open Research’, *IEEE Access*, vol. 8, pp. 108952–108971, 2020, doi: 10.1109/ACCESS.2020.2998358.
[18] B. R. Barricelli, E. Casiraghi, and D. Fogli, ‘A Survey on Digital Twin: Definitions, Characteristics, Applications, and Design Implications’, *IEEE Access*, vol. 7, pp. 167653–167671, 2019, doi: 10.1109/ACCESS.2019.2953499.
[19] ‘Autoregressive Integrated Moving Average (ARIMA) Prediction Model’, *Investopedia*. https://www.investopedia.com/terms/a/autoregressive-integrated-moving-average-arima.asp (accessed May 30, 2023).
[20] ‘Exponential Smoothing for Time Series Forecasting - Statistics By Jim’. https://statisticsbyjim.com/time-series/exponential-smoothing-time-series-forecasting/ (accessed May 30, 2023).
[21] R. Huang *et al.*, ‘Well performance prediction based on Long Short-Term Memory (LSTM) neural network’, *J. Pet. Sci. Eng.*, vol. 208, p. 109686, Jan. 2022, doi: 10.1016/j.petrol.2021.109686.
[22] H. M. Ramos *et al.*, ‘New Challenges towards Smart Systems’ Efficiency by Digital Twin in Water Distribution Networks’, *Water*, vol. 14, no. 8, p. 1304, Apr. 2022, doi: 10.3390/w14081304.
[23] M. Allen, A. Preis, M. Iqbal, and A. Whitttle, ‘Case study: A smart water grid in Singapore’, *Water Pract. Technol.*, vol. 7, Jan. 2012.
[24] T. Oates, ‘Sydney Water implements IoT wastewater monitoring devices’, *Utility Magazine*, Mar. 17, 2023. https://utilitymagazine.com.au/sydney-water-implements-iot-wastewater-monitoring-devices/ (accessed May 23, 2023).
[25] H. R. Sakhale, ‘How IOT can be used to Solve the Problems of Mumbai City’, *Int. J. Res. Appl. Sci. Eng. Technol.*, vol. 7, no. 6, pp. 2174–2177, Jun. 2019, doi: 10.22214/ijraset.2019.6365.
[26] ‘What is the Internet of Things (IoT)?’ https://www.oracle.com/internet-of-things/what-is-iot/ (accessed May 28, 2023).
[27] G. TRONIC, ‘Module NodeMCU ESP8266’, *GO TRONIC*. https://www.gotronic.fr/art-module-nodemcu-esp8266-27744.htm (accessed May 28, 2023).
[28] ‘Liquid Flow Meter - Plastic 1/2" NPS Threaded’. https://www.robotpark.com/Liquid-Flow-Meter-Plastic-1-2-NPS-Threaded (accessed May 28, 2023).
[29] ‘What is MQTT? - MQTT Protocol Explained - AWS’, *Amazon Web Services, Inc.* https://aws.amazon.com/what-is/mqtt/ (accessed May 28, 2023).
[30] ‘AWS IoT Immersion Day Workshop’. https://catalog.workshops.aws/aws-iot-immersionday-workshop/en-US/amazon-timestream/lab135-timestreamandgrafana (accessed Jun. 04, 2023).
[31] K. Aggarwal, ‘Amazon Timestream: Overview, Limitations, Pricing & Many More’, Sep. 20, 2022. https://k21academy.com/amazon-web-services/amazon-timestream/ (accessed Jun. 04, 2023).
[32] ‘Unleash Your Data Insights with Amazon Managed Grafana: The Ultimate Analytics Service’, *CloudThat Resources*. https://www.cloudthat.com/resources/blog/unleash-

your-data-insights-with-amazon-managed-grafana-the-ultimate-analytics-service/ (accessed Jun. 05, 2023).
[33] P. Berry, ‘AWS IoT TwinMaker’, *Industrial Digital Transformation & Industry 4.0*, Mar. 06, 2022. https://medium.com/industrial-digital-transformation-industry-4-0/aws-iot-twinmaker-7027a558c9d8 (accessed Jun. 05, 2023).
[34] ‘Amazon SageMaker - Developer Guide’. [Online]. Available: https://docs.aws.amazon.com/pdfs/sagemaker/latest/dg/sagemaker-dg.pdf?icmpid=docs_sagemaker_lp
[35] J. C. J, ‘Water Consumption Dataset of Smart City Users’. IEEE, Dec. 14, 2021. Accessed: Jun. 14, 2023. [Online]. Available: https://ieee-dataport.org/documents/water-consumption-dataset-smart-city-users